# NEOTECTONICS AND EVOLUTION OF THE ESKİPAZAR BASIN, KARABÜK – TURKEY

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Approval of the Graduate School of Natural and Applied Science.

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## ABSTRACT

### Neotectonics and Evolution of the Eskipazar Basin, Karabük - Turkey


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Study area, the Eskipazar Basin, is located in the western part of the North Anatolian Fault System. It is a 3-5 km wide, 10 km long and NW-SE trending depression, bounded by a complex array of oblique-slip normal faults and strike-slip faults.

The Eskipazar Basin is interpreted to be a superimposed basin. The basin fill is composed of two different units deposited under the control of different tectonic regimes, namely the paleotectonic and the neotectonic regimes. The latest paleotectonic fill of the basin is the fluvio-lacustrine deposits of the paleotectonic Eskipazar formation. This formation is unconformably overlain by a group of neotectonic units namely, the Budaklar, the Karkın and the İmanlar formations. The unconformity in between these paleotectonic and neotectonic units represents the time interval during which the paleotectonic period comes to end and the neotectonic period started. Thus, onset age of the strike-slip neotectonic regime in the study area is Late Pliocene (~2.6 My).

Common basin margin-bounding faults of the Eskipazar Basin are the Kadılar fault set, the Beytarla Fault Zone, the Budaklar fault set, the Arslanlar fault set, the Dibek fault, the Karkın fault, the Boztepe fault and the Acısu fault. These faults display well preserved fault scarps, in places. Morphological expressions of these faults and their geometrical relationships to regional stress system indicate that these faults are mostly strike-slip faults with normal component. However the Kadılar fault set displays a different characteristic, being the major fault controlling the basin to the west and it is indeed an oblique slip normal fault.

Long term seismicity and their epicentral distribution in and very close to the study area suggest that the Eskipazar basin is located in an area of seismic quiescence, nevertheless the morphotectonic expressions of the faults exposing in the basin suggest that these faults are active. Since the most of settlements are located on different lithologies of poorly consolidated deposits of the Eskipazar formation susceptible to landslides, the area is open to future earthquake hazard. Therefore, structures and settlements have to be constructed on strong ground away from active faults.

**Keywords:** neotectonic, strike-slip fault, seismicity, Eskipazar Basin

# ÖZ

## Eskipazar Havzasının Evrimi ve Neotektoniği, Karabük – Türkiye

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Çalışma alanı olan Eskipazar Havzası, Kuzey Anadolu Fay Sistemi'nin batısında yer almaktadır. Havza 3-5 km genişliğinde, 10 km uzunluğunda düzensiz, doğrultu atımlı ve verev atımlı faylar tarafında sınırlandırılan KB-GD yönelimli bir basendir.

Eskipazar Havzası çok genç çökellere sahip ve gelişimini aktif olarak devam ettiren, aynı zamanda bunların altında daha yaşlı çökellerin bulunduğu bir havza olarak tanımlanır. Bu iki farklı birim farklı tektonik rejimlerin kontrolü altında oluşmuştur, ve bu rejimler paleotektonik ve neotektonik rejimler olarak adlandırılır. Basenin en son paleotektonik çökeli Eskipazar formasyonunun gölsel – karasal çökelidir. Bu formasyon, neotektonik birimler olan Budaklar, Karkın ve İmanlar formasyonu tarafından uyumsuz olarak örtülürler. Aynı zamanda paleotektonik ve neotektonik birimler arasındaki uyumsuzluk neotektonik ve paleotektonik periodlar arasındaki değişim zamanını temsil ederler. Böylelikle, çalışma alanındaki doğrultu atımlı neotektonik rejimin oluşum yaşı Geç Pliyosen (~2.6 My) olarak ifade edilebilir.

Eskipazar basenini sınırlayan faylar, Kadılar fay seti, Beytarla fay zonu, Budaklar fay seti, Arslanlar fay seti, Dibek fayı, Karkın fayı, Boztepe fayı ve Acısu fayıdır. Bu bölgedeki yapıların fay sarplıkları çok iyi korunmuştur. Fayların topografik ve morfolojik belirtileri ve bunların, bölgenin stres dağılımıyla olan geometrik ilişkisi, bu fayların normal bileşene sahip doğrultu atımlı faylar olduğuna işaret eder. Fakat, Kadılar fay seti bunlardan değişik bir karaktere sahip basenin batı kenarını kontrol eden verev atımlı normal fay özelliği gösteren önemli bir faydır.

Çalışma alanının içinde ve civarındaki, uzun süreli sismik aktivite ve bunların episantır dağılımı Eskipazar Havzasında sismik bir sessizlik döneminin hüküm sürdüğünü morfotektonik belirtiler ise basendeki fayların aktif olduğunu gösterirler. Bölgedeki bir çok yerleşim alanı heyelan tehlikesi taşıyan, gevşek tutturulmuş Eskipazar formasyonu üzerinde inşa edildiği için oluşacak deprem zaralarına açıktır. Dolayısıyla, yapılar ve yerleşim alanları aktif faylardan daha uzak ve sağlam zeminli bölgelere inşa edilmelidir.

**Anahtar Kelimeler:** neotektonik, Eskipazar baseni, doğrultu atımlı fay, sismik aktivite

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"Ich will!!"

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# CHAPTER I

# INTRODUCTION

## 1.1. Purposes and Scope

North Anatolian Fault System is one of the world's well-known dextral intracontinental transform fault system that lies within the Alpine-Himalayan belt. Numerous basins have formed within this fault system that extends from Karlıova triple junction where Northern Anatolian Fault System meets with the East Anatolian Fault System, and extends along the northern boundary of Anatolian platelet until it disappears in the Aegean Sea. The basins within this fault system have different geometry and evolutionary histories. The evolution pattern and the tectonic complexities of these basins are governed by the westward escape of Anatolian platelet due to post-collisional convergence between the Arabian plate and the Eurasian plate. Neotectonic basins and their infills are the best places where the style of deformation and relevant features are recorded and well-preserved. In order to contribute to the tectonic characteristics and evolution pattern of the NW-SE trending Eskipazar Basin, located along western portion of the North Anatolian Fault System, stratigraphical, structural and seismic characteristics of the basin is analysed.

## 1.2. Method of Study

In order to achieve the above mentioned purposes, a research has been carried out at three stages; 1) office work, 2) field work and 3) laboratory to Office work.

During the Office work, first of all available literature were collected and reviewed. Later on available borehole data were also compiled and used for assessment of Plio-Quaternary sedimentary pile.

At the stage of field work, field geological mapping is carried out at 1/25.000 scale and lithological boundaries as well as related geological structures are mapped. These features were also documented by photography. During the field work faults were identified by their structural data from and morphological properties. In addition, available data were gathered from these faults as well as other available shear planes and planar-linear elements were measured for the use of kinematic analysis. Besides, detailed stratigraphy and deformational features of the latest paleotectonic fill of the basin (Upper Miocene – Lower Pliocene rocks) are studied in order to make a distinction between paleo- and neotectonic periods. For these purposes, latest paleotectonic basin fill and neotectonic units are studied and analysed by measured type sections. In addition, the orientation of extensional fissures associated with travertine deposits of dissimilar age the amount of opening are measured as well as their opening amounts in order to find the principle stress orientation during the deposition of these travertines.

In the next stage of this research, which is laboratory to office work, some field data on the kinematic properties of the faults are analysed by making use of data gathered in the field work. The includes dip amount, dip direction, strike and rake of the faults and similar linear and planar properties of shear planes. These data are analysed by using computer program, ‘Tector’, developed by Angelier 1989; it provides stereographic plots of fault planes and orientations of principle stress axes.

This thesis is prepared by using softwares “Freehand 11 MX”, “Office Work 2000”, “Tector” and “Rockware – Rockworks 2002”.

## 1.3. Location and Accessibility

Study area, the Eskipazar Basin, is located between 40,97° N – 40,95° N latitudes and 32,47° E – 32,68° E longitudes in the eastern part of Arkot Mountain (Figure 1). It falls in the Bolu 628-b2, 629-a1-629-a2 quadrangles and covers an area of more than 65 $km^2$. The Eskipazar Basin is an about NW-SE trending depression with the maximum relief of 500 m between the lowest basin floor and the highest peak of the margin-bounding highlands.

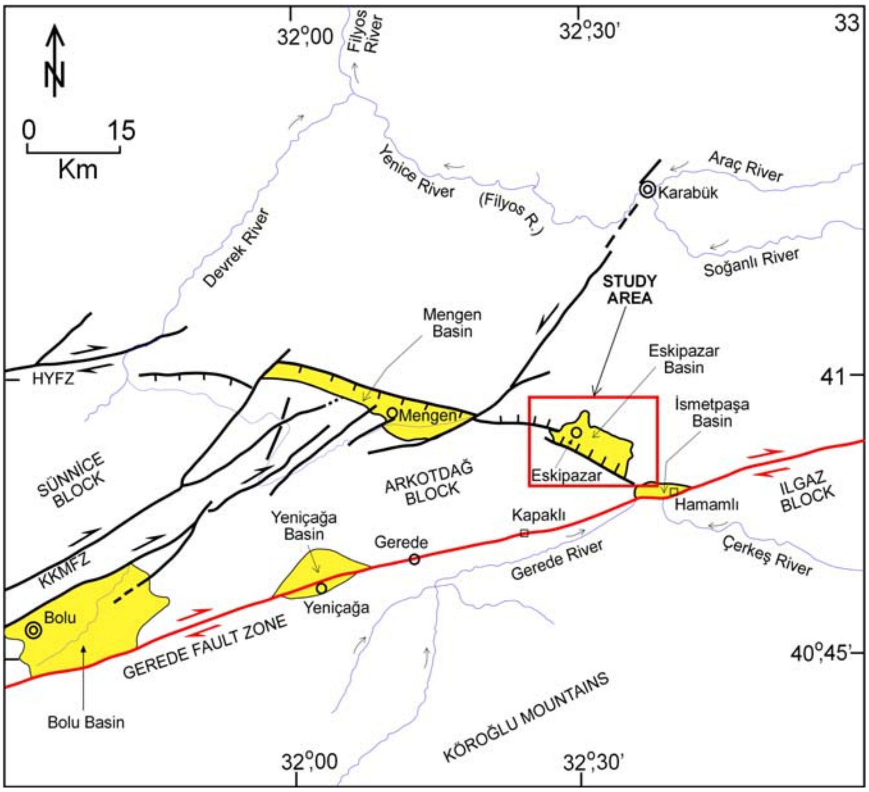


**Figure 1.** Simplified neotectonic map of the study area and its close vicinity showing major neotectonic structures and basins. HYFZ: Hendek - Yığılca Fault Zone, KKMFZ: Karadere -Kaynaşlı - Mengen Fault Zone.

The accessibility to the study area is provided by Gerede-Karabük highway running through the study area. There are also some other asphalt roads as well as stabilized and earthy roads cutting or joining to the main road. By using these roads both northeastern margin and southwestern margin of the basin are accessible.

### 1.4. Previous Works

Eskipazar Basin and its near surroundings have been studied by both foreign and native researchers for different purposes over the last century, and the gathered information has been published in Turkish and foreign literatures. These works will be summarized in the following paragraphs.

First study about the Eskipazar Basin was carried out by Blumenthal (1941). He introduced different rock units and gave information about the geology of the area. Within the study area, he identified mainly six rock units. He also reported information about the general characteristics of major structures within the Eskipazar Basin. Besides these, he also investigated and studied the distribution and general characteristics of travertines exposing throughout the study area, and finally, he carried out some chemical analysis of the mineral waters of the thermal springs of these travertines. He defined the Eskipazar Basin as a closed basin that was probably connected to Ilgaz-Çerkeş Basin in the past.

Tokay (1973) carried out some geological investigations along the Gerede-Ilgaz portion of the North Anatolian Fault System by utilizing twentyone 1/25.000 scale topographic sheets. In this study, he investigated and reported some significant characteristics of the five different rock units cropping-out within the study area. Besides these, he also identified six different and major faults/fault sets that are exposed within the study area or surrounding the study area. He documented some important information about the characteristics, geometrical relations and properties of these faults as well as their recent or past activities. These faults are namely the Ulusu, Gerede, and Çerkeş, Dikmen, Kızılibrik, Yılanlı faults. He explained that these faults are comprising the Gerede - Ilgaz portion of the North Anatolia Fault System. He noted that the Ulusu Fault is the most active fault of the system along which the recent seismic activity has taken place and which can be identified as the Master Strand of the North Anatolian Fault System. According to him, the Gerede faults are the margin-bounding structures with the Gerede-Ilgaz portion of the fault system; however, other faults such as the Çerkeş, Dikmen, Kızılibrik and Yılanlı faults are the ones determining both northern and southern walls of the zone of deformation controlling the morphology at these parts of the fault system. He also dealt with the seismotectonics of the region and seismicity along the fault system. Finally, he evaluated the previous models on the origin of the NAFZS and discussed their reliability based on his own observations.

Barka (1984) studied the Çerkeş-Kurşunlu-Ilgaz Basin situated near east of the study area. He identified mainly two groups of rock units, namely the “Lower Pontus” (Tortonian) and the “Upper Pontus” formations (Pliocene-Early Pleistocene). He emphasized that understanding the deformation pattern and time-dependent structural characteristics of these formations cropping-out within the basin, would lead to understand the emergence age of the latest tectonic period (neotectonic period). For this purpose, he observed the fold axes orientations of the lower as well as upper “Pontus formations” and identified three episodes of folding. Based on his observations and structural and stratigraphical analyses, he claimed that emergence of Neotectonic period took place in Early Pliocene. He also claimed that the Çerkeş-Kurşunlu-Ilgaz basin is an intermountain basin. Şengör *et al.* (1985) aggreed with this idea as well.

Another basin situated at relatively near west of the study area, namely the Yeniçağa Basin, is identified to be a tectonically controlled depression by Erinç (1961) as well as Şengör *et al.* (1985). Şengör and Şaroğlu claimed that this basin is located at the point of bifurcation of the North Anatolian Fault System and stated that this depression may be an extensional fault wedge basin.

Kato *et al.* (1990) carried out radon measurements at İsmetpaşa region, that is characterized by active tectonic creep, to find out traces and activeness of the faults exposing at this locality. Unfortunately, the measurements indicated no meaningfull results due to the wrong sampling techniques conditions. The tectonic creep here was previously studied by Aytun (1980) and he expressed that the average slip-rate of right-lateral sense is estimated to be about 1 cm/year based on the instrumental data.

Şaroğlu *et al.* (1995) mapped the area between Yeniçağa and Eskipazar at a scale of 1/25.000. They studied the geology of this area in detail. They identified several rock units exposing within the study area and subdivided them into two categories: the rock units on the northern block and on the southern block of the North Anatolian Fault System. In addition, they also focused on the geomorphology and the economical geology of this region. Based on their analysis and observations, the North Anatolian Fault System is Late Pliocene in age.

Yiğitbaş and Elmas (1997 and 2001) studied the Bolu-Eskipazar-Devrek-Çaycuma region and they divided this region into mainly seven subareas; namely the Sakarya Continent, Bolu-Eskipazar Zone, Karabük Basin, Sünnice high, Ulus Basin, Devrek-Çaycuma lowland, and the Western Blacksea coastal mountain chains. Within the Bolu-Eskipazar Zone, they identified mainly eight rock units, as the Ağalar metamorphic Group, the Bakacak metamorphics, the Ulumescit group, the Yayla Granite, the Gölcük Group, the Apala Group, the Neogene units and the Quaternary units. Based on their observations, the Neogene deposits cover all other units with an angular unconformity and they are mainly composed of fluvio-lacustrine deposits. Besides these, they identified units such as Quaternary alluvium, slope scree and the fault-parallel exposing travertine deposits. From the tectonic point of view, they identified the WSW-ENE trending Bolu-Eskipazar zone to be a narrow zone confined by the Sakarya Continent to the south and Sünnice high to the north.

Koçyiğit *et al.* (2001a) studied the İsmetpaşa-Kargı section of the North Anatolian Fault System and identified mainly six subfault zones within this section. These fault zones are namely the Eskipazar, the Ulusu, the Tosya, the Çerkeş-Kurşunlu, the Devrez and the Dodurga fault zones. In their study, for the first time in the literature, they named, defined and focused on the Dodurga Fault Zone (DFZ), that is located about 35 km SE of Eskipazar Basin. They identified its geometrical characteristics as well as its age, total displacement and mechanism. Besides, they also gave information about the seismic activity along this fault zone, before and after the June 6 2000 Orta (Çankırı) earthquake. They also presented information about the historical and recent seismicities that took place along the İsmetpaşa-Kargı section of the NAFS.

### 1.5. Regional Tectonic Setting

Turkey is located in the Mediterranean-Himalaya Seismic zone.The structures characterizing this belt are responsible for high seismicity. Among the structures are mainly North Anatolian, East Anatolian and the Dead Sea fault systems and the Hellenic-west Cyprus arc (Figure 2).

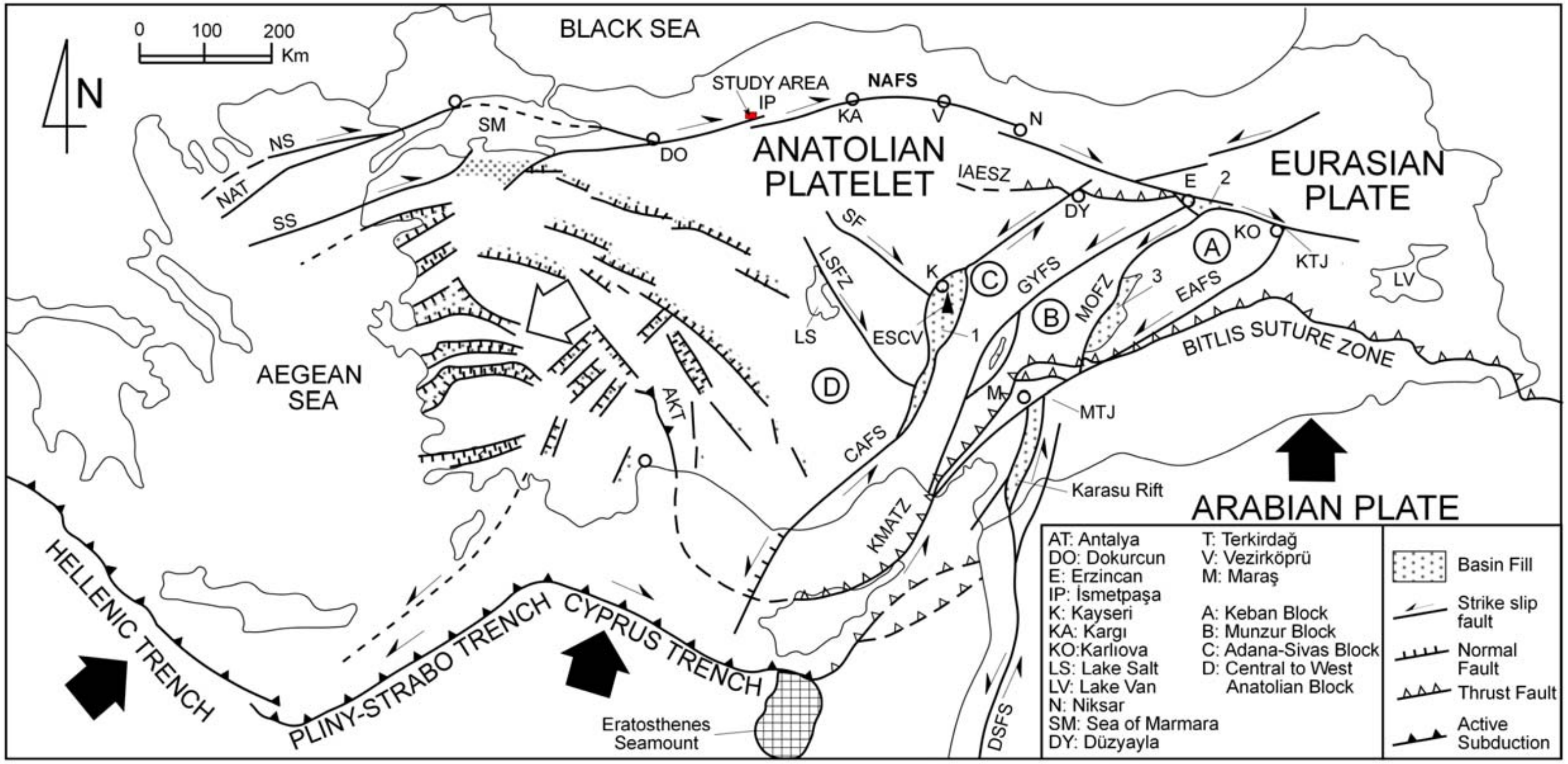


**Figure 2.** Simplified map showing the study area and major tectonic structures in Turkey and adjacent regions. AKT: Aksu Thrust, CAFS: Central Anatolian Fault Sysyem, DSFS: Dead Sea Fault System, EAFS: East Anatolian Fault System, ESCV: Erciyes andesitic-basaltic stratovolcano complex, GYFS: Göksu-Yakapınar Fault System, IAESZ: İzmir-Ankara-Erzincan Suture Zone, KMATZ: Kyrenia-Misis-Andrın Fold-Thrust Fault Zone, KTJ: Karlıova Triple Junction, LSFZ: Lake Salt Fault Zone, MTJ: Maraş Triple Junction, MOFZ: Malatya-Ovacık Fault Zone, NAT: North Aegean Through, NAFS: North Anatolian Fault System, NS: Northern Strand of NAFS, SF: Salanda Fault, SS: Southern Strand of NAFS, 1. Erciyes Pull-Apart Basin, 2. Erzincan Pull-Apart Basin, 3. Malatya Pull-Apart Basin. Large black arrows indicate the direction of plate motion and Large white arrow indicates the escaping direction of Anatolian platelet (modified from Koçyiğit 1996).

The Dextral North Anatolian intracontinental transform fault system formes the contact between the Eurasian Plate and Anatolian platelet that are situated in the north and south of the system, respectively. This fault system is formed together with the sinistral East Anatolian Intracontinental transform fault system at Late Early Pliocene, as natural response to the post-collusional north-south directed convergence between the Arabian plate and the Eurasian plate (Koçyiğit *et al.* 2001a). At eastern Anatolia, this convergence produces N-S oriented compression. Today, the westward escaping Anatolian platelet moves onto the oceanic lithosphere of eastern-Mediterranean Sea, and the African plate has been subducting northwards beneath the Anatolia platelet with a rate of 35 mm/yr (McKenzie 1972; Le Pichon and Angelier 1979; Meulenkamp *et al.* 1998; Kahle *et al.* 1998) along the active subduction zone of Hellenic – west Cyprus arc. This subduction results in a roll-back geometry (Le Pichon and Angelier 1979; Koçyiğit 1984; Royden 1993) which can be considered to be the reason of nearly N-S extension and formation of nearly E-W, NW, NE trending horst-graben system in western Anatolia. The westward tectonic escape of Anatolian platelet along East Anatolian intracontinental transform fault and North Anatolian intracontinental transform fault continues since Late Pliocene and Late Pliocene is accepted to be the initiation age of neotectonic period (2.6 Ma) (Tokay 1973; Hempton 1987; Şaroğlu 1988; Koçyiğit and Beyhan 1998; Koçyiğit *et al.* 2001; Bozkurt 2001). Average rates of slip along the NAFS and EAFS are estimated at 10 mm/yr and 6 mm/yr, respectively, based on field observations (Tokay 1973; Tatar 1978; Barka and Hancock 1984; Barka and Gülen 1988; Şaroğlu 1988; Koçyiğit 1988, 1989, 1990) while they appear to be 26 mm/yr and 13 mm/yr respectively, based on Global Positioning System (GPS) and seismological data (Mckenzie 1972; Canıtez 1973; North 1974; Reilinger *et al.* 1997b Stein *et al.* 1997, Kahle *et al.* 1998, 2000; McClusky *et al.*, 2000). In addition, Anatolian platelet is divided into four blocks by the intracontinental transcurrent faults, namely Lake Salt, Salanda, Central Anatolia, Göksu-Yakapınar, and the Malatya-Ovacık fault zones. The blocks whose boundaries are identified by the above mentioned transcurrent faults are; the Keban, Munzur, Adana-Sivas, and the Central to West Anatolian Blocks (Figure 2) (Perinçek et al. 1987; Koçyiğit and Beyhan 1998, Koçyiğit 1996).

The North Anatolian Fault System is an approximately 1500 km-long and 10 to 110 km wide dextral shear zone trending first NW, and then E-W and SW between Karlıova in the east and northern Agean Sea in the west (Figure 2). The north western part of the fault system has a trend of NE-SW, and is characterized by a number of fault zones, fault sets, isolated faults and anastomosing and splay-type geometry of distribution pattern of faults (Koçyiğit *et al.* 2001b). The anastomosing-type geometry of master strand creates a series of lensoidal highlands (pressure ridges) such as the Arkotdağ, Ilgaz Mountains and lowlands (basins) such as the Yeniçağa, Dörtdivan, Eskipazar and the Çerkeş-Kurşunlu basins, whose long axes are parallel to the general trend of the NAFS.

The Eskipazar Basin is located at the eastern end of the Arkotdağ tectonic block. At close proximity to this basin, the Mengen Basin and the İsmetpaşa basin are present at the NW and immediate south, respectively (Figure 1). The Eskipazar Basin is an about 11 km long and 3 – 6 km wide NW-SE trending actively growing depression controlled by strike-slip faults. Within the Eskipazar Basin, two groups of rock units are exposed. That are the paleotectonic and the neotectonic units and they will be given to described in next chapter. A special emphasis will be put on the stratigraphy of the latest paleotectonic and neotectonic units in order to understand the evolutionary history of the Eskipazar Basin.

# CHAPTER II

# STRATIGRAPHY

The rock units exposed in the study area are divided into two groups as basement and cover units. The units formed in the neotectonic period comprise the young cover. However, the deformed units underlying the undeformed units here are categorized into basement units. The distribution of rock units exposing within the study area are plotted on a geological map at 1/25000 scale and their various characteristics and boundary relationships are illustrated on generalized stratigraphical columnar section (Plate 1 and Figure 3, respectively). The detailed descriptions of these units are given below.

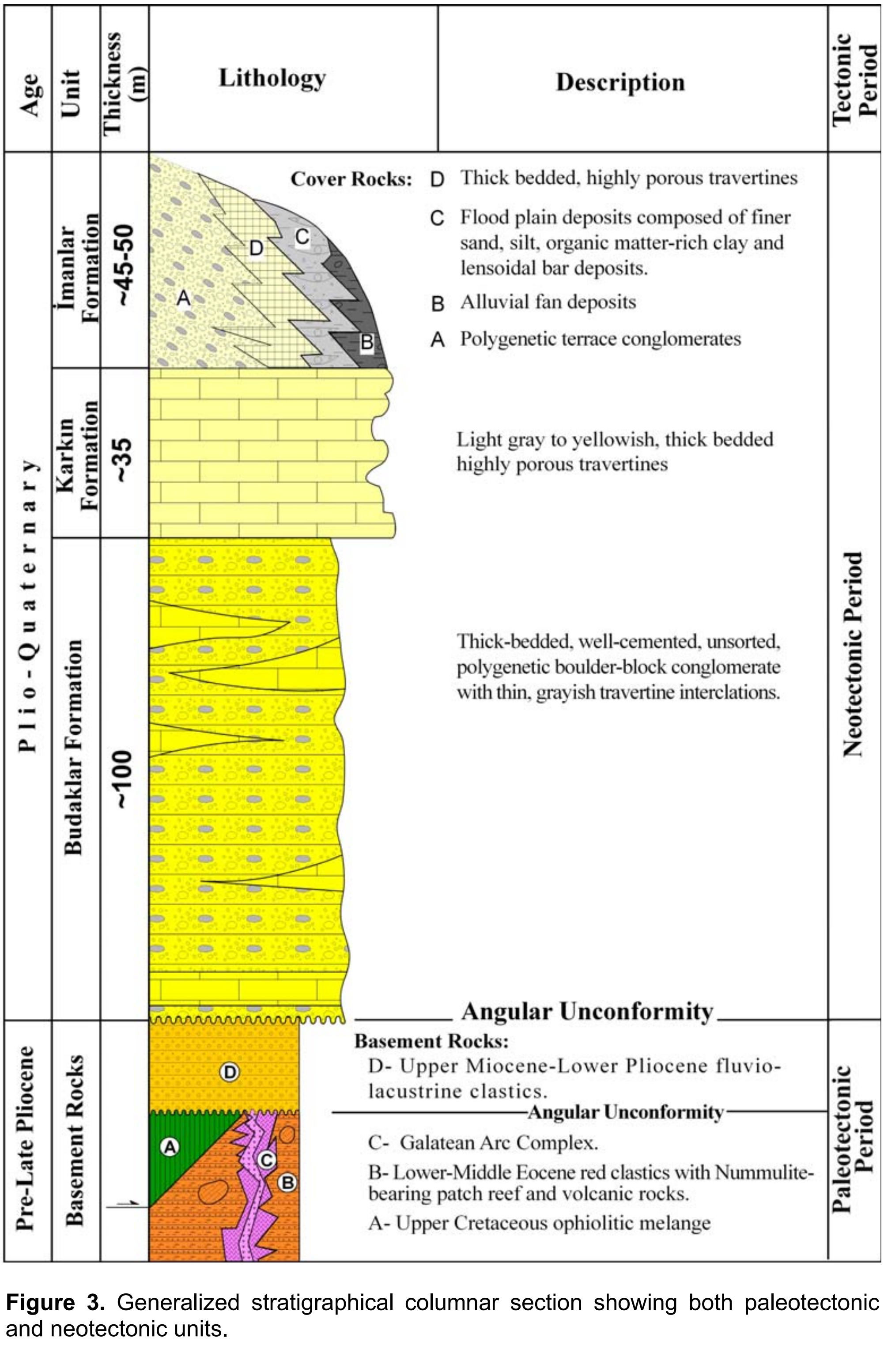


**Figure 3.** Generalized stratigraphical columnar section showing both paleotectonic and neotectonic units.

## 2.1. BASEMENT UNITS

The Basement units comprise Upper Cretaceous ophiolitic mélange ("Arkotdağ Formation"), Lower – Middle Eocene red clastics (Taşlık Formation) which laterally grades into Lower – Middle Eocene volcani-clastics of the Galatean Arc Complex (GAC). Besides these Upper Miocene – Lower Pliocene fluvial clastics (Eskipazar formation) comprises the youngest paleotectonic unit exposing within the study area.

### 2.1.1. Arkotdağ Formation (KTa)

The "Arkotdağ Formation" was first named by Tokay (1973). It is composed of a mélange, characterized by a chaotic assemblage of sedimentary, metamorphic and intrusive igneous rocks. Although this rock unit was termed as a formation, it is an informal usage; this rock unit is a chaotic one and it does not have a well defined top and bottom boundaries. It also does not have any certain type locality. Therefore it is not defined according to international stratigraphic nomenclature (North American Commission on Stratigraphic Nomenclature 1983), so in this study the name of this unit will be used in quotations, indicating that the usage is informal. Indeed, "Arkotdağ Tectonic Complex" may be a proper name for this rock unit.

The "Arkotdağ Formation" is exposed mainly in the northern and the southwestern part of the study area (Plate 1). Its bottom boundary is not exposed within the study area, but it is unconformably overlain by the Eskipazar formation (Figure 4) and the younger units. However the "Arkotdağ Formation" tectonically overlies the Taşlık Formation of Early – Middle

Eocene age outside the study area. In addition, it has tectonic contact relationship with the Upper Miocene – Lower Pliocene Eskipazar formation (Plate 1) in places, within the NAFS.

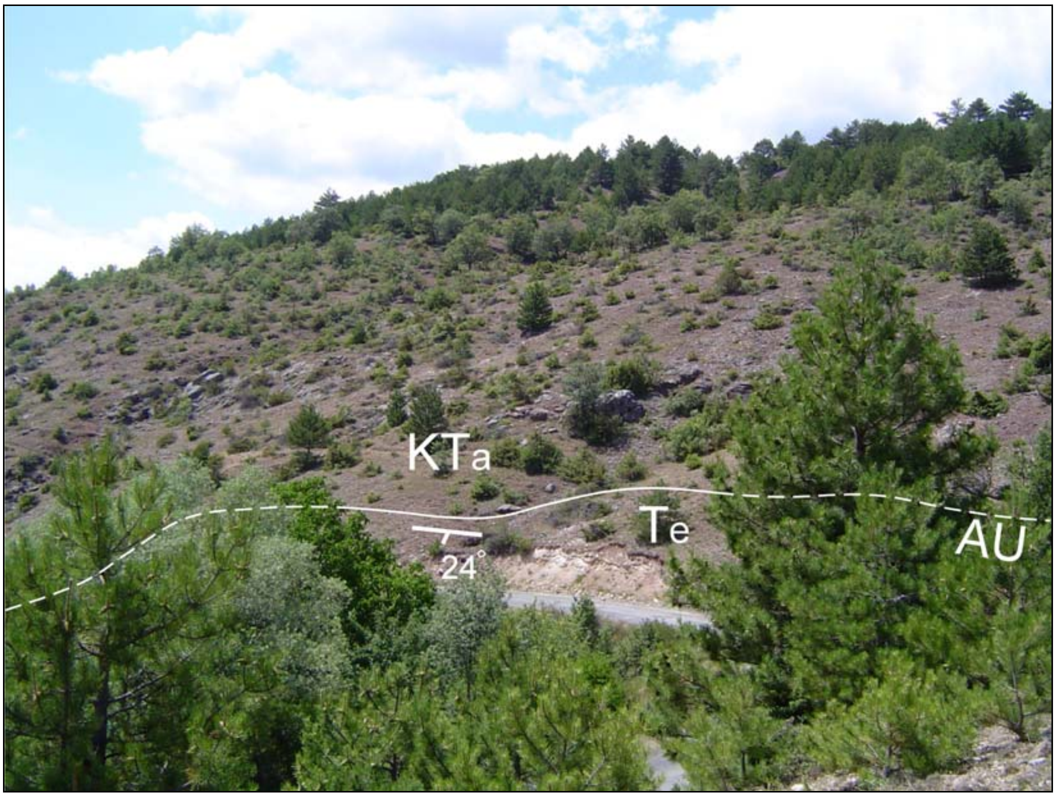


**Figure 4.** General view of the unconformable contact (AU) between the "Arkotdağ Formation" (KTa) and the Eskipazar formation (Te). (Location: ~1 km NW of Budaklar Village, view towards NW). AU: Angular Unconformity.

In the study area, the "Arkotdağ Formation" is characterized by various limestone blocks, belonging to various sedimentary environments in the nature of neritic to pelagic depositional settings, set in a fine-grained matrix characterized by sandstone, siltstone and mudstone. The matrix is intensely deformed, sheared, folded and faulted (Figure 5).

According to Tokay (1974), these units are part of the Upper Cretaceous Ophiolitic Mélange exposing all around Turkey (Koçyiğit, 1991a). It is correlated with the Mengen Complex of Serdar *et al.* (1989).

**Figure 5.** Close up view of intensely sheared and folded matrix of the "Arkotdağ Formation" (Location: ~4km North of Arslanlar Village). Hammer is 32 cm long. Hammer for scale.

### 2.1.2. Taşlık Formation (Tt)

The Taşlık Formation was first named by Şaroğlu *et al.*(1995). It is characterized by the alternation of red clastics with *Nummulites* – bearing patch reefs and volcanic rocks. This formation is defined according to international stratigraphic nomenclature (North American Commission on Stratigraphic Nomenclature 1983) with its type locality situated at Taşlık Village, in the near south of the study area. Therefore, in this study the name, Taşlık Formation, is used for this rock unit.

The Taşlık Formation is exposed mainly in the southeastern part of the study area (Plate 1). Its bottom boundary is not exposed within the study area, but it is unconformably overlain by the Upper Miocene – Lower Pliocene Eskipazar formation and the younger units. The Taşlık Formation displays both lateral and vertical gradations with the Galatean Arc Complex of the same age. In addition, it has tectonic contact with Quaternary units, in places, along the active faults.

The Taşlık Formation is characterized by conglomerate, sandstone, siltstone, mudstone and clayey limestone alternation with thin intercalations of tuff layers within the study area. At approximately 2.5 km northwest of Bayındır Village the dominant lithology is thickly bedded, polygenetic conglomerate composed of mainly pelagic to micritic limestone and radiolarite pebbles set in a sandy matrix (Figure 6). On the other hand, near Sadeyaka Village (Plate 1), upper parts of this formation is exposed and dominated by alternation of thinly bedded marl, siltstone, sandstone and clayey – silty limestone (Figure 7). According to Şaroğlu *et al.* (1995), in some sandstone layers of this formation *Nummulites sp.*, *Assilina sp.*, *Orbitolites sp.*, *Asterigerina sp.*, Rotaludae, Miliolidae, Valvulinidae are present. Based on this fauna, they have assigned Early – Middle Eocene age to the Taşlık Formation. The fossil assemblage and presence of thickly bedded polygenetic conglomerates indicate that this formation was deposited in a mixed environment ranging from fluvial to shallow marine environments.

**Figure 6.** Close-up view of polygenetic conglomerates of the Taşlık Formation (Location: 2.5 km northwest of Bayındır Village). Pencil for scale.

**Figure 7.** Close-up view of marl, siltstone, sandstone and clayey – silty limestone alternation in the Taşlık Formation (Location: Sadeyaka Village). Hammer for scale.

### 2.1.3. Galatean Arc Complex (KTg)

The sequence of volcanic rocks exposing between İzmir- Ankara – Erzincan Suture Zone (IAESZ) in the south and North Anatolian Fault System in the north have long been mapped and studied by many researchers (Stchepinsky and Lahn 1941; Erol 1951, 1954, 1955; Akyol 1969; Fourquin 1970; Öngür 1977; Ach 1982; Akyürek 1984; Kazancı and Gökten 1988; Tankut 1990; Türkecan 1991; Koçyiğit 1991a, b; Keller 1992; Gökten *et al.* 1996; Toprak *et al.* 1996; Wilson *et al.*1997; Koçyiğit *et al.* 2003a). Based on geological mapping at 1/100.000 scale Erol (1951, 1954, 1955) used various terms, such as the 'Tertiary Volcanic Series', 'Köroğlu Volcanic Series', 'Köroğlu Complex' to describe this sequence of volcanic rocks. Besides, Tankut *et al.* (1990) studied the geochemistry of some spot samples collected from the southeastern part of the outcrops of this sequence and renamed these rocks as 'Köroğlu (Galatia) Volcanic Complex'. However, Koçyiğit (1991a) and Koçyiğit *et al.* (2003a) carried out some detailed studies at southern part of this sequence. They defined top and bottom of the sequence, measured several stratigraphical sections to define and describe these rock units and to find out the tectonic significance of presence and spatial distribution of these rocks. Stating that these rocks formed under multi-phase magmatic arc evolution, Koçyiğit *et al.* (2003a) named this sequence of volcanic rocks as, Galatean Arc Complex that is characterized by a very thick volcano – sedimentary rock sequence. As this nomenclature provides a broader and stratigraphically better stated description of the unit, in this study, this volcano – sedimentary rock sequence is referred to as Galatean Arc Complex (GAC).

A part of the Galatean Arc Complex is exposed mainly at southeastern part of the study area (Plate 1). Its bottom boundary is not exposed within the study area but it is seen along the Gerede – Kızılcahamam road, where the unit is conformable with the Upper Campanian sedimentary sequence (Koçyiğit 1991b). The top contact is unconformably overlain by the Upper Miocene – Lower Pliocene Eskipazar formation and younger units. This Formation laterally grades into the Lower – Middle Eocene Taşlık Formation. In addition, at the southeastern most parts of the study area it has tectonic contact relationship with Quaternary units along the active faults.

The small portion of the Galatean Arc Complex, exposing within the study area, is characterized and dominated by massive agglomerates mainly composed of cobble sized blasts of andesite and basalt set in a tuffaceous matrix (Figure 8). Besides, this unit contains thinly bedded tuff layers in the lower parts of the succession (Figure 9). No fossil have been found in the unit during the field studies, however, it laterally grades into the Lower – Middle Eocene Taşlık Formation. Accumulation of the volcano-sedimentary rocks of GAC took place in a very long time period ranging from Late Cretaceous to Late Miocene as previously stated by Koçyiğit (1991b) and Koçyiğit *et al.* (2003a).

The Galatean Arc Complex comprises the Late Cretaceous to Early Pliocene volcanic rocks mainly produced by pre- and post collisional magmatic events. This magmatic activity is indeed related to the northward subduction of floor of northern branch of Neotethys (Şengör and Yılmaz 1981) and development of Galatean Magmatic Arc at the north of the subduction zone. Nevertheless, this subduction-related volcanic activity (Galatean arc activity) did not take place in a single and continuous phase, but it is indeed a polyphase volcanic activity. This polyphase volcanic activity is mainly related to three stages of magmatic arc evolution, namely early phase of arc evolution, late phase of arc evolution and post-collisional phase of arc evolution. Thus, Galatean Arc Complex is developed by these three stages starting from Late Cretaceous, up to Late Miocene (Koçyiğit 1991a; Koçyiğit *et al.* 2003a).

**Figure 8.** Close-up view of massive agglomerates of the Galatean Arc Complex (Location: ~2 km SE of Sadeyaka Village).

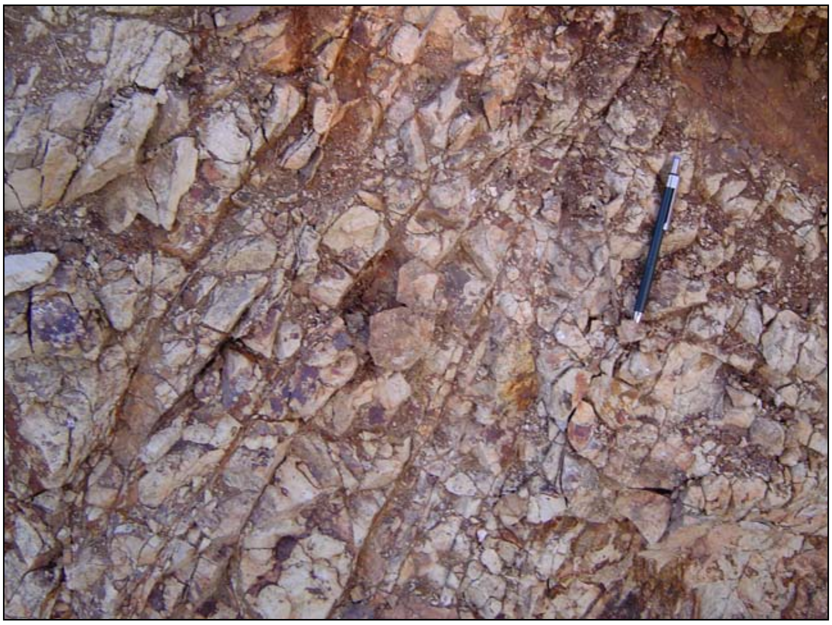

**Figure 9.** Close-up view of tuff layers of the Galatean Arc Complex (Location: ~1 km SE of Sadeyaka Village). Pencil for scale.

### 2.1.4. Eskipazar formation (Te)

Eskipazar formation is named for the first time in this study. It comprises fluvio-lacustrine red clastics. This formation was previously named as “Pazarbaşı Formation” by Şaroğlu *et al.* (1995). However, “Pazarbaşı Formation” was poorly defined in their study, without presenting any type or measured sections. Therefore, in this study the unit is redefined by presenting type and measured sections in accordance with the international stratigraphic nomenclature (North American Commission on Stratigraphic Nomenclature, 1983).

Eskipazar formation is the youngest basin-fill in the paleotectonic period. It is exposed extensively all around the study area (Plate 1). The unit unconformably overlies the “Arkotdağ Formation” in the western and central parts of the study area (Figure 4). On the other hand, in the eastern parts of the study area, it unconformably overlies the Eocene Taşlık Formation and the Upper Campanian – Upper Miocene Galatean Arc Complex. Eskipazar formation is unconformably overlain by the Budaklar, Karkın and İmanlar formations (Figure 10). In addition, it has also a tectonic contact relationship with the “Arkotdağ Formation” and other Quaternary units along the active faults.

The Eskipazar formation is the last paleotectonic unit in the study area, and thus it has a critical role in understanding the evolutionary history of the Eskipazar Basin. Based on the lithofacies the Eskipazar formation is subdivided into three parts. Each part is analyzed and documented by measured sections (see MS1, MS2 and MS3 in Plate 1 and Figures 11, 12 and 13). The MS1 represents lowermost facies of the formation, while the MS3 represents uppermost facies of the Eskipazar formation.

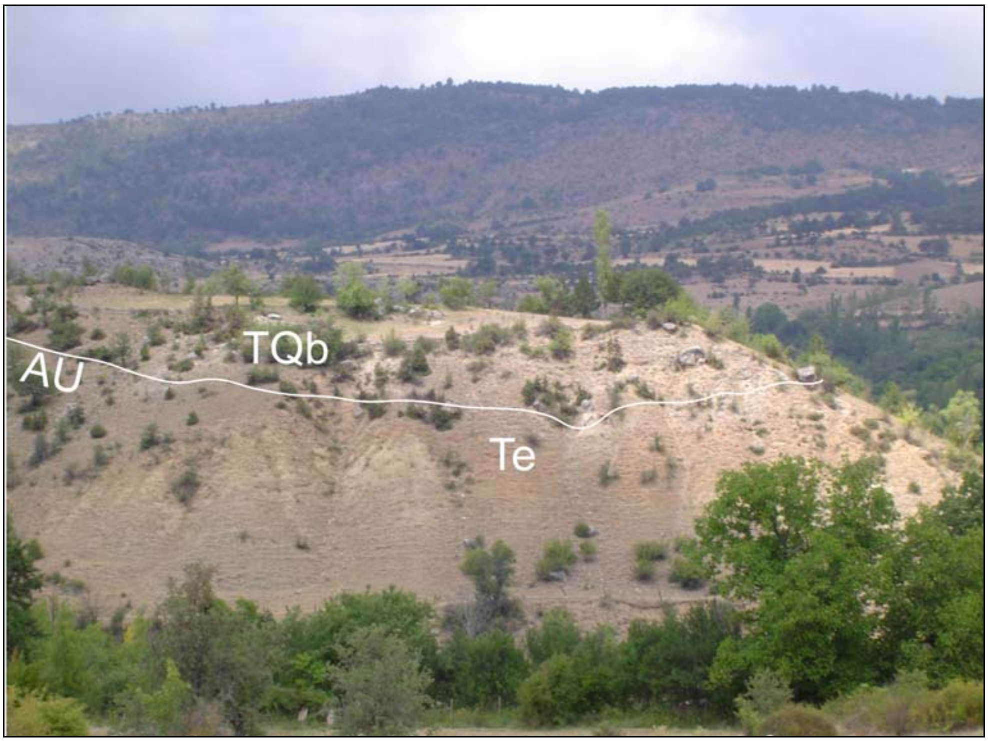


**Figure 10.** General view of the unconformable (AU) contact between the Eskipazar formation (Te) and the Budaklar formation (TQb) (Location: ~1 km SW of Durmuşlar Village, view towards N). AU: Angular Unconformity.

The locality for MS1 is 750 m NE of Gevrekler district (Plate 1). At this locality, bottom portion of Eskipazar formation is well exposed, and it rests unconformably on the “Arkotdağ Formation”. At the same locality, this formation starts with light-gray, thickly bedded argillaceous lacustrine limestone and continues upward with alternation of thinly laminated mudstone, and thinly bedded sandy – pebbly mudstone horizons. This argillaceous limestone is succeeded by thinly bedded sandy – pebbly mudstone with chalk lenses at certain horizons. At the top of this measured section, pebbly siltstone, laminated mudstone, pebbly mudstone and pebbly – sandy mudstone contain polygenetic epsilon cross-bedded channel conglomerates composed mainly of andesite and limestone pebbles set in a silty matrix.

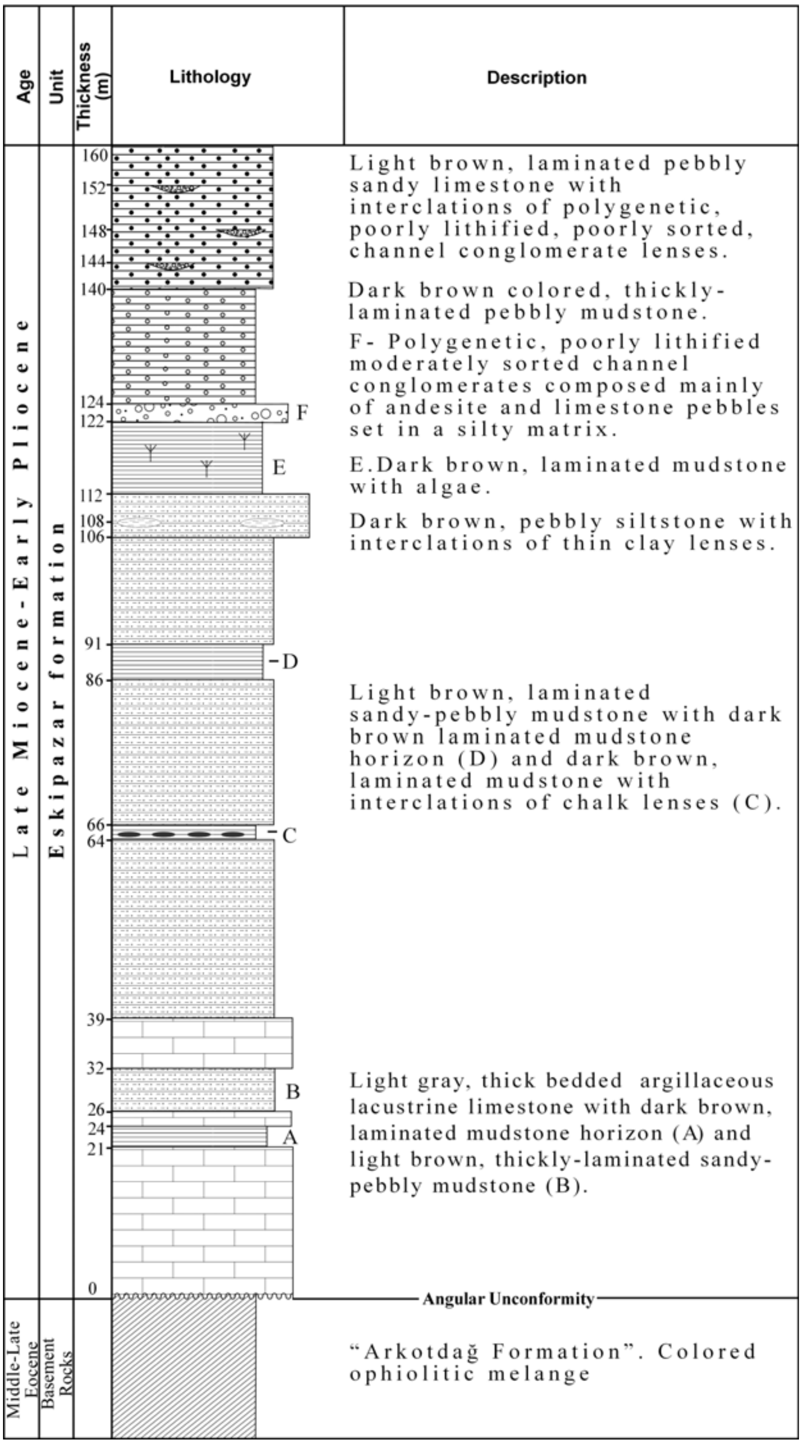


**Figure 11.** Gevrekler measured stratigraphical column (Type locality: 750 m NE of Gevrekler Village: see Plate 1 for location of MS1).

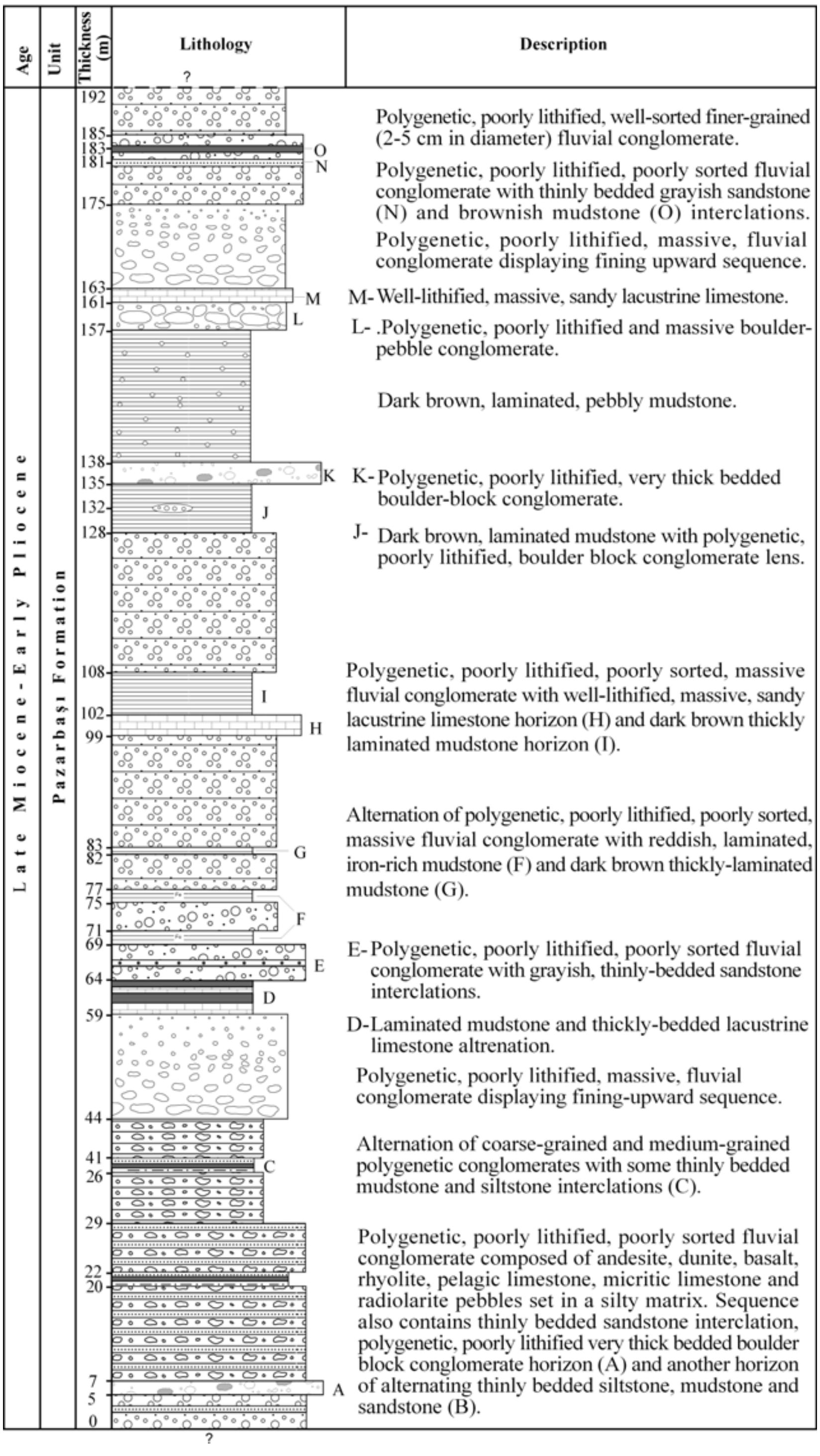


**Figure 12.** Sarıahmetler measured stratigraphical column (Type locality: ~1 km WNW of Sarıahmrtler Village: see MS2 in Plate 1 for location).

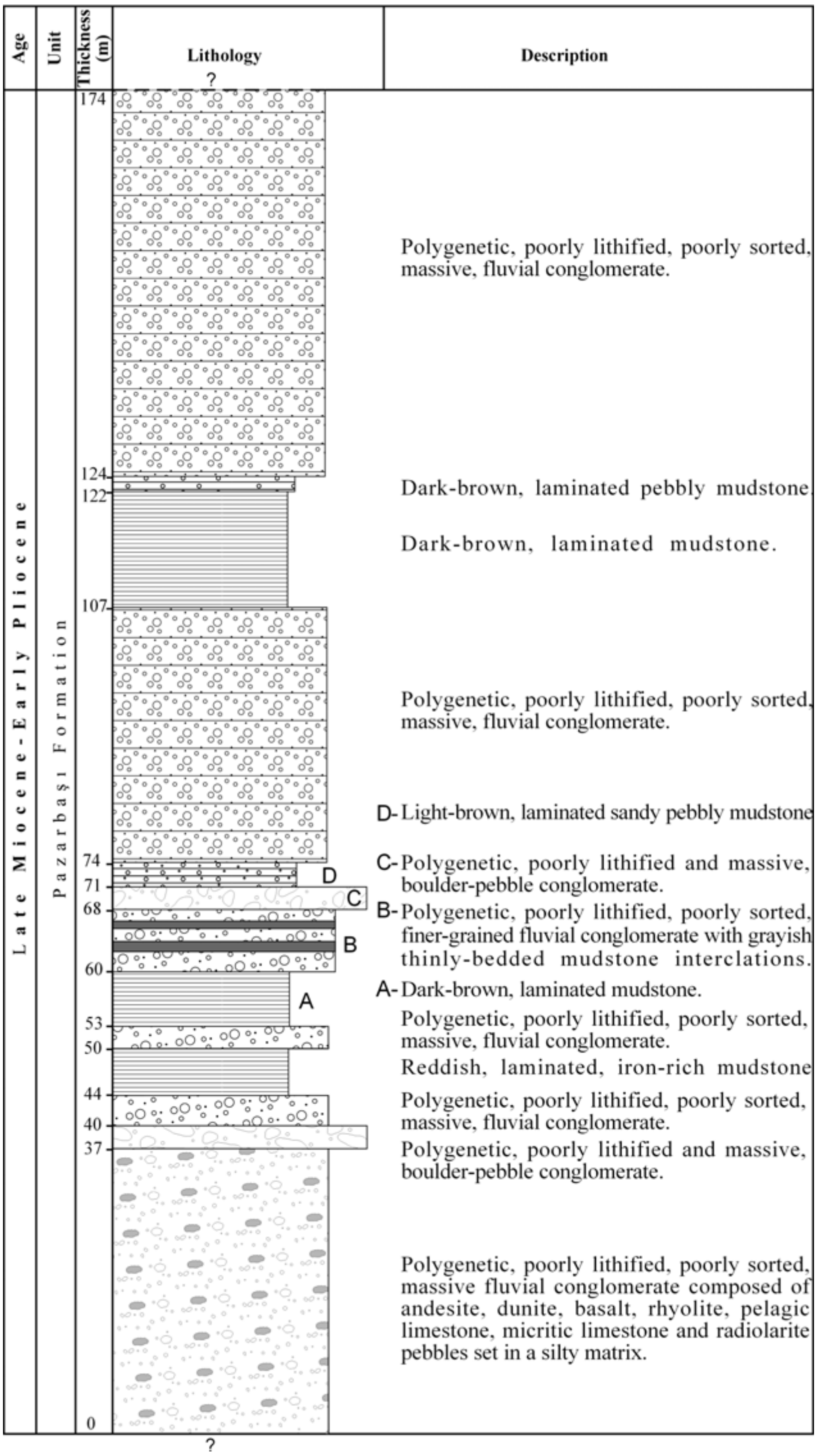


**Figure 13.** Ahmetci Hill measured stratigraphical column. (Type locality: ~750 m WNW of Ahmetci Hill: see MS3 in Plate 1 for location).

The locality of the MS2 is about 1 km WNW of Sarıahmetler Village (Plate 1). At this locality, middle portion of the Eskipazar formation is exposed and the dominant lithology here is polygenetic, poorly lithified, poorly sorted conglomerate of fluvial origin. The pebbles are composed of andesite, dunite, basalt, rhyolite, pelagic limestone, micritic limestone and radiolarites set in a silty matrix. This section is also characterized by presence of iron-rich mudstone intercalations, well-lithified, massive, sandy, limestones of possibly lacustrine origin and polygenetic boulder block conglomerates (Figure 14).

**Figure 14.** Close-up view of polygenetic conglomerates of the Eskipazar formation (Locality: ~1.5 km west of Sığıreyrek Hill).

The locality of the MS3 is approximately 750 m WNW of Ahmetci Hill (Plate 1). At this locality upper part of the Eskipazar formation is exposed. Here the dominant lithology is polygenetic, poorly lithified, poorly sorted fluvial conglomerates composed of pebbles derived from various volcanic rocks including andesite, basalt, rhyolite, and dunite, pelagic limestone, micritic limestone and radiolarite set in a silty matrix. In contrast to the MS2, the conglomerates at this locality are massive and in general their vertical continuity is interrupted by thick sequences of thinly bedded mudstones within the sequence. There are also some polygenetic, poorly lithified and massive boulder – pebble conglomerates at the lower and the middle parts of this section.

The combined thickness of Eskipazar formation is about 520m and it contains micro- and macro-mammalian fossil assemblages (Şaroğlu *et al.* 1995). Based on the mammalian fossil content of *Miyomımus sp.,* Spalacidae gen*. et sp. indet, Talpidae sp.* indet *(Desmana* or *Dibolia),* Şaroğlu *et al.* (1995) assigned a Late Miocene – Early Pliocene age to the "Pazarbaşı Formation" and Eskipazar formation of this study.

The limestones comprising the bottom part of the Eskipazar formation (MS1, Figure 11) were possibly deposited in a lacustrine environment and the conglomerates and mudstones in the upper parts of the succession were possibly deposited in a fluvial environment. Thus, the Eskipazar formation was deposited possibly in fluvio-lacustrine environment.

## 2.2. NEOTECTONIC UNITS

The neotectonic units comprise Plio-Quaternary travertine deposits and their lateral correlatives of terrace and fluvial conglomerates (Budaklar, İmanlar and Karkın formations). Since these units unconformably overlie the paleotectonic units and are actively developing, they are attributed to the neotectonic units. Here it is important to note that the travertines of these units have not been directly dated by means of laboratory analysis, however their geometrical and structural characteristics may give an idea about the relative age of each travertine occurrence with respect to each other. In this study, the travertines of the neotectonic units are dated relative to each other based on the geometrical and structural criterion that was first proposed by Hancock *et al.* (1999). According to them travertine fissures displaying constant and small fissure widths on their profiles are relatively younger than the ones displaying fissure widths increasing gradually downward or displaying stepped-profiles with relatively larger fissure widths (Figure 15). The reason for this is that, a fissure displaying uniform fissure width on its vertical profile indicates that it has not been subjected to local stress long enough to give it a stepped or widening – downward geometry. Within the study area all the travertines exposed, display fissures with constant fissure widths and this indicates that these units are very young and belong to the neotectonic period.

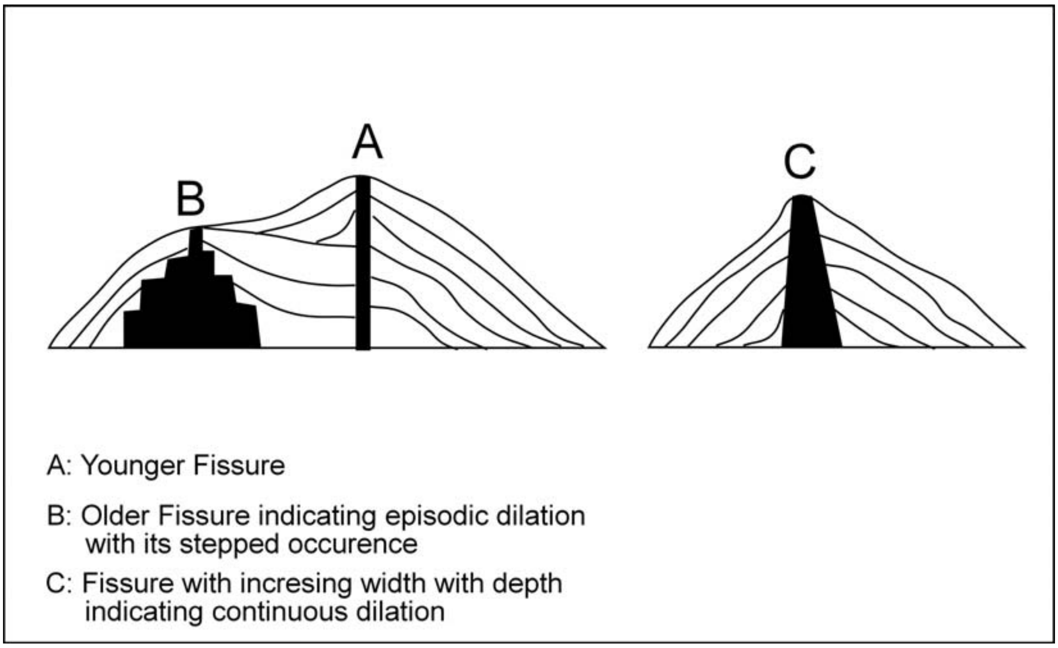


**Figure 15.** Figure showing three types of fissures. Note that black areas are the central fissure travertines and they cut through the beded travertines flanking these fissures. (Modified from Hancock *et al.*, 1999).

### 2.2.1. Budaklar formation (TQb)

This formation is named for the first time in this study. Its type locality is about 1 km southwest of Budaklar Village (Plate 1). It is characterized by travertine – conglomerate alternation and exposed in the northwestern and western parts of the study area (Plate 1). The unit unconformably overlies the Eskipazar formation and the "Arkotdağ Formation" at the western part of the study area (Figure 10). The Budaklar and the Karkın formations, which also include travertine deposits, do not have physical contact in the study area. The Budaklar formation comprises relatively more degraded feeder vents (fissures) than the Karkın formation. Therefore, the Budaklar formation is older than the Karkın formation. In addition, in the western part of the study area, the Budaklar formation is unconformably overlain by the İmanlar formation (Figure 16) and recently developing flood plain deposits of the Göksu stream.


**Figure 16.** General view of unconformable contact (D) between the Budaklar formation (TQb) and clastics of the İmanlar formation (TQi) (Location: ~500m NE of Eleler Village, view towards SE). D: Disconformity.

The Budaklar formation is the oldest neotectonic unit exposing in the study area. It is analyzed and documented by measured section MS4 (Figure 17 and Plate1). In this section, the Budaklar formation is characterized by thickly - bedded, consolidated, unsorted, polygenetic boulder – block conglomerates with thin travertine intercalations. The conglomerates composed of well - rounded pebbles to blocks up to 60 cm in diameter derived mainly from sandstones, andesite, basalts, rhyolite, radiolarite and limestone set in a sandy matrix cemented by $CaCO_3$ (Figure 18). The travertines are light to medium gray, thin to medium layered and have high porosity (Figure 19).

There is no direct evidence to date the Budaklar formation. However, the fissures of the unit are degraded as observed in several places in the study area. In addition, it unconformably overlies the Upper Miocene – Lower Pliocene Eskipazar formation, but is unconformably overlain by the Quaternary alluvial deposits. Based on this information, the Budaklar formation may have deposited in a time interval ranging from post-early Pliocene to pre-Quaternary period.

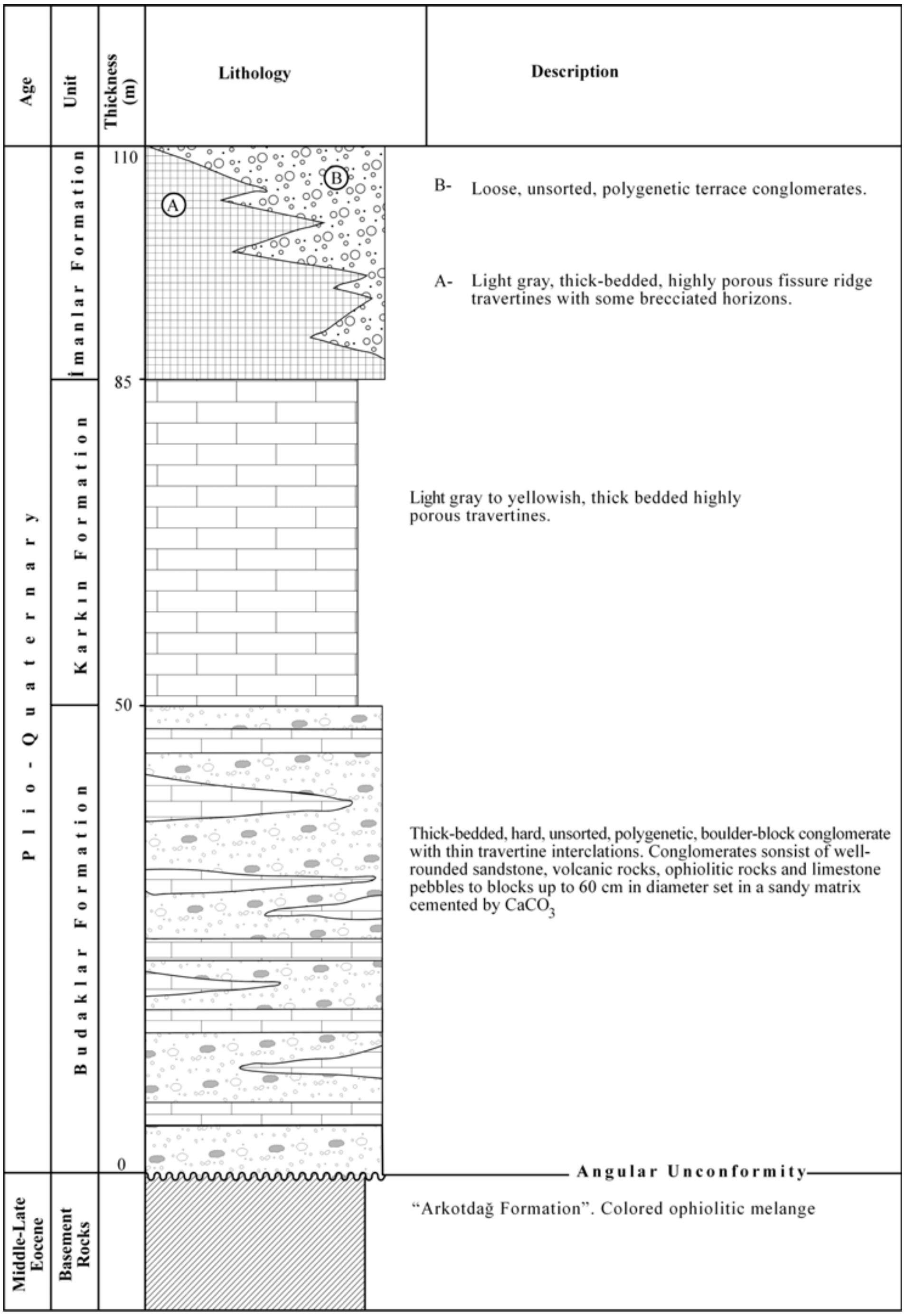


**Figure 17.** Budaklar Karkın and İmanlar combined measured stratigraphical column (Type locality: 1 km southwest of Budaklar Village, see MS4 in Plate 1 for location; 250m southwest of Karkın Village, see MS5 in Plate 1 for location; 1 km north of İmanlar Village, see MS6 in Plate 1 for location).

**Figure 18.** Close-up view of well-lithified polygenetic conglomerates of the Budaklar formation cemented by $CaCO_3$ (Location: ~500 m NE of Çöküşler Village). Hammer for scale.

**Figure 19.** Close-up view of highly porous travertines of the Budaklar formation (Location: ~600m S of Budaklar Village).Hammer for scale.

### 2.2.2. Karkın formation (TQk)

This formation is named for the first time in this study. Type locality of the formation is near southwest of Karkın Village (MS5 in Plate 1 and Figure 17). It is characterized by travertine deposits with well preserved depositional features. Together with the Budaklar formation, the Karkın formation was named as Bahçepınar Formation by Şaroğlu *et al.* (1995). However, Bahçepınar formation was poorly defined in their study, without presenting any type or measured sections. Therefore, in this study, the Budaklar and the

Karkın formations are redefined by presenting type and measured sections in accordance with the international stratigraphic nomenclature (North American Commission on Stratigraphic Nomenclature, 1983).

Karkın formation is exposed in the northwestern and eastern parts of the study area (Plate 1). It unconformably overlies the Eskipazar formation and the “Arkotdağ Formation” (Figure 20) in the eastern part of the study area but is unconformably overlain by continental clastics of the İmanlar formation and unconsolidated flood plain deposits of the Göksu Stream.

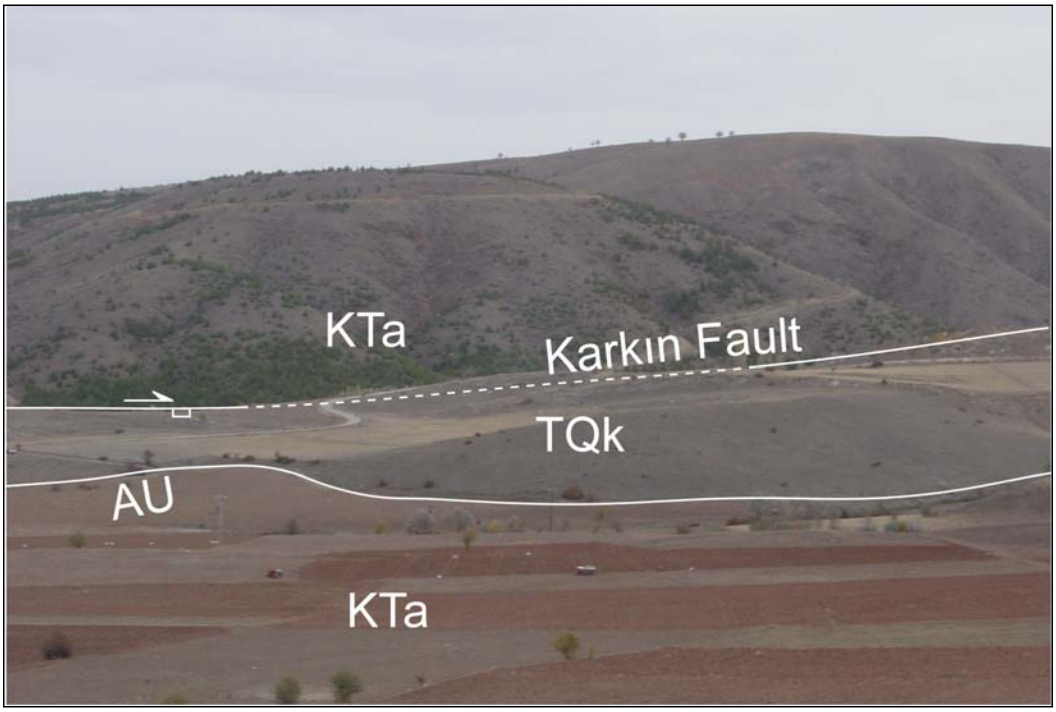


**Figure 20.** General View of the unconformable contact (AU) between the “Arkotdağ Formation” (KTa) and the Karkın formation (TQk) (Location: ~2 km WNW of Karkın Village, view towards N). AU: Angular Unconformity.

At the type locality, the Karkın formation is generally characterized by light gray to yellowish, thickly - bedded, monogenic highly porous travertines (Figure 21). Since it rests directly on the “Arkotdağ Formation”, the $CaCO_3$

source for the travertines of Karkın formation is thought to be the limestone blocks of the “Arkotdağ Formation”.  Upper portions of the Karkın formation has well preserved fissures observed at approximately 600 m north of Dedeyatağı Hill and near west of Karkın Village (Figure 22). Its unconformable relationship with the Quaternary alluvium indicates that the Karkın formation is younger than the Budaklar formation and older than Quaternary alluvium. Based on this information, Plio-Quaternary age is assigned to the Karkın formation. Both the Karkın formation, and the Budaklar formation, can be correlated with Bahçepınar Formation of Şaroğlu *et al.* (1995).

**Figure 21.** Close-up view of travertines of the Karkın formation (Location: ~1 km west of Karkın Village). Hammer for scale.

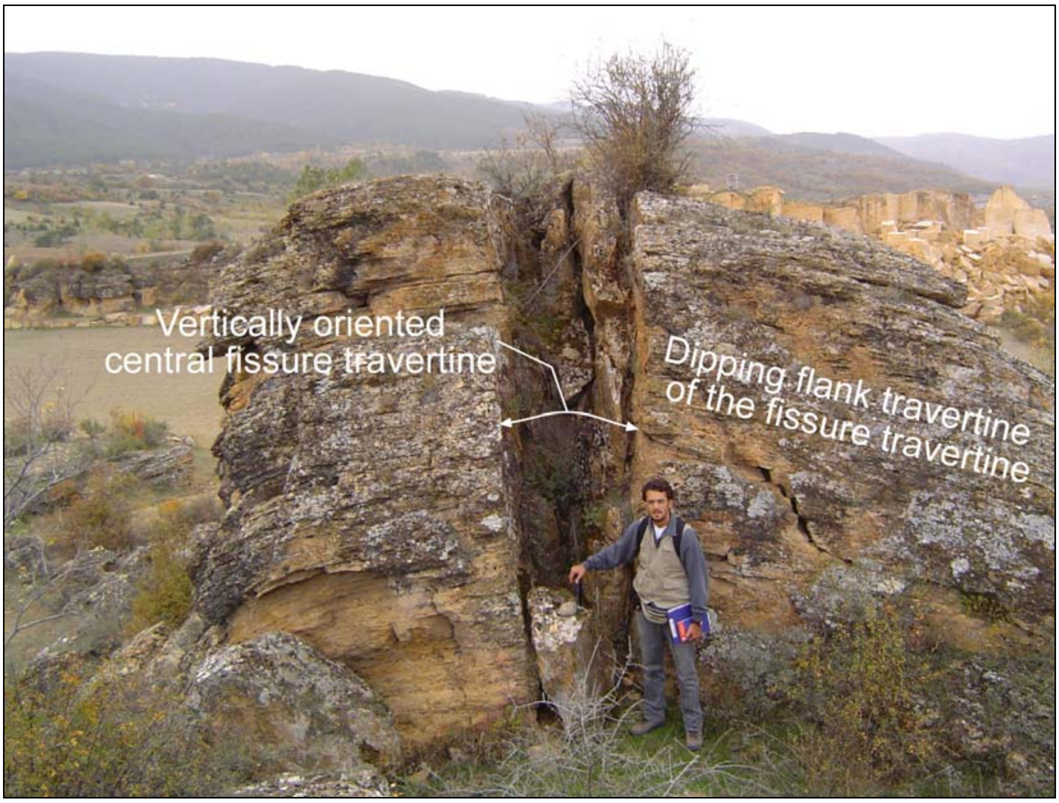


**Figure 22.** An example of a well-preserved extensional fissure ridge travertine comprising the Karkın formation (Location: 600 m N of Dedeyatağı Hill).

### 2.2.3. İmanlar formation (TQi)

This formation is named for the first time in this study. Type locality of the formation is about 1 km north of İmanlar Village (MS6 in Plate1). It is characterized by actively developing travertine occurrences, which grade laterally into continental clastics. This formation is exposed in the central part of the study area, about 1 km north of the İmanlar Village (Plate 1). It conformably overlies the Karkın formation at near west of Karkın Village. In other parts of the study area, clastics of the İmanlar formation unconformably overlie the Eskipazar, Budaklar formations and the "Arkotdağ Formation". The erosional top surface of this formation is covered by Quaternary fluvial deposits in the central part of the study area.

The İmanlar formation is one of the youngest neotectonic units exposing in the study area and it is analyzed and documented by measured section (MS6 in Figure 17 and Plate1). At the type locality this formation is characterized by light gray, thick-bedded, highly porous, fissure ridge travertines (Figure 23) with some brecciated horizons (Figure 24), laterally passing into the loose, unsorted, well-rounded and polygenetic terrace conglomerates composed of pelagic limestone, micritic limestone, andesite, basalt, rhyolite and radiolarite pebbles set in a sandy matrix. At some localities, these clastics get well cemented by $CaCO_3$ precipitated from hydrothermal waters (Figure 25). The travertines of this formation source from İmanlar thermal spring which is indeed an active fissure ridge travertine (Figure 26).

The clastics of the İmanlar formation is Quaternary in age since these are alternating with the actively developing İmanlar Fissure Ridge travertines.

**Figure 23.** General view of fissure ridge travertines of the İmanlar formation (Location: ~2 km N of İmanlar Village, view towards E).

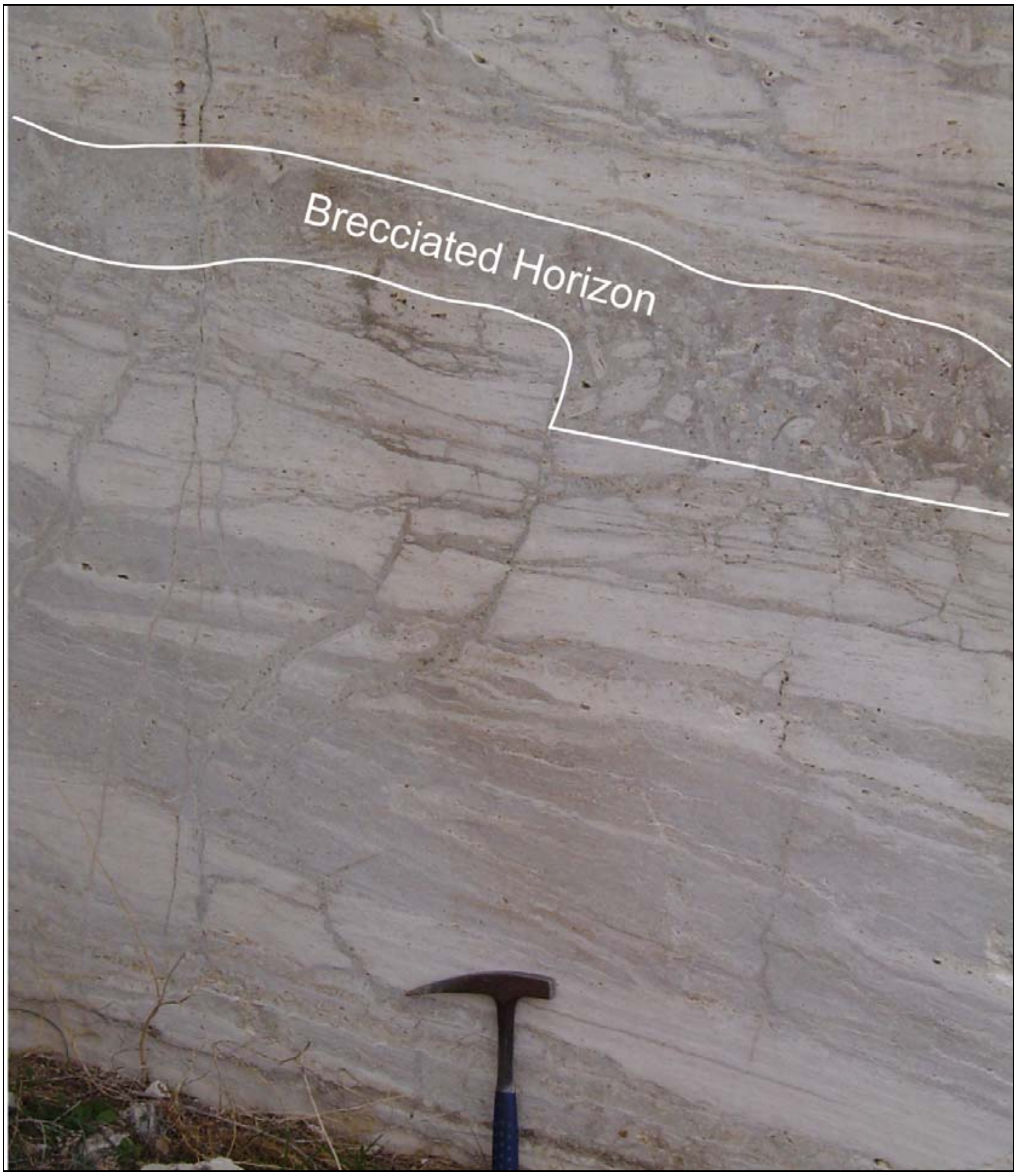


**Figure 24.** Close-up view of a brecciated horizon of the fissure ridge travertines belonging to the İmanlar formation exposed on a quarry wall (Location: ~2km N of İmanlar Village)

**Figure 25.** Close-up view of well cemented polygenetic conglomerates of the İmanlar formation. The cement is $CaCO_3$ that is precipitating from hydrothermal waters flowing on the surface (Location: ~2,5 km N of İmanlar Village)


**Figure 26.** A general view of an active thermal spring and hot water pools of the İmanlar fissure ridge travertine deposits (Location: ~2 km N of İmanlar Village).

### 2.2.4. Upper Quaternary Deposits (Qal)

Late Quaternary deposits consist mainly of flood plain deposits composed of finer sand, silt, organic matter – rich clay and lensoidal bar deposits and alluvial fan deposits. Flood plain deposits are generally observed in valley floors such as Yaylacık, Ozan, Göksu, Acısu, Çayır, Kısık and Kuruçayır streams. On the other hand, Gerede River at southern margin of the study area is the main agent filling the depocenter of the adjacent İsmetpaşa basin. Recent alluvial fans that change from a few hundreds of $m^2$ to approximately 1 $km^2$ in size occur at places where streams enter flood plains of main stream branches and loose their energy of high transporting capacity. A series of diverse-sized alluvial fans with apices adjacent to basin margin bounding faults in the southern part of the study area are well exposed (Plate 1), and they imply to the activeness of the related faults. Besides this some fans are perched on flat topography without being able to reach the flood plain floors. These fans are observed near Karkın Village and about 1.7 km SE of Boncuklar Village (Plate 1), near Boz Hill.

# CHAPTER III

# STRUCTURAL GEOLOGY

This chapter deals with the description and analysis of the geological structures including, beds, folds, unconformities, faults and travertine fissures observed in the study area. Based on tectonic period during which these structures formed, they can be divided into two categories; 1) Paleotectonic structures and 2) Neotectonic structures.

Hence the Pre-Neogene structures, formed by deformation of Pre-Neogene basement rocks lies out of the scope of this study, these structures will not be discussed here. Indeed, as the Eskipazar formation is the latest Paleotectonic unit of the study area and as it plays an important role in analysing the evolution pattern of the Eskipazar basin, only the above mentioned geological structures hosted by this unit will be described and analysed in this study. Besides the structures formed by deformation of these units, the neotectonic structures determining the present day configuration and outline of the Eskipazar Basin will be described and analysed. An important point that should be kept in mind is that, not all the structures (such as faults) hosted by paleotectonic Eskipazar formation are paleotectonic in origin but present day morphology of land surface is the indication that some may have neotectonic origin.

The database for the structural analysis is attained by field geological mapping at 1/25.000 scale during field studies, attitudes of various planar and linear structures such as strike, dip, trend-plunge, rake were measured, and later on, the raw data sets were analysed by using pole plots, histograms and computer software named as ‘Tector’ and its sub-programs ‘Mesure’, and ‘Tensor’ (Angelier, 1989). Besides for visual presentation of the results of the analysis of these raw data, sub-program of ‘Tector’ that is named as ‘Diagra’ (Angelier, 1989) and ‘Rockware, 2002’ are utilized.

Basically the sub-programs ‘Mesure’ and ‘Tensor’ are the computer softwares that provide the user, with the relation between the faults or shear planes, principle stress directions. The sub-program ‘Diagra’ presents the results of the processed data (by sub-programs ‘Mesure’ and ‘Tensor’) on Stereographic projection and this projection includes slip-planes and principle stress axes.

In addition to these softwares, basically the orientation and opening amounts of the extensional travertine fissures developed in the neotectonic units are utilized to interpret principle stress directions as well as the age of the travertine deposits and time-dependent activity pattern of the fissure travertine, indicated by geometry of the fissure. The principle behind this interpretation is indeed simple; the trend of the extensional fissure of a travertine body indicates the local orientation of maximum stress axis ($\sigma_1$) in the areas of compressional tectonic regimes, and the opening direction of the fissure, which is perpendicular to the fissure trend, indicates the local orientation of the least stress axis ($\sigma_3$) (Figure 27). Also, extensional fissures gradually increasing in width with depth are products of continuous fracture dilation in contrast to those that form during episodic dilation which display stepped increases of width with depth (Hancock et al., 1999).

In this study the orientation of the principle stress axis is accepted to have a trend of N79°W based on the results of the study by Eyidoğan et al.(1990).

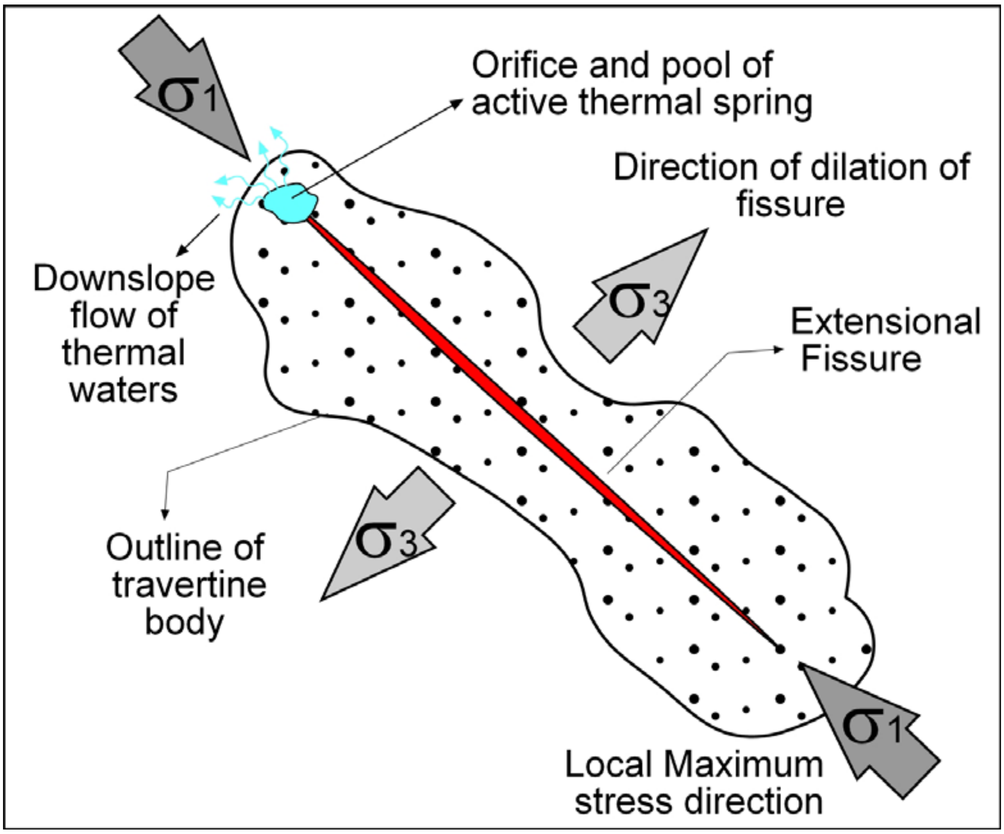


**Figure 27.** Sketch drawing illustrating structural relationship between local principle stress directions and extensional fissure of a travertine body (fissure ridge) developed in the areas of compressional neotectonic regimes.

### 3.1. Paleotectonic Structures

Paleotectonic structures that have a significant role in the evolution history of the Eskipazar Basin are hosted by Upper Miocene-Lower Pliocene Eskipazar formation. These structures can be named as well-developed syn-depositional structures such as the growth faults and shear fractures, tilted beds and folds. The analysis of the geological structures will enlighten the tectonic history, namely the tectonic regime coeval with sedimentation and phase(s) of deformation, prior to onset of neotectonic regime.

### 3.1.1. Syn-Depositional Shear Fractures and Growth Faults: Tectonic regime coeval with deposition

The Eskipazar formation was deposited in a fluvio-lacustrine depositional system, and the lower most lacustrine deposits of this formation are characterized by the syn-depositional shear fractures and growth faults (Figure 28). These structures possibly formed during the time of deposition and therefore they are interpreted as the result of paleotectonic deformation of the Eskipazar formation. The shear fractures and growth faults display well-developed slip planes and slickenlines exposed well at station 2 ($S_2$ on Plate 1). Data was gathered from the shear fractures for kinematic analysis are dip amounts, dip directions, rakes of slickenlines. They are documented in Table 1. The slip plane measurements of these shear fractures indicated that the sense of motion was generally oblique to the strike of the fracture plane and slip was in the direction of the dip of the plane (oblique-slip normal motion). The field data were kinematically analysed by using the computer program ‘Tector’ and its sub-programs, ‘Mesure’, ‘Tensor’ and ‘Diagra’ (Angelier, 1989). Kinematic analysis of this slip planes (shear fractures) consistently yielded, approximately NW-SE directed paleotectonic extension with a nearly vertical maximum stress axis ($\sigma_1$)(Figure 29). Nearly vertical orientation of maximum stress axis ($\sigma_1$) supports the idea of normal faulting and extensional paleotectonic regime dominating the study area and the surrounding region during the Late Miocene as. This idea is also supported by the frequent presence of growth faults at the lower parts of the Eskipazar formation.  To sum up, results of the analysis indicates that during the deposition of lower parts of this formation in Late Miocene, NW-SE directed extension was taking place within the study area and at the surrounding region.

**Figure 28.** Close-up view of the growth faults exposing on a road cut, within Easkipazar formation (Location: ~750 m SE of Yeniköy, see $S_3$ on Plate 1 for location).

**Table 1.** Growth faults and Shear fracture measurements collected from Pazarbaşı Formation at station 2 ($S_2$)(see Plate 1 for location of the station)

| Station 2 | Shear Fracture (Strike and Dip) | Rake |
|---|---|---|
| 1 | N15° E, 62° W | 50° N |
| 2 | N14° W, 44° SW | 50° N |
| 3 | N20° E, 74 °NW | 90° |
| 4 | N42° E, 57° NW | 73° S |
| 5 | N65° E, 49° NW | 57°W |
| 6 | N50° E, 45° NW | 70°S |
| 7 | N10° W, 42° SW | 75° S |
| 8 | N12° E, 75° SE | 48° S |
| 9 | N34° E, 72° SE | 68° S |
| 10 | N10° E, 54° NW | 60° N |
| 11 | N17° W, 58° SW | 42° N |
| 12 | N-S, 48° NW | 66° S |
| 13 | N65° E, 48° NW | 65° W |
| 14 | N65° E, 49° NW | 80° SW |
| 15 | E-W, 42° N | 70° W |
| 16 | E-W, 70° N | 60° W |
| 17 | N85° W, 55° NE | 56° W |
| 18 | N40° E, 63° NW | 60° S |
| 19 | N40° E, 63° NW | 80° N |
| 20 | N55° E, 64° NW | 68° S |
| 21 | N30° E, 57° NW | 75° S |
| 22 | N60° E, 56° NW | 85° W |
| 23 | N45° E, 46° NW | 72° E |
| 24 | N35° W, 59° SW | 50° NW |
| 25 | N79° E, 56° NW | 56° W |
| 26 | N62° E, 58° NW | 90° |
| 27 | N75° E, 43° SE | 79° E |

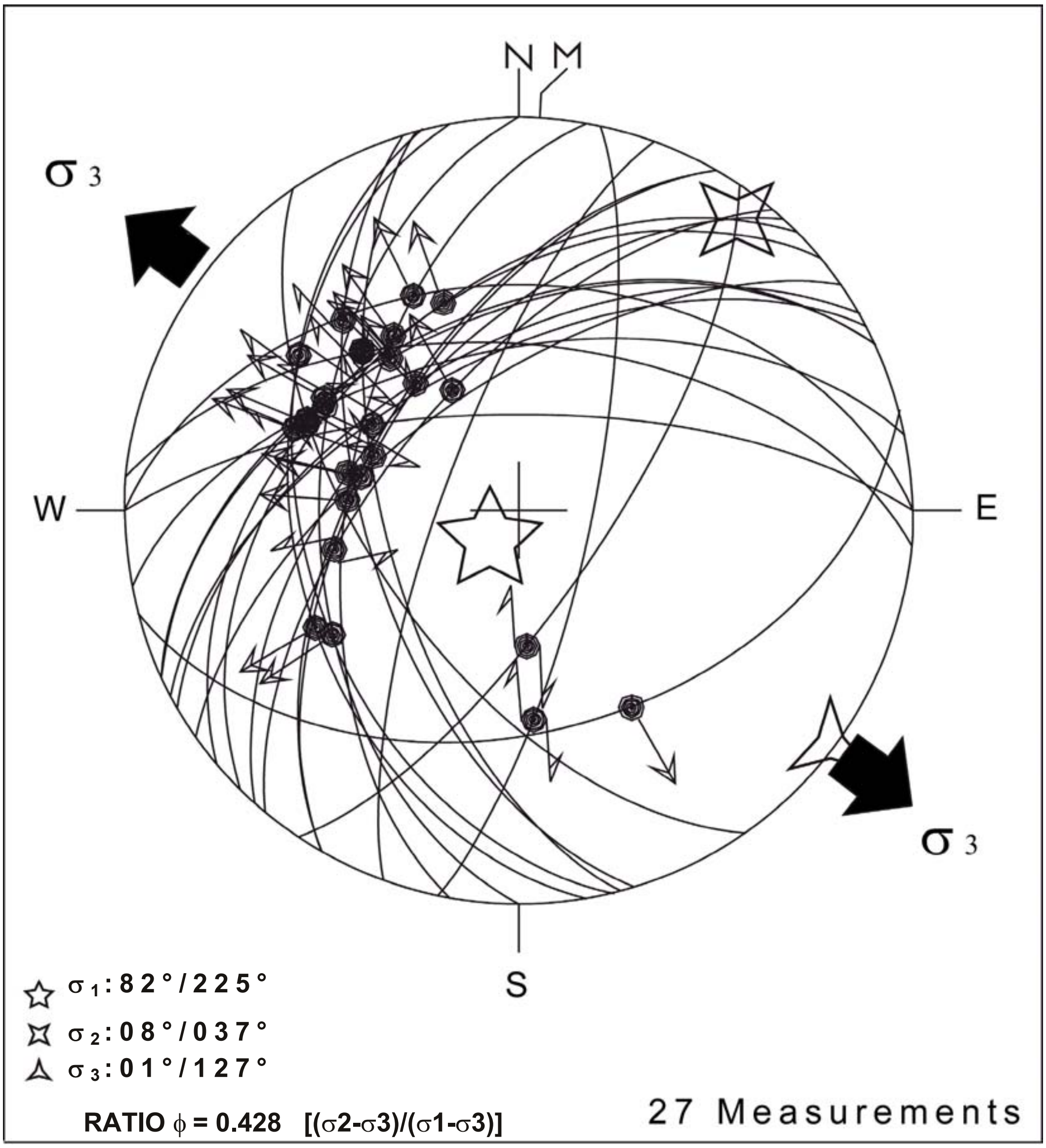


**Figure 29.** Kinematic analysis of syndepositional structures such as growth faults and fractures within the Eskipazar formation at station 2 (~ 1 km ESE of Yeniköy). The diagram shows the streographic plots of slipplanes with orientations of slip lines as well as the orientations of stress axes ($\sigma_1$, $\sigma_2$ and $\sigma_3$). The nearly vertical orientation of maximum stress axis ($\sigma_1$) indicates normal faulting and NW-SE directed extension.

## 3.1.2. Structures Deforming Latest Paleotectonic Unit

These structures can be named as tilted beds, and folds. The analysis of the geological structures will enlighten the tectonic history, namely the phase(s) of deformation of the study area prior to onset of Neotectonic regime.

#### 3.1.2.1. Tilted Beds

The outcrops of the Eskipazar formation exposed at road cuts, and deeply carved valleys within the study area projects well developed beds and bedding planes with bedding thicknesses ranging from a few tens of centimetres to a few meters. The attitudes of these bedding planes, all around the study area, are documented and mapped at 1/25.000 scale by measuring dip amounts and dip directions (Figure 30). Observations related to these measurements at several localities within the study area showed that, dip amounts of these beds vary from 20°, up to 70°, but on avarege dip amounts vary within a range of 40°-50° (Figure 31). When considered spatially it is observed that, the dip amounts of the beds are relatively high, closer to the S and SW margins of the Eskipazar Basin (Plate 1). As a consequence, it can be interpreted that the amount of paleotectonic deformation of this unit was relatively high in these parts of the study area. Besides, at some localities that are closer to the large outcrops of the “Arkotdağ Formation” within the central parts of the basin, again dip amounts are relatively high and this possibly indicates that the intensity of deformation is also high around these outcrops of the “Akotdağ Formation” as compared to the other parts of the basin. When dip directions are taken into consideration, they vary greatly within the range of 000°-330° in azimuth, (Figure 32) throughout the study area, and this again implies the intensity of Paleotectonic deformation of the Eskipazar formation.

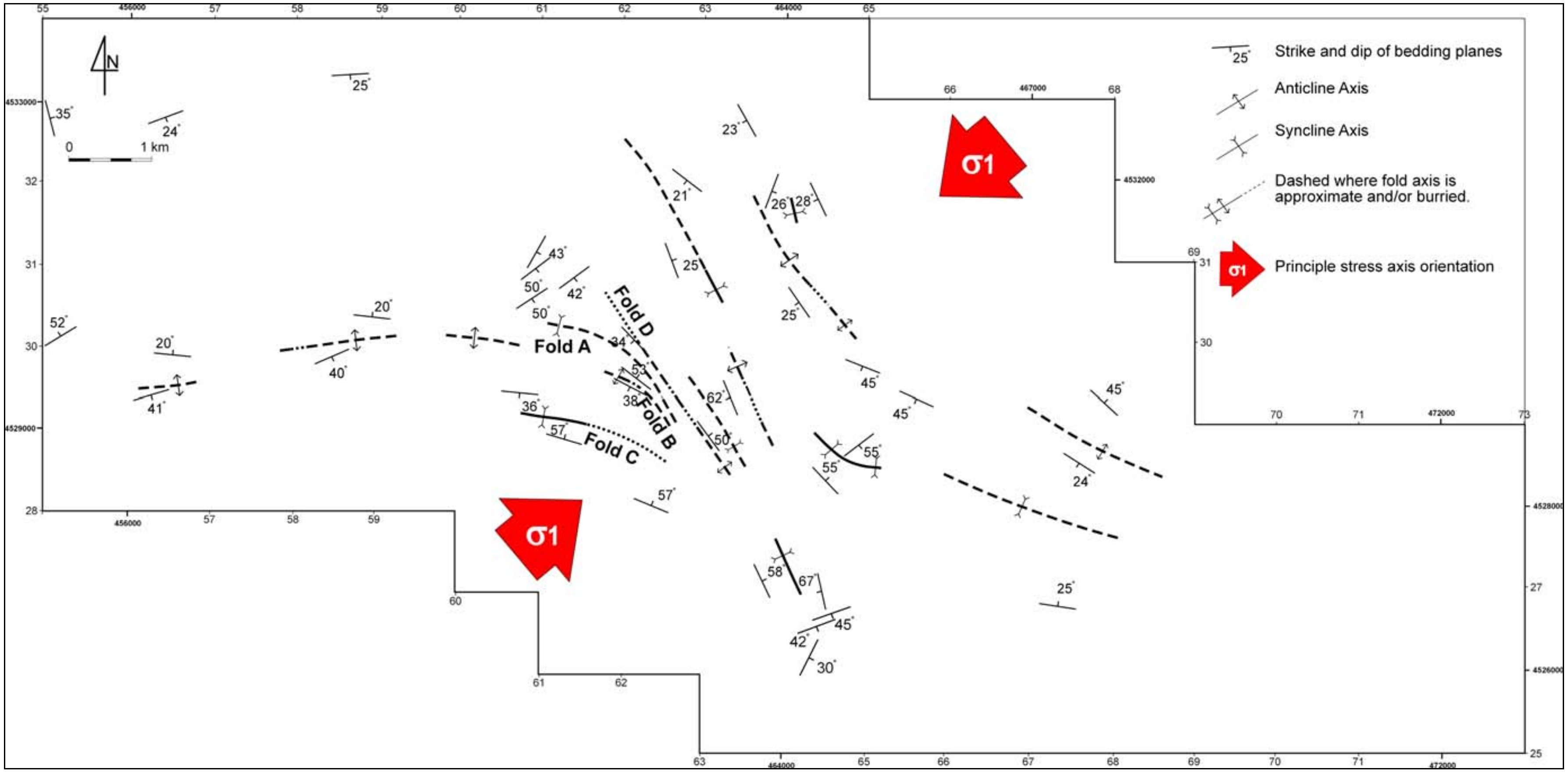


**Figure 30.** Structural map showing deformation of bedding planes within the Upper Miocene –Lower Pliocene Eskipazar formation by folding. Orientation of the fold axes indicates that the operation direction of the principle stresses ($\sigma_1$) was NE-SW during Early Pliocene or sometime after it.

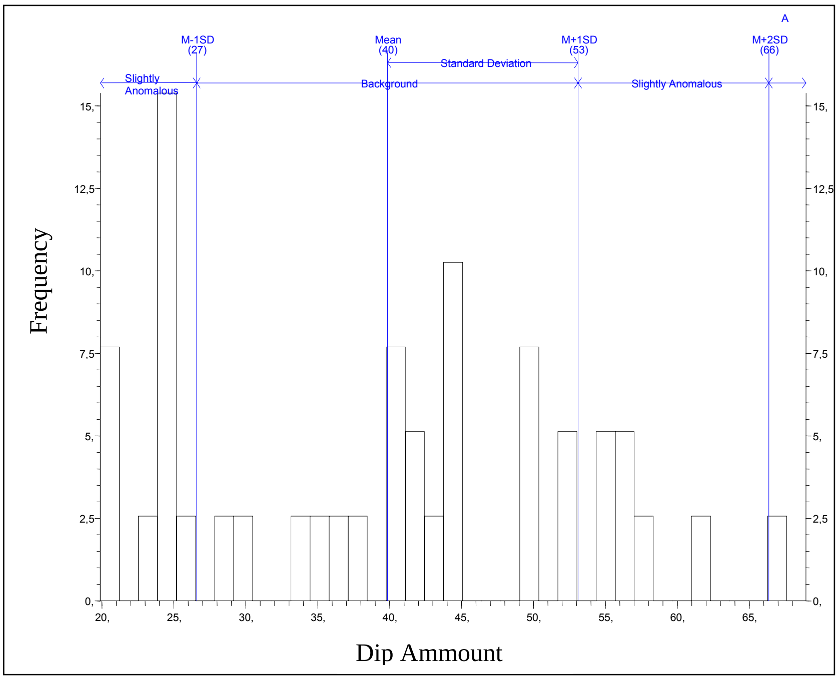


**Figure 31.** Histogram showing predominant dip amounts of bedding planes belonging to the paleotectonic Eskipazar formation.

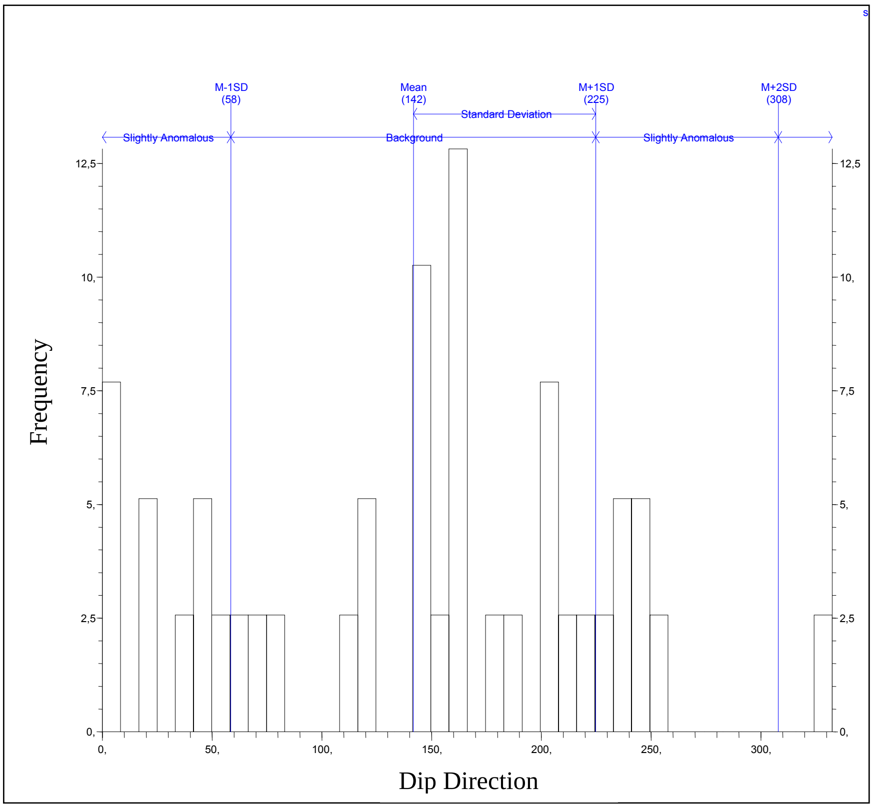


**Figure 32.** Histogram showing predominant dip directions of bedding planes belonging to the paleotectonic Eskipazar formation.

#### 3.1.2.2. Folds

Field geological mapping at 1/25.000 scale and the strike - dip measurements taken from the bedding planes revealed several synclines and anticlines with different tightness at different localities within the study area (Figure 28). The fold axes are plotted on the geological map of the study area (Plate1) with the help of the strike - dip measurements taken from the bedding planes of the Eskipazar formation. The outcrop patterns of the “Akotdağ Formation” also aided this positioning of fold axes.

The folds hosted by the Eskipazar formation differ in tightness from place to place within the study area. In the southwestern (near Tefen and Taşpınar Villages and Kıraçtarla Hill) parts of the study area (at SW margin of the Eskipazar Basin) these folds occur as tight folds with interlimb angles (Ramsay, 1967) ranging from 55° to 89° (SW part of the cross-section $A_3$-$A_3$ on Plate 2). On the other hand, starting from this SW margin, towards northern parts of the study area folds become open with interlimb angles around 130° (cross-sections $A_1$-$A_1$, $A_2$-$A_2$ and NE part of the cross-section $A_3$-$A_3$ in Plate 2). Also in the western and eastern parts of the study area the Eskipazar formation displays open folds. This analysis of tightness of folds may imply that the paleotectonic deformation of the Eskipazar formation in the SW part of the study area was relatively more intense compared with the other parts of the study area, and this result fit well with the results obtained by analysis of dip and dip direction measurements.

The folds observed within the study area comprise a series of anticlines and synclines. These anticlines and synclines are generally symmetrical in the western, eastern and northern parts of the study area, but in the SW parts, they become slightly asymmetrical (Figure 30 and see also cross-section $A_3$-$A_3$ on Plate 2). On the other hand, in the southwestern parts of the study area (near Tefen and Taşmanlar Villages) the wave length of the folds are short (<1 km) and at other parts wave lengths are long (>1 km). The change in wavelengths and symmetry of folds may be another indicator of intensity of deformation in the southwestern part of the study area.

The axes of the anticlines and synclines display a parallel, sub-parallel pattern with trends generally in NW-SE to NNW-SSE direction. The axes of the folds are generally curvilinear and starting from SW parts of the study area, their trend changes from NNW-SSE to nearly E-W towards western parts. (Folds A, B and C on Figure 30). In the eastern parts of the study area, the trend is nearly NW-SE, and in the western parts, it is nearly E-W. Besides, linear alignment of small outcrops of the “Akotdağ Formation” (near Tefen Village and South of Taşmanlar Village) along the anticline axes for folds B and D in Figure 30 indicates that this formation crops out at the core of anticlines; then revealing that the unit is on the basement rock (Plate 1).This in turn also explain why the Eskipazar formation is thinner in this part of the study area compared with the other parts. The length of the fold axes range from few hundreds of meters to few kilometres.

From the NNW-SSE to NW-SE trends of the fold axes is consistent with a nearly NE-SW directed compression (Figure 30). In addition to this stereographic pole plots of the 39 bedding planes from the Upper Miocene - Lower Pliocene Eskipazar formation, have confirmed the NE-SW directed compression during the latest phase of paleotectonic period (Figure 33). Besides, at western parts of the study area the fold axes nearly becomes E-W, which may imply that at the later phases of the deformation nearly N-S directed compression took place causing refolding of the Eskipazar formation at this part of the study area.

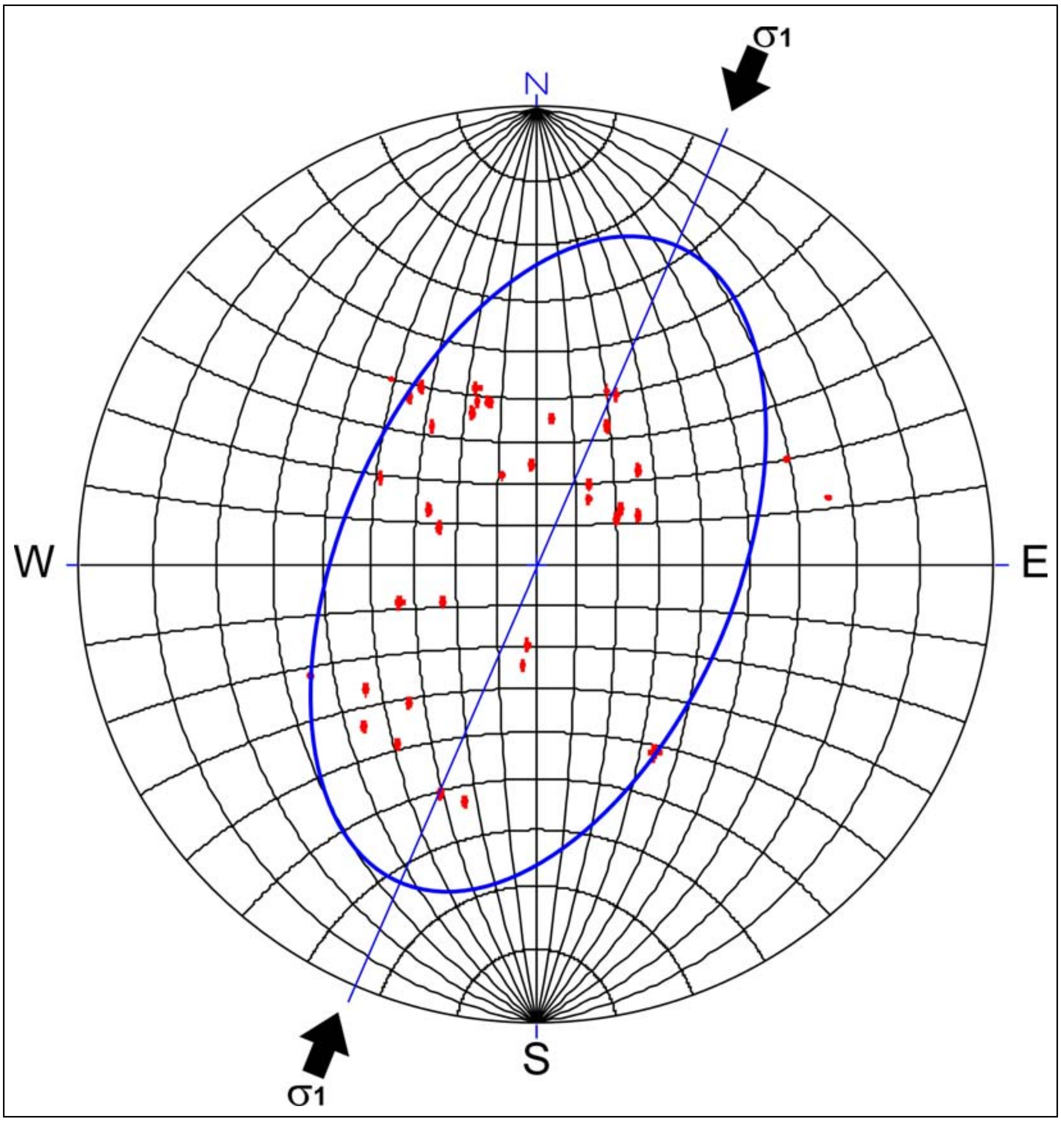


**Figure 33.** Stereographic pole plots to bedding planes of the Eskipazar formation, black arrows indicate the average operation direction of the compressive stresses during the latest phase of paleotectonic period.

## 3.2. Neotectonic Structures

In this section, characteristics of the neotectonic structures exposed within the study area will be dealt with. Here, neotectonic term is considered as a period of time that has elapsed since the last major wholesale tectonic reorganization in a region of interest (Şengör, 1980) which started and this tectonic reorganization in Anatolia by the formation of the North Anatolian Fault System in Early Pliocene (Barka, 1984) or later (Late Pliocene) (Koçyiğit and Beyhan 1998). Under the light of this information, structures that developed under the present day strike-slip tectonic regime in the study area are defined as the neotectonic structures which constitute beds, unconformities, faults and extensional fissures. The field based study and analysis of these structures will enlighten the characteristics of present-day deformation that takes place within the study area and will be helpful in interpreting final stage of evolutionary history of the Eskipazar Basin.

#### 3.2.1. Beds

Undeformed younger neotectonic units and infill of the Eskipazar Basin occur as patches of Plio-Quaternary Budaklar, Karkın, İmanlar formations and Holocene sediments in different localities throughout the study area. They, except for Holocene sediments are characterized by bedded to massive travertine deposits and the Budaklar, İmanlar formations contain some clastic intercalations with in. Original dips of all these formations are nearly 0°, meaning that the beds of these formations are nearly flat lying. On the other hand, some travertine layers display dip angles that are more than 20°, but this dip angle is the original dip angle of these travertine layers and formed by precipitation of $CaCO_3$ from down slope flowing hydrothermal waters that are coming out from the fissures, which have relatively high elevations due to the build-up of travertine around them. During the field studies the dip amounts and directions of these travertine layers were used to locate the positions of the travertine fissures, from which these layers dip in radial pattern. The thicknesses of travertine layers range from few millimetres up to few centimetres. On the other hand, the thicknesses of these travertine layers do not remain constant and decrease away from the source of hydrothermal waters (fissures). Besides these, the clastic sediments of the neotectonic period have thicknesses ranging from a few centimetres to a few tens of meters.

### 3.2.2. Unconformities

All units termed as the neotectonic units overlie the highly deformed paleotectonic basement rocks, including the Upper Miocene-Lower Pliocene, Eskipazar formation, with an angular unconformity. In the certain parts of the study area, the angular differences between the nearly flat-lying unconformity surfaces and the underlying Eskipazar formation range from 20° up to 50° (Plate 2). The age of this angular unconformity is Late Early Pliocene. Also, in several parts of the study area, the “Arkotdağ Formation” is unconformably overlain by either travertine deposits or clastics of Plio-Quaternary age. The unconformities between these two units occur as patches in front of the downthrown blocks of faults bounding the nearly flat-lying terraces (Plate 2).

In addition, minor erosional surface, which is a short-term time gap in the nature of disconformity, occurs between the Plio-Quaternary, and Upper Quaternary deposits. Here it should be kept in mind that both the Plio-Quaternary sediments and the Upper Quaternary units are nearly horizontal and undeformed. The age of the disconformity is probably Late Pleistocene.

### 3.2.3. Faults

Faults observed and mapped within the study area can be categorized based on their trends in three major groups. These are: (1) E-W trending faults or fault sets, (2) ENE-WSW trending faults or fault sets, and (3) NE-SW trending faults or fault sets. In addition to this categorization, the faults exposed within the study area can be based on their locations within the study area analysed within two groups. These two groups are: (1) fault or fault sets forming the outline of the Eskipazar Basin, and (2) faults exposed within the central parts of the Eskipazar Basin (Plate 1). Each group has a control on morphology and characteristics of the basin itself. During the field observation and examinations these faults are mapped based on their geomorphologic expressions. In general, these faults occur as nearly vertical, dextral or sinistral strike-slip faults cutting through the pre-Pliocene basement rocks and the pre-Quaternary cover units.

As is mentioned before, the outline and characteristics of the Eskipazar Basin is determined by the faults surrounding it and occurring within. In the southern part of the study area, Eskipazar Basin starts as a depression, compared with its eastern and western highlands, and it is separated from the adjacent, relatively lower İsmetpaşa Basin in the south by gently rolling hills on the upthrown block of the E-W trending, south dipping Acısu Fault (~7 km long long). Further to the North, the basin is bounded by the WNW-ESE trending Karkın fault (~2 km long) and the NW-SE trending Arslanlar fault set (~2 km long) together with E-W trending Dibek (~3 km long) and Karkın (~2 km long) faults to the east of the basin. On the other hand, the basin is bounded by NE-SW trending Budaklar fault set (~4 km long) and E-W trending Beytarla fault zone (~4 km long) in the west (Plate 3). In addition to this, the eastern part of the basin may be considered to be controlled by NNE-SSW trending Boztepe fault (~1.2 km long).

The faults exposed within the central parts of the basin are generally, relatively short, isolated and closely-spaced. Therefore, among these faults only the Yeniköy (~3 km) and İmanlar faults are considered in this study. The reason for this discrimination is that both the Yeniköy and the İmanlar faults play important role in the evolution of the Eskipazar Basin.

Morphologically the southern margin of the basin is fairly straight because of the straight geometry of the Acısu Fault. In contrast to this, the northern margin of the basin, that is determined by the Dibek fault and the Aslanlar fault set, is curvilinear whereas the northwestern and western margins of the basin are stepped in morphology because of the step-like nature of the Budaklar, Beytarla and the Kadılar fault sets. In addition to this, the geometric arrangement of faults surrounding the basin is also a controlling factor for the distribution and geometry of drainage pattern and flood plains of streams.

In the study area, existence and activeness of the faults are indicated by sudden break in slope, juxtaposition of different units, down cutting of streams through traces of faults, fault-parallel alignment of springs, alignment of alluvial fans along to traces of faults, presence of hot springs along the traces of faults, presence of young travertine deposits on downthrown blocks of faults and presence of terraced Plio-Quaternary units. Major faults taking part in the Neotectonic evolution of the Eskipazar basin will be explained in more detail in the following sections.

#### 3.2.3.1. Acısu Fault

Acısu Fault, which was first named by Koçyiğit (2003), determines the southern margin of the Eskipazar Basin. It comprises relatively straight E-W trending southward facing oblique slip normal fault with minor amount of dextral strike-slip component. This fault makes a left, restraining step-over approximately 1.5 km east of Karaağaç Hill. The length of this fault is approximately 7 km (Plate 3). Along the fault Quaternary infill of adjacent İsmetpaşa Basin and Taşlık Formation are tectonically juxtaposed.

The Acısu fault does not display clear scarps at the western parts, but at eastern parts the scarps of this fault is steep and clear. Especially in the southern parts of the Acısu Hill and the Karaağaç Hill the fault scarp is well exposed and displays well-preserved slickenside with striations on it (Figure 34). Slip plane data measured on this slickenside (Station 1, $S_1$ on Plate 1) and their kinematic analysis indicates that the Acısu Fault is an oblique slip normal fault with minor amount of dextral strike-slip component. The kinematic analysis also indicated that the local extension direction is nearly N-S (NNE-SSW) (Figure 35 and Table 2).


**Figure 34.** A close-up view of slickenside of steeply dipping Acısu Fault (Location: ~ 1 km SE of İmamlar Hill ; Station 1 on Plate 1).

Sudden change in slope, presence of aligned of alluvial fans with apices adjacent to faults, presence of sulphurous springs on the trace of the fault nearby Acısu and Karaağaç Hills (Figure 36) are indicators of activeness of the Acısu fault. The Taşlık Formation on the downthrown southern block of the fault is covered by Quaternary alluvium. As there is no borehole data available along or near by the fault trace. The throw amount of this fault could not be calculated. Outside of the study area this fault joins with other subsidiary faults and acts as riedel fault of North Anatolian Fault System (Gerede I Fault of Tokay, 1974).

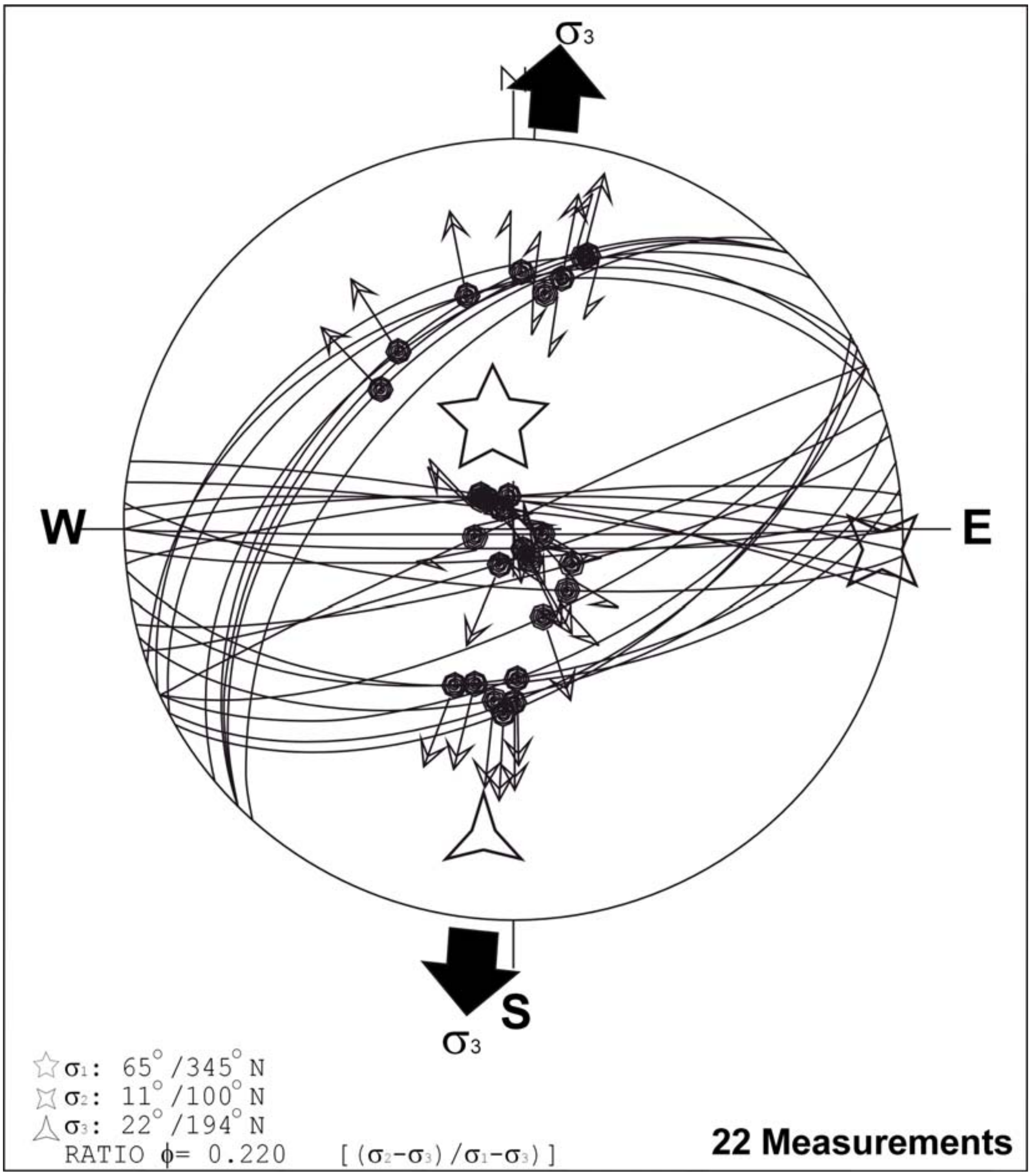


**Figure 35.** Kinematic analysis data taken from the slip-planes of Acısu Fault. Diagram showing the streographic plots of slip-planes with slicken-line orientations as well as the principle stress orientations and the nearly the N-S extension direction.

**Table 2.** Slip plane measurements collected from Acısu Fault at Station 1 ($S_1$) (see Plate 1 for location of station)

| Station 3 | Fault Plae (Strike and Dip) | Rake |
|---|---|---|
| 1 | N85° E, 83° W | 85° W |
| 2 | N87° W, 84° SW | 83° W |
| 3 | E-W, 83° N | 89° |
| 4 | N83° W, 86° NE | 87° W |
| 5 | N80° W, 84° NE | 82° W |
| 6 | N62° E, 40° NW | 77° E |
| 7 | N42° E, 55° NW | 50° E |
| 8 | N70° E, 39° NW | 65° E |
| 9 | N45° E, 49° NW | 90° E |
| 10 | N66° E, 35° NW | 57° N |
| 11 | N75° W, 72° SW | 90° W |
| 12 | N72° E, 84° SE | 85° W |
| 13 | N50° E, 45° NW | 58° E |
| 14 | N45° E, 45° NW | 53° E |
| 15 | N45° E, 47° NW | 40° E |
| 16 | N65° E, 71° SE | 88° W |
| 17 | N60° E, 56° NE | 70° W |
| 18 | N84° E, 58° SE | 75° W |
| 19 | N74° E, 56° SE | 77° W |
| 20 | N65° E, 61° SE | 78° W |
| 21 | N80° E, 59° SE | 77° W |
| 22 | N62° E, 57° SE | 74° W |

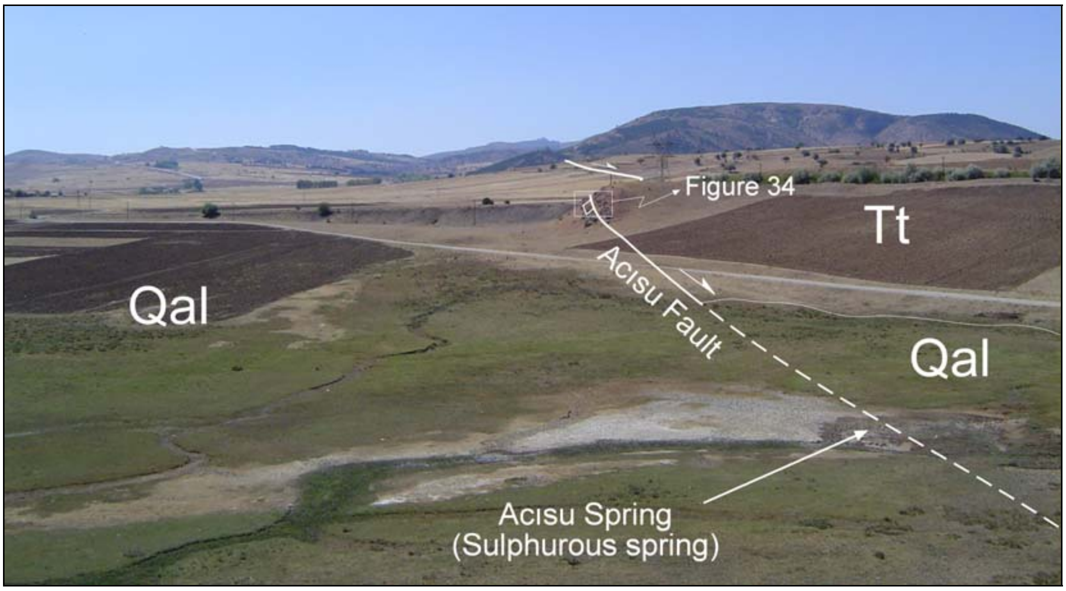


**Figure 36.** A general view of the scarp of the Acısu Fault with sulphurous springs located on the trace. Tt: Taşlık Formation, Qal: Upper Qaternary Alluvium (Location : ~ 500 m SW of Acısu Hill, view towards W).

### 3.2.3.2. Kadılar fault set

Kadılar fault set is first named by Koçyiğit (2004). This fault set determines southwestern to western margin of the Eskipazar Basin. It comprises a series of relatively closely spaced basinward-facing (dipping), parallel to sub-parallel oblique-slip normal faults with minor amounts of sinistral strike-slip component (Plate 1, Figure 37). In general, the Kadılar fault set displays a curvilinear pattern with a NW-SE trend, and is represented by an approximately 1 km wide shear zone in the southern parts of the study area. In contrast to this, towards northwest direction, it continues as a single strand. The fault set starts outside of the study area in the south and continues to the northwest in the form of two discontinuous strands of parallel to sub-parallel faults (Plate 1). As these strands are oblique-slip normal faults facing towards the basin, they formed stepped morphology at this margin of the basin (cross-sections $A_3$-$A_3$ and $A_4$-$A_4$ on Plate 2).

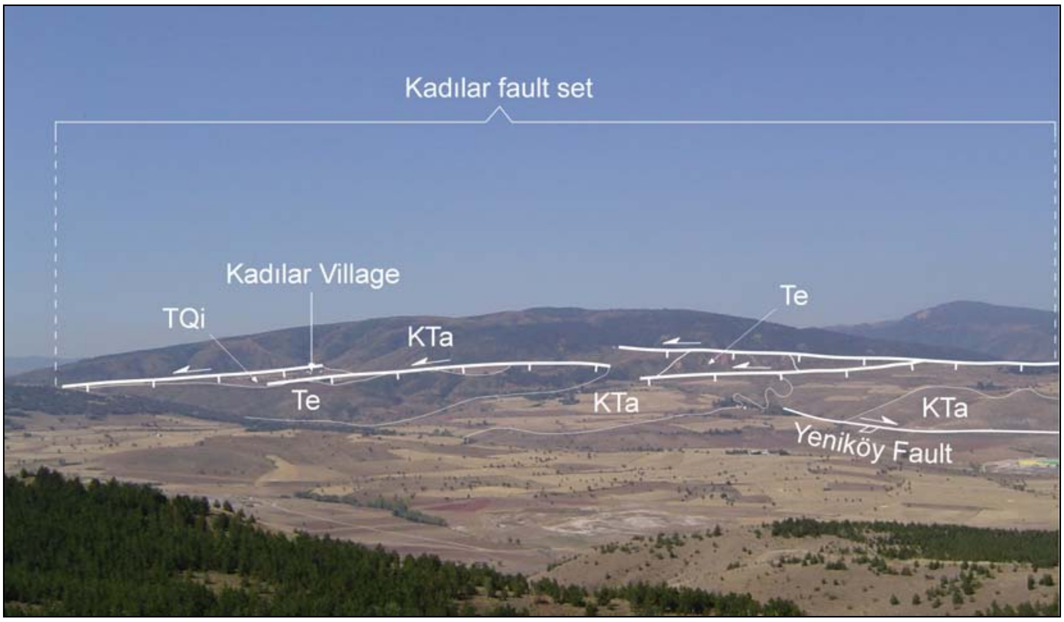


**Figure 37.** A general view of fault scarps of the Kadılar fault set. KTa: "Arkotdağ Formation", Te: Eskipazar formation, TQi: İmanlar formation. (Location : ~ 1 km W of Kıraçtarla Hill, view towards SW).

Near the Kadılar Village, the western strand jumps to northeast and eastern strand curves towards north. At further northwest, the strands of this fault set become more continuous and joins with each other approximately 500 m ENE of Erentek Hill and continues further northwest in the form of a single strand. The longest eastern strand of this fault set measures approximately 6.5 km. The western strand of this fault comes into contact with Beytarla fault zone towards northwestern parts of the study area. Further northwestern continuation of this fault set comes into a close relationship with Budaklar fault set (Plate 3). The travertine outcrops, at these two localities where Beytarla fault zone and Budaklar fault set nearly comes into contact with Kadılar fault set. The reason for this may be development of joints and fractures by activation of both fault sets and fault zone, thus forming conduits for hydrothermal waters to flow to the surface and consequent deposition of travertines at these localities.

Western strand of the Kadılar fault set passes through Kadılar Village and it juxtaposes the “Arkotdağ Formation” with the İmanlar formation and in other localities it juxtaposes the Eskipazar formation with the İmanlar formation or Quaternary units (at further northwestern parts of the study area; Plate 1).

The Kadılar fault set displays clear scarps all along it’s trend but they lack slickensides and striations that are necessary for kinematic analysis. Nevertheless the topographic and morphological expressions of this fault indicates that the fault set is composed of oblique-slip normal faults with minor amount of sinistral strike slip component. This is also indicated by the relationship between the general trend of the fault set and the operation direction of the principal stresses.

Development of fault parallel alluvial fans at its eastern parts with apices adjacent to faults, sudden change in the slope and deeply carved valleys all together indicate both the existence and activeness of the Kadılar fault set (Figure 37).

### 3.2.3.3. Beytarla fault zone

Beytarla fault zone is named for the first time in this study. This fault zone determines the southern margin of the Eskipazar Basin. It comprises a series of relatively closely spaced basinward facing parallel to sub-parallel dextral strike-slip faults with minor amount of dip slip components. The general trend of the fault zone is nearly E-W and the faults of this fault zone display generally a curvilinear pattern. The width of the fault zone ranges between ~ 1 to 1,5 km. It comprises two segments, namely the northern and the southern segments. The southern segment consist of short, relatively closely-spaced, discontinuous oblique slip normal faults. This segment starts at approximately 1 km east of Beytarla Village. The strands of this segment converge to each other near Beytarla Village and continue to the west in the form of three parallel strands, forming a stepped morphology and nearly flat-lying terraces (Plate 3). The southern segment of the Beytarla fault zone cuts through the “Arkotdağ Formation” and juxtaposes it with the Eskipazar formation at some certain localities (cross-section $A_1$-$A_1$ on Plate 2). The northern segment of Beytarla fault zone comprises relatively long and continuous strike-slip faults. This segment starts at the contact with the Kadılar fault set, at 500 m north of Dedeyatağı Hill and continues in SW direction. About 750 m NW of Tilkiçukuru Hill, it curves towards west and in the north of Yaka Hill it becomes nearly E-W in trend (Plate 3). Further to the west, it rebends towards south and continues outside of the study area with a WSW-ENE trend. The northern segment of the Beytarla fault zone cuts through the Eskipazar and Budaklar formations and juxtaposes Quaternary flood plain deposits of Göksu stream (Plate 1 and cross-section $A_1$-$A_1$ on Plate 2). The southern and northern segments of this fault zone are linked to each other by small, nearly NNE-SSW-trending subsidiary faults, which are also sites for fault controlled valleys; the two segments converge to each other in western parts of the study area. The longest strand of the Beytarla fault zone is about 2 km long and this fault zone includes Beytarla, Çöküşler, Güvez and Kadirgil Villages. Beytarla fault zone extends outside the study area in the west and the two segments possibly get closer to each other there.

The Beytarla fault zone displays a stepped morphology with young fault terraces, the scarp of each fault is relatively short and due to the rheological conditions, they are nearly smoothened, with no slickensides. On the other hand, the topographical and morphological expressions of this fault zone and the geometrical relationship of regional maximum stress axis orientation with its trend indicate that it is a of dextral strike-slip fault zone with minor amount of dip-slip component.

Development of fault parallel alluvial fans in its northern parts with apices of these adjacent to faults, sudden change in slope and presence of travertine deposits and fault terraces all together indicate the existence and activeness of the Beytarla fault zone (Figure 38).

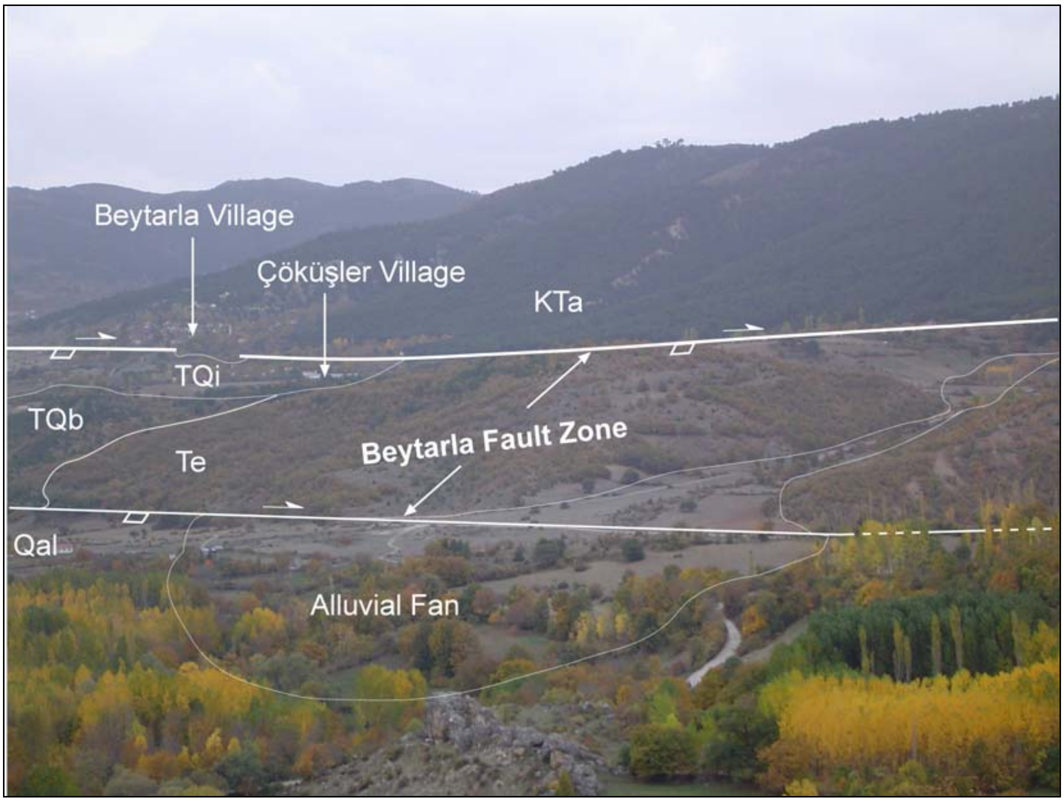


**Figure 38.** A general view of scarps and terraces of the Beytarla fault zone. KTa: "Arkotdağ Formation", Te: Eskipazar formation, TQb: Budaklar formation, TQi: İmanlar formation (Location: ~500 m south of Eleler village, view towards SE).

### 3.2.3.4. Budaklar fault set

The Budaklar fault set is named for the first time in this study, and it determines the western-northwestern margin of the Eskipazar Basin. It comprises relatively closely spaced basinward-facing, parallel to sub-parallel to oblique-faults with minor amount of dip-slip components. The general trend of the fault set is nearly NE-SW, and some faults display slightly curvilinear pattern. Thus, they are generally straight faults. The width of the fault set is approximately 1,5 km in its narrowest part. The narrower part of the fault set occurs in northeastern parts of it and wider part occurs in the southwest. The reason for this may be the presence of northwestern extension of the Kadılar fault set exposing in this part of the study area.

The general trend of the fault set fall into two distinct directions. One is a dominant NE-SW trend, and a ESE-WNW trend. The NE-SW trending faults display parallel and closely-spaced patterns in the southern part of the Budaklar fault set, especially about 300 m east of Eleler Village (Plate 3). On the other hand, towards northern parts of the fault set, the faults with this trend become more widely spaced and the fault terraces between two faults, become wider. As in the case of Beytarla fault zone, the NE-SW trending faults also display a step-like morphology (cross-section $A_1$-$A_1$ on Plate 2). In contrast to the NE-SW-trending faults, the ESE-WNW-trending faults of this set are generally closely-spaced and parallel segments and display step-like morphology (cross-section $A_2$-$A_2$ on Plate 2). The different trend of these faults that are diverging characteristically from the dominant trend may be due to the reason that these faults are linkage faults between parallel sets of the NE-SW trending dominant set of faults. Another fault that is exposed within the Budaklar fault set is located at approximately 250 m west of Yol Hill. This fault is a minor and a short one that trends in NW-SE direction paralleling to the Kadılar fault set. Based on this relationship and matching of their trends and characteristics, one may suspect that this minor fault may be included in Budaklar fault set. Keeping this in mind, the area, where the two fault sets meet, is the site of thick and extensive deposits of travertines (Figure 39) formed due to conjugate fracturing and resulting conduit by which the $CaCO_3$-rich thermal water came out of the ground surface and precipitated as travertines.

The Budaklar fault set cuts through the Eskipazar formation (Plate 1), and juxtaposes it with the “Arkotdağ Formation” in the northern parts of the study area (Plate 1 and cross-section $A_1$-$A_1$ on Plate 2). Towards the south, the Budaklar fault set also juxtaposes the Eskipazar formation with the Budaklar formation (Plate 1, and cross-sections $A_1$-$A_1$ and $A_2$-$A_2$ on Plate 2). The longest fault segment of the Budaklar fault set measures more than 1,7 km in length.


**Figure 39.** General view of widespread travertine occurrences, exposed within the limits of Budaklar fault set. TQb: Budaklar formation. (Location : ~ 1 km SW of Budaklar village, view towards SE).

The Budaklar fault set displays distinct scarps where the faults are long and widely spaced. At places, where the faults are closely spaced the stepped morphology is narrow and the scarps become unclear. During the field observation no slickensides and striations are recognized on the fault scarps. Due to the lack of slickensides, kinematic analysis could not be held for this fault set but topographical and morphological expressions of the faults, and their geometrical relationship with the current direction of principal stress, indicate that the fault set is a dextral strike-slip fault with minor amount of dip slip component.

Sudden change in the slope, presence of relatively young travertine deposits on hanging wall blocks of faults and tectonic juxtaposition of units along straight and sharp lines, indicate both the existence and the activeness of Budaklar fault set (Figure 40).

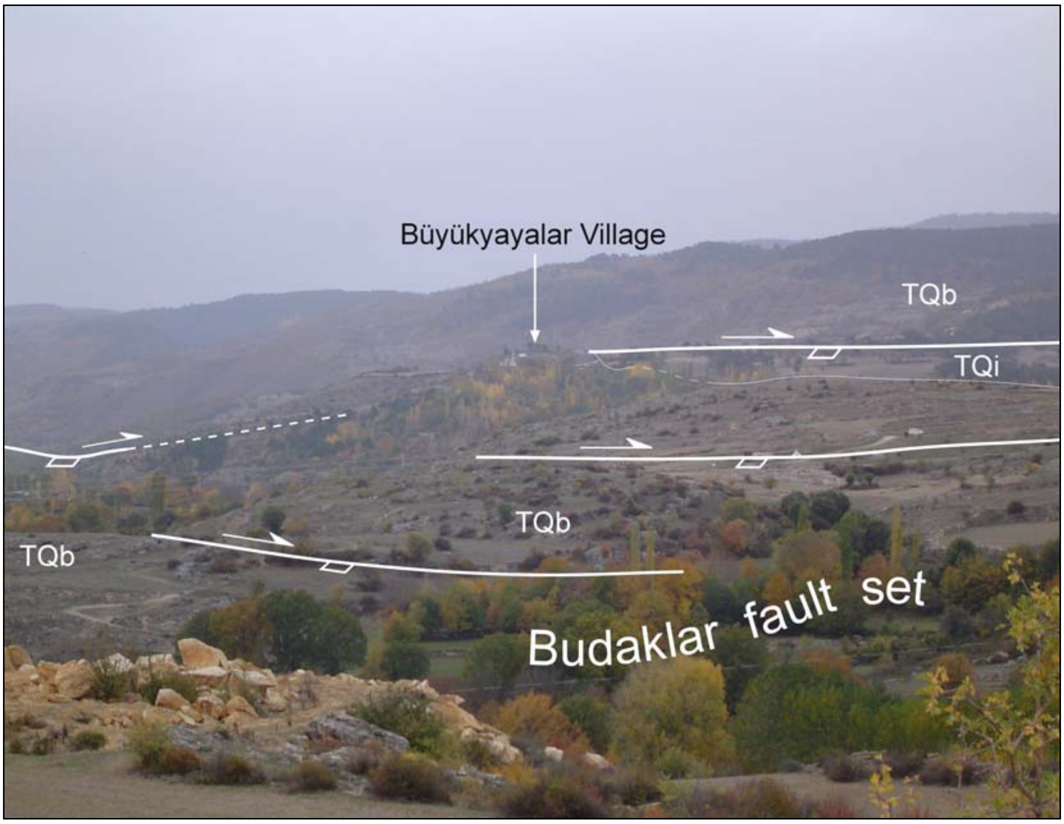


**Figure 40.** General view of western part of the Budaklar fault set and the stepped topography shaped by the terraces of it. TQb: Budaklar formation, TQi: İmanlar formation (Location : ~ 1,5 km SE of Büyükyayalar village, view towards NW).

### 3.2.3.5. Arslanlar fault set

Arslanlar fault set is named for the first time in this study. This fault set determines the northeastern margin of the Eskipazar Basin together with the Dibek fault set and the Karkın fault (Figure 41). It comprises relatively closely-spaced, basinward-facing, parallel to sub-parallel sinistral strike-slip faults with minor amount of dip-slip components. The general trend of the fault set is NW-SE and the fault segments display curvilinear to linear outcrop pattern. The width of the fault set is about 500 m. Within the study area, only two faults of this set are observed. These two faults make a left step-over approximately 300 m east of Arslanlar Village. The width of the step over is about 500 m. Within the zone of this step-over, the Eskipazar formation exposes. However on the other sides of this zone, older “Arkotdağ Formation” crops out (Plate 1 and cross-section $A_3$-$A_3$ on Plate 2). This step-over is a releasing step-over. Therefore, the area is topographically lower than the surrounding parts. Presence of both the Eskipazar formation and the travertines of the Budaklar formation along the step-over located on the downthrown block of the NW-SE trending fault of the Arslanlar fault set may form an evidence of a local extension, that is being experienced by this step-over (Plate 1, Figure 42)

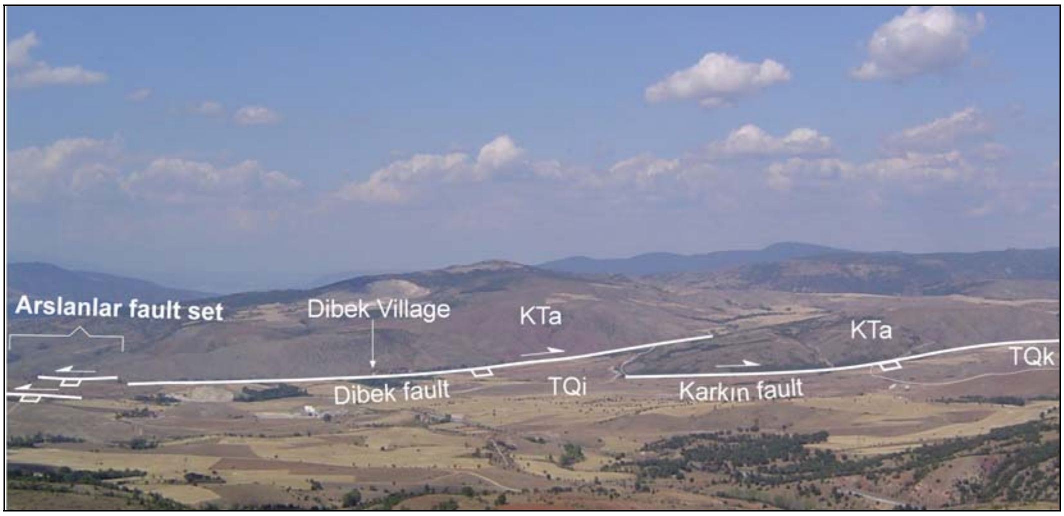


**Figure 41.** General view of scarps of the Arslanlar fault set, the Dibek and Karkın faults KTa: “Arkotdağ Formation”, TQk: Karkın formation, TQi: İmanlar formation (Location: ~ 1 km N of Ahırtaş Village, view towards NNE).

**Figure 42.** General view of travertine deposits of the Budaklar formation, cropping out within the step-over zone of the Arslanlar fault set (Location : ~ 1 km E of Arslanlar Village, view to SW).

The Arslanlar fault set mainly cuts through the “Arkotdağ Formation” and it juxtaposes it with the Eskipazar formation (Plate 1), clastics of the İmanlar formation, and travertines of the Budaklar formation (Plate 1 and cross-section $A_3$-$A_3$ on Plate 2). The Arslanlar fault set is comes to end very close to the western tip of the Dibek fault, however it possibly continues for some distance outside of the study area in the northwest. The longest fault segment measures about 2 km.

The Arslanlar fault set displays distinct and relatively straight fault scarps in its northern and northeastern parts. The traces of the faults are cut across by major stream valleys, in places. The kinematic indicators of the motion sense along these faults have been eroded and removed away leaving behind an uneven oxidized zone. On the other hand, topographic and morphological expressions of the faults and geometric relationship between faults and principal stresses indicate that the fault set is composed of sinistral strike-slip faults with minor amount of dip slip components.

Sudden change in the slope, presence of relatively young travertines and Plio-Quaternary clastics on the hanging wall blocks of faults, and the tectonic juxtaposition of units along straight and sharp fault traces indicate both the existence and the activeness of the Arslanlar fault set.

#### 3.2.3.6. Dibek fault

Dibek fault is named for the first time in this study. This fault determines the northern margin of the Eskipazar Basin together with the Arslanlar fault set and the Karkın fault (Figure 41). It is a linear to curvilinear dextral strike-slip fault with minor amount of dip-slip component. The general trend of the fault is ESE-WNW.

The fault starts at approximately 750 m south-southeast of Sığıreyrek Hill, and continues to the west in a straight manner in ESE-WNW trend, for about 1 km (Plate 3). At a distance of 1 km SW of

Sığıreyrek Hill, the Dibek fault jumps to south for about 100 m and forms a restraining step-over. Within this step-over zone, the “Arkotdağ Formation” crops out and forms a relatively higher topography (Plate 1). In the further west, the fault trends nearly E-W for about 500 m, and bends towards northwest. Later on it continues in the same direction for about 750 m and rebends to west and continues in E-W trend for approximately 1 km, and than terminates. A small-scale releasing type of right bending occurs along this fault 500 m east-southeast of Dibek Village. The relatively wide area of Quaternary flood plain deposits accumulated nearby this releasing bend can be attributed to a depression caused by the releasing bending here and recent filling of the depression with flood plain deposits.

The Dibek fault cuts through the “Arkotdağ Formation” and juxtaposes it with the Eskipazar formation and the clastics of the İmanlar formation as well as Quaternary units (Plate 1). The total length of this fault is nearly 5 km. Dibek fault displays distinct and clear fault scarps in its eastern and middle parts. The scarp of the fault nearly vanishes in the few hundred meters west of Dibek Village. In the east, where it cuts through the “Arkotdağ Formation”, the trace of this fault is carved deeply resulting in a steep-sided canyon by the Söğüt stream. No slickensides were recognized along the trace of this fault but the speculative offset of the Söğüt stream was recognized in the eastern side of the step-over zone along this fault. The right lateral offset measures nearly 70 m. When the morphological indicators together with the geometrical relationships between the general trend of the fault and the principal stresses are considered, it can be concluded that this fault is dextral strike-slip fault with minor amount of dip-slip component.

The existence and activeness of the Dibek fault is indicated by sudden change in the slope, the tectonic juxtaposition of lithofacies of dissimilar age and origin along straight and sharp traces, and the offset drainage system (Figure 43).

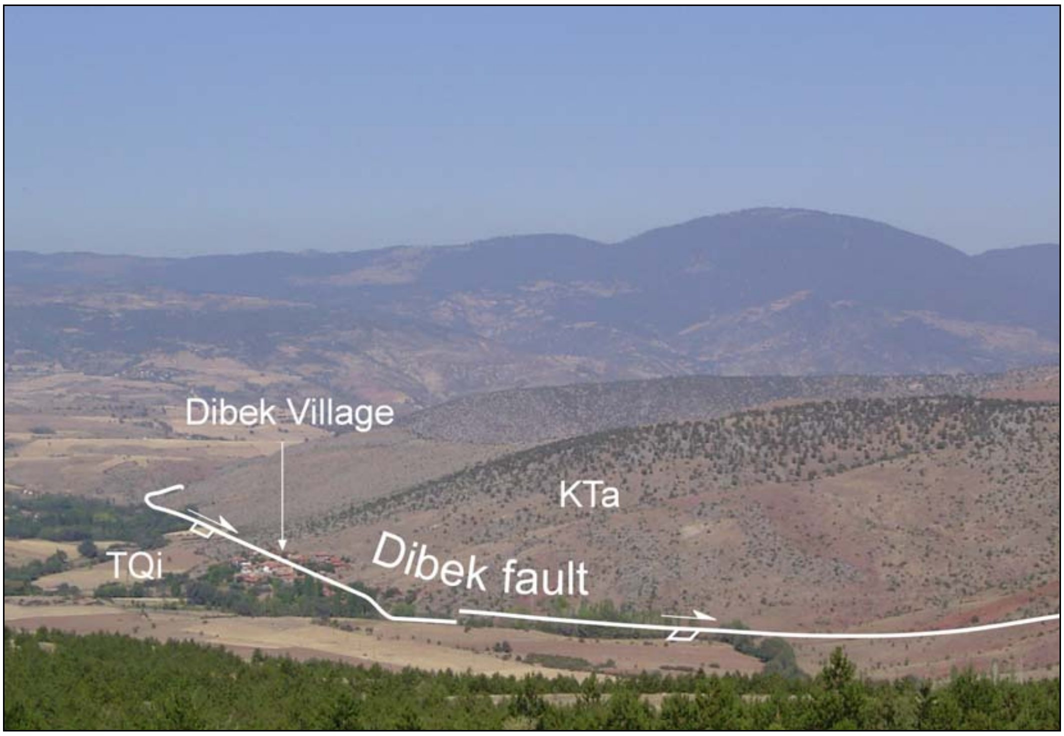


**Figure 43.** General view of scarp of the Dibek fault. KTa: “Arkotdağ Formation”, TQk: İmanlar formation. (Location : ~ 1 km North of Ahırtaş Village, view towards NW).

### 3.2.3.7. Karkın fault

Karkın fault is named for the first time in this study. It also determines the eastern-northeastern boundary of the Eskipazar Basin (Figure 41). It is a linear dextral strike-slip fault with minor amount of dip slip component. The Karkın fault trends in ESE-WNW direction and runs parallel to the Dibek fault.

The Karkın fault starts about 500 m southeast of Kale Hill and continues in a straight trend for about 2 km until it reaches the İmanlar faults. The Karkın stream seems to be offset by about 750 m in right-lateral sense (Plate 1). Indeed, this may not be a clear offset and it may be the control of fault on the flow direction of the stream. Another property of this fault is that, a well-developed fissure ridge travertine deposit crop out on the downthrown block. Axis of fissure is oriented nearly parallel to the trend of the Karkın fault. This may be considered to be an indicator of the local extension direction.

The Karkın fault mainly cuts across the “Arkotdağ Formation” and juxtaposes it with the younger Eskipazar, Karkın and İmanlar formations. The total length of the fault is about 2 km. The Karkın fault displays a distinct and clear fault scarp. No slickensides or slickenlines could be found on this fault scarp. The extension direction indicated by travertine fissure located 250 m west of Karkın Village and offset of Karkın stream along this fault, altogether, reveal that this fault is dextral strike-slip fault with minor amount of dip-slip component.

The existence and activeness of the Karkın fault is indicated by the sudden change in the slope, tectonic juxtaposition of different units along a straight line, the offset streams and the large travertine deposits accumulated on the hanging wall block of it (Figure 44).

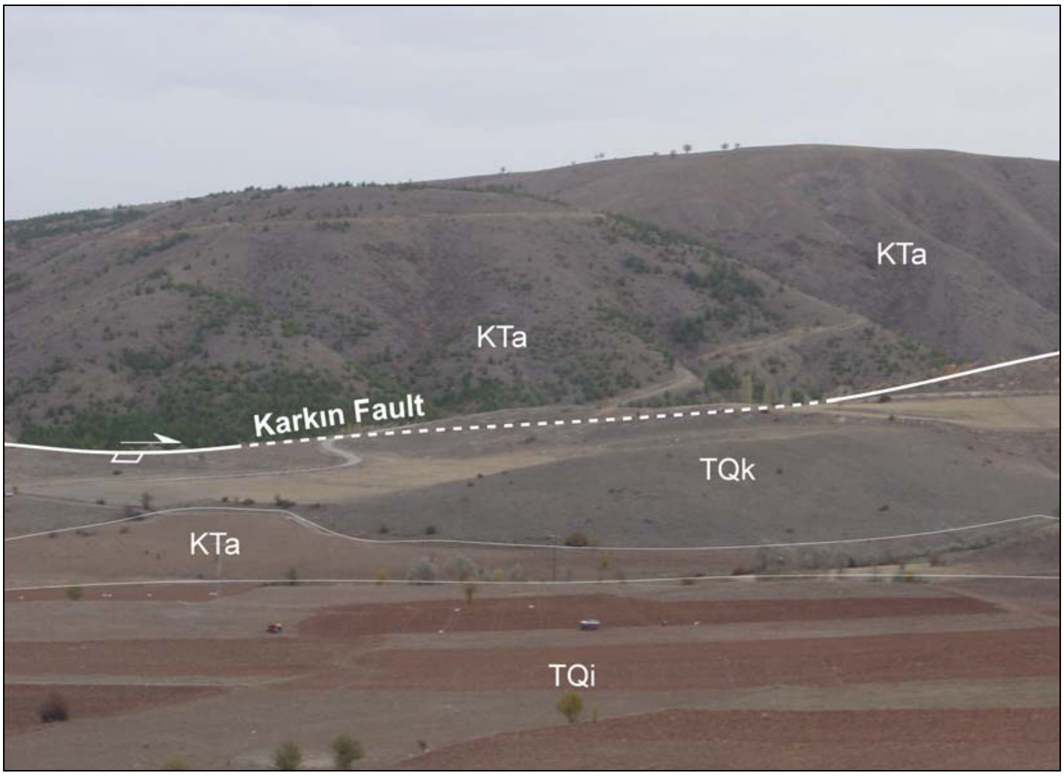


**Figure 44.** General view of scarp of the Karkın fault. KTa: “Arkotdağ Formation, TQk: Karkın formation, TQi: İmanlar formation (Location: ~ 500 m NW of Karkın Village, view toward NE).

#### 3.2.3.8. Yeniköy fault

Yeniköy fault is named for the first time in this study. This fault is a major fault with a distinct morphological expression within the basin. It is a curvilinear right-lateral strike-slip fault with minor amount of dip-slip component. The fault trends SW-NE. The Yeniköy fault starts in about 500 m southwest of Durallar Village and terminates in about 300 m northeast of Taşlık Hill, in the northeast. The Yeniköy fault has an important role in the evolution of the Eskipazar Basin. It separates a highland in the northwest from the lowland in the southeast. The hanging-wall block is the site of nearly flat-lying widespread outcrops of the Plio-Quaternary neotectonic units, such that this part is the depocenter of the very young and active strike-slip basin.

The Yeniköy fault cuts across the "Arkotdağ Formation" and the Eskipazar formation, and juxtaposes them in places. The total length of this fault is approximately 3 km.

Yeniköy fault displays a distinct and clear fault scarp where it cuts the "Arkotdağ Formation". Unfortunately, no slickensides and slickenlines could be observed along this fault but its topographical to morphological expressions and the geometrical relationship with the principal stresses indicate that it is a dextral strike-slip fault with minor amount of dip-slip component.

The activeness and existence of the Yeniköy fault is indicated by the sudden change in the slope and the tectonic juxtaposition of different lithological units along a straight fault trace (Figure 45).


**Figure 45.** General view of the scarp of the Yeniköy fault. KTa: “Arkotdağ Formation”, Te: Eskipazar formation (Location : ~ 500 m south of Yeniköy, view towards WSW).

### 3.2.3.9. İmanlar faults

The İmanlar faults are named for the first time in this study. These faults are relatively short curvilinear to linear, parallel to sub-parallel in spatial distribution. The trend of the faults ranges from ENE-WSW to WNW-ESE (Plate 3). These faults are located in the area between Dibek, Yeniköy, Karkın and Boztepe faults. Two of closely-spaced faults, which are parallel and sub-parallel to each other form a pressure ridge in approximately 750 m SW of Karkın Village (PR on Plate 3). This pressure ridge is characterized by the sharp and elongated morphology of the “Arkotdağ Formation”. The sharpness of the pressure ridge is controlled by the rheological property of this formation (Figure 46). Besides, within the area where the İmanlar faults are present, the “Arkotdağ Formation” exposes as isolated outcrops on the footwall blocks of the faults. These patch like outcrops may indicate that the cover units including the Eskipazar formation, is relatively thin, they may also show that this portion of the study area was highly deformed by the closely spaced, conjugate and isolated faults, thus resulting in a depocenter ( cross-section $A_4$-$A_4$ on

Plate 2). In this area the deformation is recently active as indicated by the actively precipitating travertines. These travertines are the parts of Plio-Quaternary Karkın and İmanlar formations possibly formed due to the complexity of deformation and active faulting taking place at this locality. The active İmanlar travertines (Figure 47) are located approximately 1 km north-northwest of İmanlar Village, at the junction of a curvilinear ENE-WSW-trending oblique-sip normal fault and the straight NNW-SSE-trending sinistral strike-slip fault running across the İmanlar Village (Plate 1 and Plate 3). The İmanlar travertines display a well-preserved active fissure and fissure ridge which indicate at least deformation along the faults. The İmanlar faults, generally, cut through the “Arkotdağ Formation”, Pazarbaşı, Karkın and İmanlar formations and juxtapose them with each other as well as with the Quaternary units. The longest fault of the İmanlar faults measures approximately 2 km.

İmanlar faults display some distinct and clear fault scarps at localities where they cut through the “Arkotdağ Formation” but no slickensides could be observed along these faults scarps. Based on the morphological to topographic expressions of these faults, and their geometrical relationships with the principal stresses it can be said that, these faults are sinistral to dextral strike-slip faults with minor amount of dip-slip components.

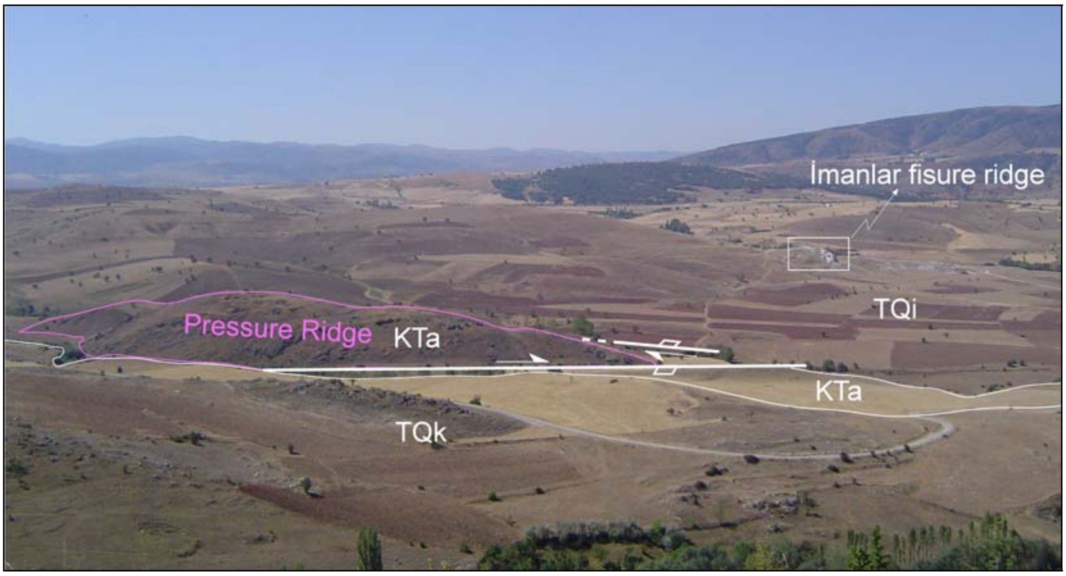


**Figure 46.** General view of pressure ridge and outcrop of the “Arkotdağ Formation” that is located 750 m SW of the Karkın Village. KTa: “Arkotdağ Formation”, TQk: Karkın formation TQi: İmanlar formation (Location : ~ 750 m SW of Karkın village, view towards S).

**Figure 47.** General view of the active İmanlar fissure ridge travertines (Location: ~ 1 km North of İmanlar village, view towards E)

#### 3.2.3.10. Boztepe fault

Boztepe fault is named for the first time in this study. This fault has a control on the eastern margin of the Eskipazar Basin. It is a straight, relatively short dextral strike-slip fault with minor amount of dip slip component. The trend of this fault is NNE-SSW. The Boztepe fault starts about 1 km southwest of Boz Hill and continues towards southwest for approximately 1,2 km and then comes to end (Plate 3). In general in the western parts of the study area, nearly all the faults cut across the "Arkotdağ Formation" located on their upthrown blocks, but in the case of Boztepe fault, the Taşlık Formation crops out on its upthrown block.

The Boztepe fault cuts through the Eskipazar formation and the Taşlık Formation, and juxtaposes them with each other. The total length of this fault is approximately 1,2 km (Plate 1).

The Boztepe fault displays a distinct and clear fault scarp where it cuts through the Taşlık Formation (Figure 48). No slickensides or slickenlines could be observed on the fault scarp. Nevertheless, the morphological to topographical expression of the fault and its geometrical relationship with the regional stress system indicate that this fault may be a dextral strike-slip fault with minor amount of dip-slip component.

The existence and activeness of the Boztepe fault is indicated by the sudden change in the slope (presence of slope break), tectonic juxtaposition of the Taşlık Formation and the Eskipazar formation along a straight fault trace, and presence of the fault parallel aligned alluvial fans with their apices adjacent to the fault.

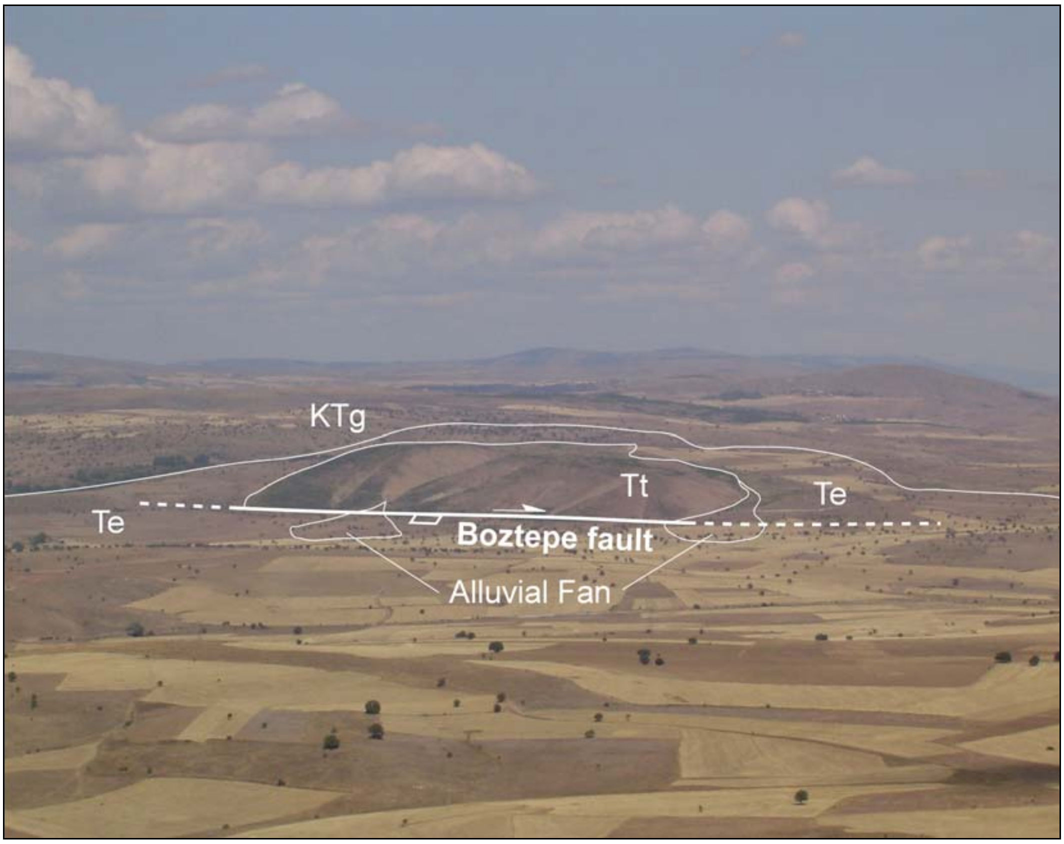


**Figure 48.** General view of the scarp of the Boztepe fault and alignment of alluvial fans along it. KTg: Galatean Arc Complex, Tt: Taşlık Formation, Te: Eskipazar formation. (Location : ~ 1,2 km SE of Boncuklar village, view towards ESE).

### 3.2.4. Extensional Fissures

The Eskipazar Basin is also characterized by the widespread active and inactive Plio-Quaternary travertine occurrences. They were named under three formations. These are, from oldest to youngest, the Budaklar, the Karkın and the İmanlar formations. The travertine deposits of these formations are characterized by the well-developed extensional travertine fissures. For clarity the fissure systems exposing within the study area, are given names based on their geographic location. These are namely Budaklar fissure, Bahçepınar fissure system, Kadılar fissure system and İmanlar fissure system (see Plate 3 and Table 3 for the locations of these fissures or fissure systems). These fissures display some characteristic features. The travertine bands of the fissures (fissure travertines) are nearly perpendicular to surrounding travertine deposits and cuts through the surrounding deposits together with the fissure itself (Figure 49). In some cases, the aperture, restricted between the two fissure walls, is filled with travertine breccias and other younger clastics (Figure 50). The fissures on the ridges are called “fissure ridges”. In general, fissure ridges are elongated in the direction of the fissure trend itself, and in some cases, the trends of the fissures determines the outline and morphology of the travertine deposits. As it is mentioned before, fissures are the good indicators of principle stress orientations acting in an area at the time of their formation. The fissures trends and their aperture amounts were measured for kinematic analysis, and they were plotted with their trends on the geological map of the study area (Plates 1 and 2). Several measurements of aperture and trends are taken from separate travertines, are summarized on Table 3.

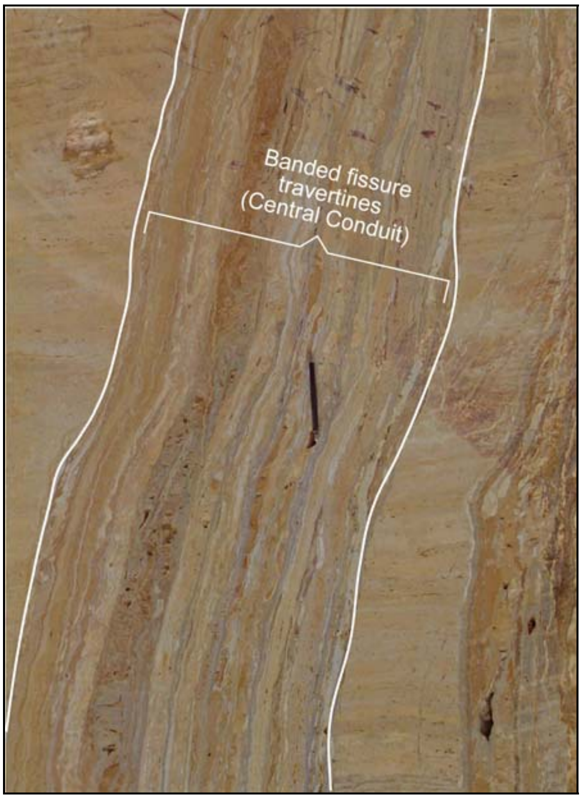


**Figure 49.** Close-up cut-away view of the Karkın fissure ridge travertine (central part). The fissure of this fissure ridge travertine belongs to the Karkın fissure system (Location: ~ 600 m north of Dedeyatağı Hill).

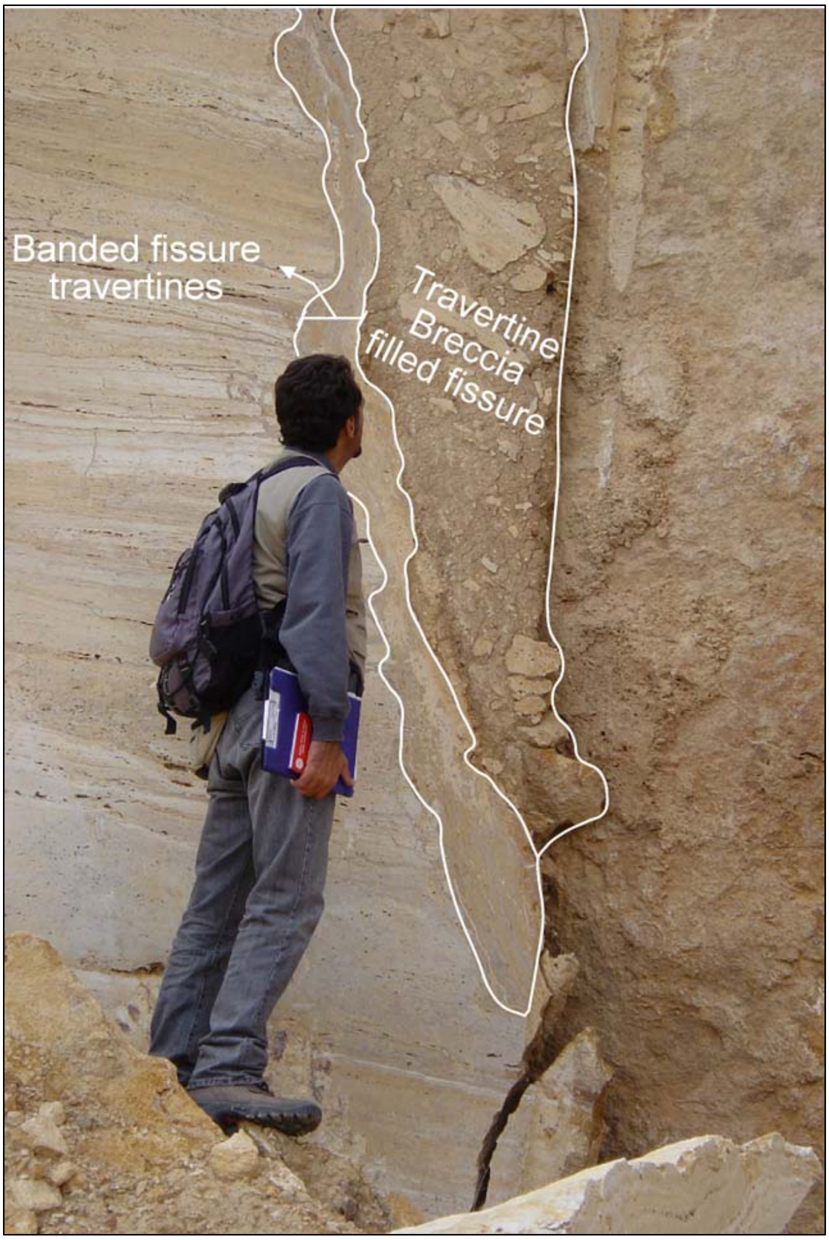


**Figure 50.** A close-up view of brecciated travertines filled extensional fissure belonging to the Karkın Fissure Sysytem ( Location : travertine quarry situated at ~ 600 m North of Dedeyatağı Hill ).

**Table 3.** Geometrical properties of extensional fissures of Budaklar, Karkın and İmanlar formations exposed at different localities within the study area.

| Formation Name | Fissure Name | Location of Fissure or Fissure System | Trend | Aperture Amount (cm) |
|---|---|---|---|---|
| **Budaklar formation** | Budaklar fissure | North of Büyükyayalar Village | N14°W | 25.5 |
| **Karkın formation** | Bahçepınar fissure system | North of Dedeyatağı Hill | N50°E | 69 |
| | | | N10°W | 72 |
| | | | N05°E | 172 |
| | Karkın fissure system | Karkın Village | N30°E | 35 |
| | | | N63°W | 42 |
| **İmanlar formation** | İmanlar fissure system | North of İmanlar Village | N10°W | 3 |
| | | | N14°W | 2 |

The travertines of the Budaklar formation display few fissures and most of them obliterated by erosion or they are covered by younger units. As the travertine deposits, in general, are very susceptible to erosion and as the Budaklar formation is the oldest (Plio-Quaternary) neotectonic unit exposed within the study area, the fissures developed within this formation was partly eroded, leaving behind few and poorly preserved fissures. Approximately 500 m north of Büyükyayalar Village, measurements of trend and aperture were taken from such a poorly preserved fissure filled with relatively younger infills as $N14^0W$ and 25.5 cm, respectively. This data indicate that, during the deposition of the Budaklar travertine, the orientation of the maximum stress axis was nearly $N14^0W$, and the observed fissure continued to dilate for a relatively short time, and then it stopped its activity, as indicated by the secondary infill in it.

The travertines of the Karkın formation display many well-preserved fissures with more or less same trends. The reason for this well preservation fissures travertines of the Karkın formation is that these travertines are relatively younger than the travertines of the Budaklar formation; the elopsed time is not enough for the complete erosion of the travertines. The measurements of trends and apertures taken from the fissures of these travertines in the near west of Karkın Village and 500 m NW of Dedeyatağı Hill (Bahçepınar District) are summarized on Table 3.

The analysis of these data indicates that the local maximum stress axis has changed in orientation from N50°E to N63°W during the deposition of this formation. Whereas the length of the apertures filled by the clastics of younger units, indicate that these travertines remained active for along time period, enough for the fissures to dilate and reach relatively high aperture lengths (see Table 3). The Karkın formation displays also well-developed fissure ridges indicated by its elongated outcrop pattern (Plate 1).

The travertines of the İmanlar formation display two well-developed fissures. One of the fissures is exposed clearly in the western part of the outcrop of the fissure ridge travertine. It is situated about 1 km north-northwest of İmanlar Village (Plate 1 and Figure 51) and has a trend of N14°W; the aperture length is about a few cm. This measurement indicates that the local maximum stress axis orientation was N14°W during the deposition of this travertine body. The other fissure is exposed in the east of the first one, and it is recently active. It forms the outline of the İmanlar fissure ridge. The trend of this active fissure is N10°W indicating a maximum stress axis orientation of N10°W, a direction consistent with the first one (Plate 1 and Figure 52). Both of the fissures have very short aperture lengths pointing out the activity of the fissures are very recent. This also indicates that the recent local maximum stress orientation is N10°W. The travertine deposits of the İmanlar formation are situated within the İmanlar faults which, indicates that the deformation in this portion of the Eskipazar Basin is still going on. The active deformation is also supported by the presence of brecciated horizons within the thick pile of travertine deposits exposed at the quarry walls near the İmanlar travertines (Figure 53).


**Figure 51.** Close-up view of extensional fissure with a trend of N14°W that is exposed at ~ 100 m east of active fissure ridge travertines of the İmamlar formation (Location : ~ 1 km NNW of İmamlar village).

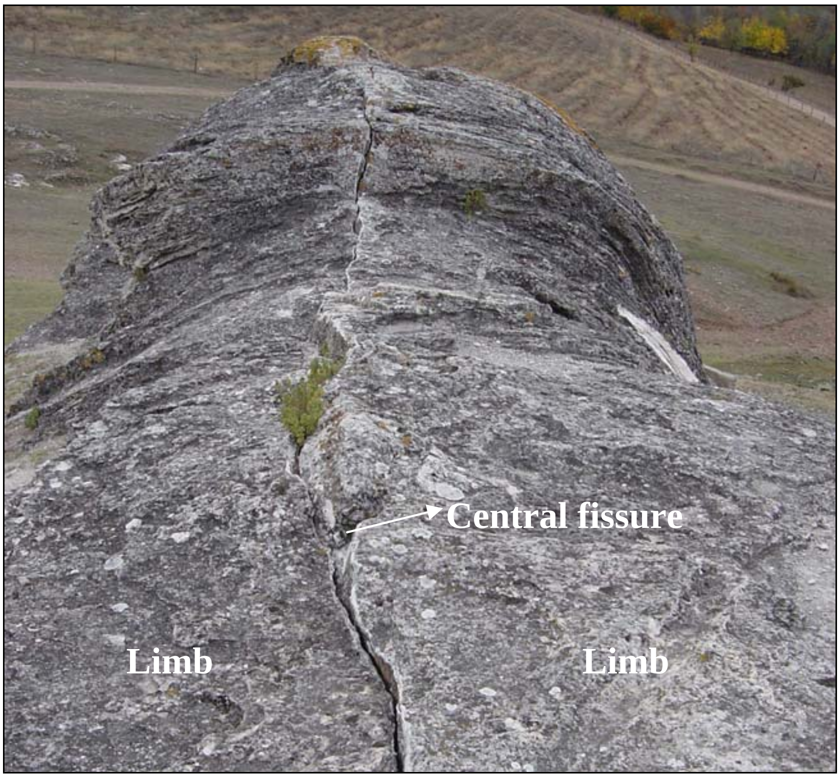


**Figure 52.** A close-up view of the active fissure ridge travertine (The İmanlar Fissure Ridge). Trend of the extensional fissure is measured to be N10°W. (Location : ~ 1 km NNW of İmamlar village).

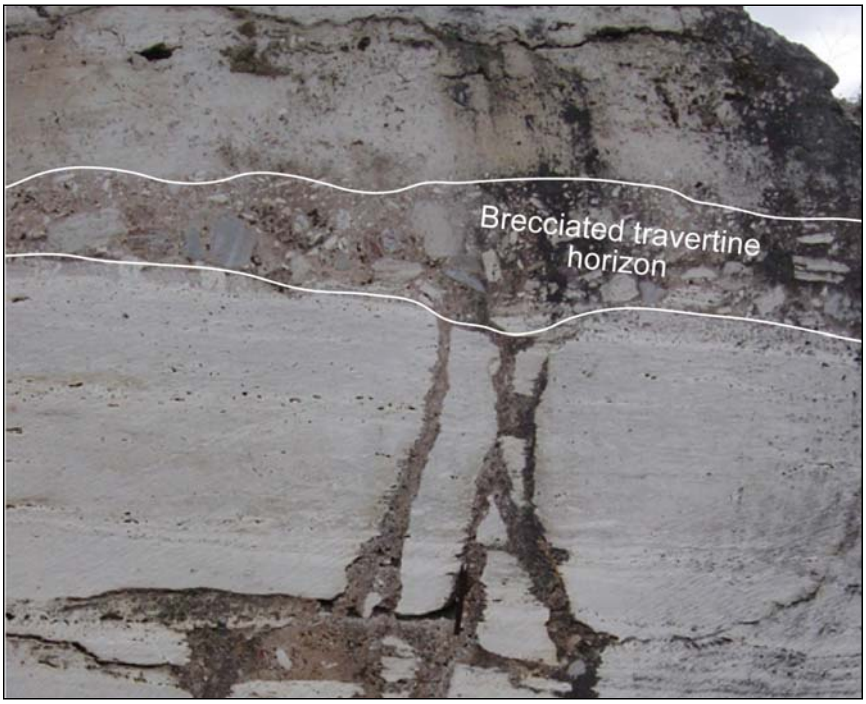


**Figure 53.** A close-up view of brecciated horizon of travertines within the İmamlar formation on the quarry wall that is situated ~ 1 km north of İmanlar village.

# CHAPTER IV

# SEISMICITY

High seismicity of the northwestern portion of the North Anatolian Fault System that is indicated by major earthquakes (such as the 1944 Gerede-Çerkeş Earthquake and the 1999 Düzce Earthquake) and their foreshocks and after shocks is the most striking evidence for the complex and active tectonics of the region. Both the instrumentally recorded data (Boğaziçi-Kandilli Observatory Laboratory and Earthquake Research Institute, and General Directorate of Disaster Affairs Earthquake Research Department-Turkey) and the distribution of historical seismicity obtained from the available literature (Ergin *et al.*, 1967, Soysal *et al.*, 1981, Ambraseys and Finkel, 1995; Ambraseys and Jackson, 1998) clearly show an intracontinental simple shearing caused by the dextral strike-slip faulting. In order to understand the long-term behaviour of the potential seismic sources (faults) within the Eskipazar Basin and their significance, earthquakes that occurred and caused damage to settlements in and adjacent to the Eskipazar Basin will be described below.

## 4.1. Historical Seismicity

Some major earthquakes took place in the northwestern portion of the North Anatolian Fault System, in historical periods. Especially, six destructive earthquakes (AD 109, AD 967, 1035, 1845, 1668, 1881) have been documented and reported from the close vicinity of the study area (Ambraseys and Finkel 1987, 1995; Ambraseys and Jackson 1998). Out of this six major earthquakes the August 17, 1668 earthquake ($M_s$= 7.9) (Ambrasseys and Jackson 1998) was the most devastative earthquake originated from the Bolu – Ladik section of the NAFS. The earthquake killed about 8000 people and formed a significant surface rupture that extends from Kelkit valley to Bolu (Ambraseys and Finkel 1987). Unfortunately, the AD 109, 1845 and 1881 earthquakes are not well-documented due to the lack of information and records about them. However, it has been reported that loss of life and heavy damage to various structures were very high (Ambrseys and Finkel 1995). The earthquakes of AD 967 and 1055 are relatively better documented with the help of knowledge gained from the historical reports. The epicenters of these earthquakes are reported to be located at close vicinity of the study area. The epicenters of these better documented earthquakes are located based on historical records, the knowledge of damage distribution around the possible epicenter of the earthquake and the assumed association of historical event with known Quaternary or recent fault-break.

The epicenter of 967 September Earthquake is located at the southeast of Yeniçağa Basin (coordinates: 40.8° N – 32.0° E) (Ambraseys and Jackson 1998) (Figure 54). Based on the knowledge of the recent seismic characteristics of this fault, the magnitude of the earthquake is reported to be large by Ambraseys and Jackson (1998), and mechanisms and attitude of the fault is reported to be the right-lateral strike-slip fault

The epicenter of 1035 May earthquake is located close to the Çerkeş at southern bock of the master strand of the Gerede Fault Zone (coordinates: 40.8 N – 33.0°E) (Ambraseys and Jackson, 1998), based on the implicated knowledge of surface faulting deduced from sources and field investigations (Figure 54). The magnitude of the earthquake is reported to be medium by Ambraseys and Jackson (1998) and right-lateral strike-slip mechanism is attributed to the surface faulting caused by this earthquake.

### 4.2. Recent Seismicity

Recent and damaging seismic events such as the 1944 Gerede, the 1951 Kurşunlu and the 1999 Düzce earthquakes attracted attention of most of researchers, and increased number of the seismotectonic study in the region. The seismicity occurred in the period of 1900-2003 displays a remarkable clustering of moderate-magnitude earthquakes. Available focal mechanism solutions for some shallow focus earthquakes (depth< 15 km), and the relevant published data by several authors (Canıtez and Büyükaşıkoğlu, 1984), (Canıtez and Üçer 1967, Harward CMT), are represented on Table 4.

The focal mechanism solutions of these earthquakes indicate substantial evidence for dextral strike-slip faulting within and nearby the study area. Besides, attitudes of the fault planes obtained by the focal mechanism solutions fit well with the observable field attitude of the surface faulting (Figure 54).

In this century, 249 shallow focus seismic events with magnitudes between 1 - 5,9 took place at close proximity of the study area (Table 5 at Appendices and Figure 54). Earthquakes, sourced from strike-slip faults of the North Anatolian Fault System, caused considerable property damage and affected the settlements located within the Yeniçağa and Eskipazar basins. The most devastative earthquakes are the 1944.02.01, Gerede-Çerkeş earthquake ($M_s$=7,6), the 1951.08.13 Kurşunlu earthquake ($M_s$=7,2) and the 1999.11.12 Düzce earthquake ($M_w$=7,2). The following sections deal with the source parameters and felt effects of these three seismic events in chronological order.

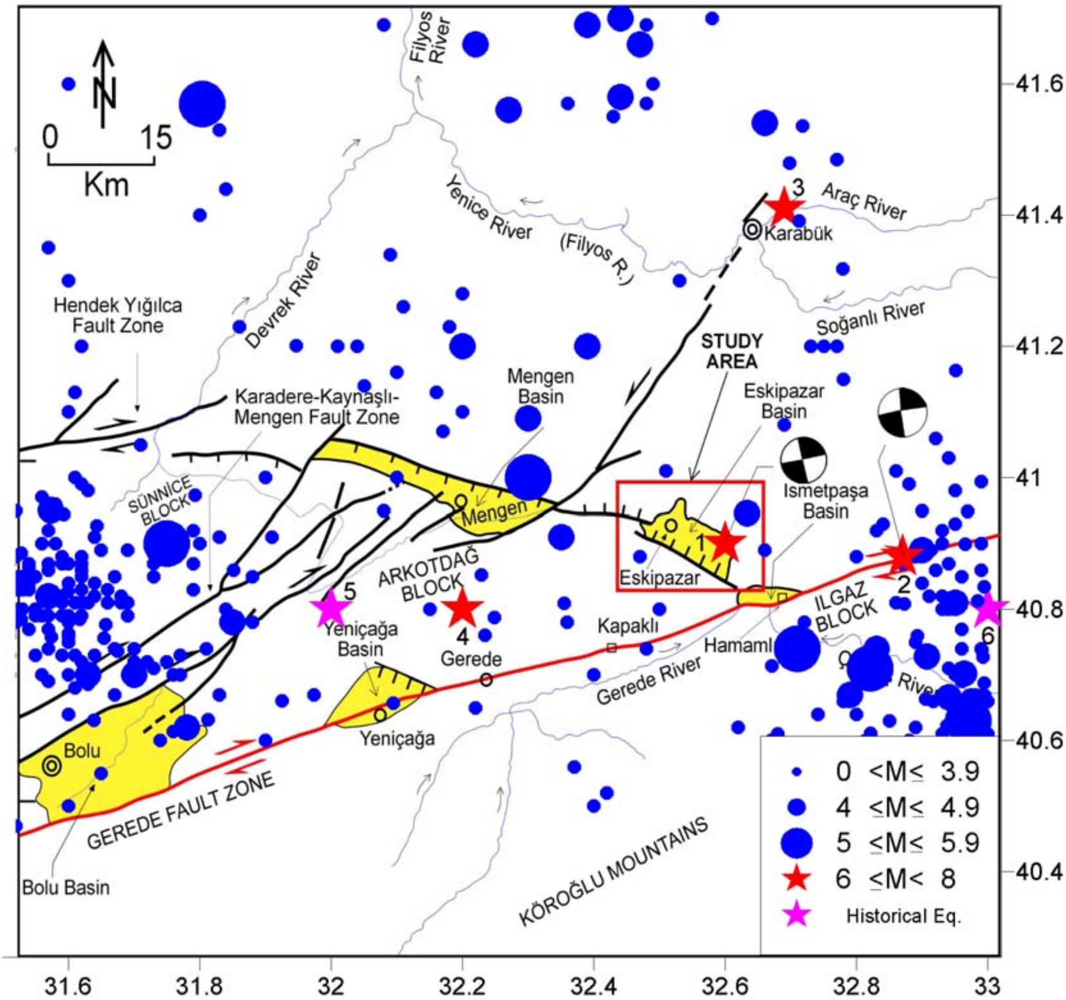


**Figure 54.** Seismotectonic map of the study area. (1) 1944.02.01 (Ms=7.6) and focal mechanism solution from Canıtez & Büyükaşıkoğlu (1984); (2) 1951.08.13 (Ms=6.9) Mechanism solution from Canıtez & Üçer 1967; (3) 1944.02.01 (Ms=7.2) (Bosphorous University Kandilli Observatory laboratory Earthquake Research Institute); (4) 1944.02.01 (Ms=7.4) (Gencoğlu, 1990); (5) 967 A.D. September (Ambraseys and Jackson, 1998); (6) 1035 May (Ambraseys and Jackson, 1998).

**Table 4**.Seismic parameters of well-defined earthquakes occurred in the northwestern part of the NAFS (References are given based on the Fault Plane Mechanism Solutions).

| **No** | **Date** | **Origin Time (GMT)** | **Epicenter N - E** | **Focal Depth (km)** | **Magnitude (M)** | **Seismic Moment ($M_o/N_m$)** | **Fault Plane Mechanism Solution (Strike/dip/rake)** | **Geographic Region** | **References** |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 1944/02/01 | 03:22:40 | 40,90 - 32,60 | 12 | 7,3 | - | 1. 348°/88°/ -<br>2. 260°/89°/ - | Gerede-Çerkeş (Bolu) | Canıtez & Büyükaşıkoğlu 1984 |
| **2** | 1951/08/13 | 18:33:34 | 40,88 - 32,87 | 10 | 6,9 | - | 1. 352°/85°/ ?<br>2. 262°/90°/ ? | Çerkeş | Canıtez & Üçer 1967 |
| **3** | 1999/11/12 | 16:57:19:55 | 40,93 - 31,25 | 18 | $M_w$=7,2 | $6,7x10^{19}$ | 268°/54°/167 | Düzce (Bolu) | (Harward CMT) |

#### 4.2.1. 1944 February 1 Gerede-Çerkeş Earthquake ($M_s$=7,6)

The 1944 seismic event is one of the largest earthquakes that took place along the western portion of the North Anatolian Fault System, in the last century (1900-2000). It was sourced from the Master Strand of the North Anatolian Fault System. The 1944 Gerede earthquake was felt over a very wide region and caused serious damage to structures in some town and counties of Bolu and Karabük (such as Gerede, Yeniçağa and Eskipazar). This earthquake mainly struck Gerede County and caused a serious damage. The earthquake killed totally 3954 people, injured thousands of them damage and destruction of 20865 houses, asphaltic and stabilized roads and bridges were characteristic. The total length of surface rupture of this earthquake was reported to be 160 km (Ambrasseys and Jackson, 1998). In Gerede, some other ground ruptures also took place in the north and south of the main rupture and created vertical displacements of 10 cm to 40 cm (Taşman 1944). The main rupture displayed en échelon pattern with small ruptures constituting the en échelon array in the lengths ranging from 100 cm to 150 m in the Gerede county. It was also reported by Taşman (1944) that the downthrown side of the surface rupture was located in the northern blocks of it. Several man-made structures, such as bridges, roads and houses on these ruptures were offset by about 30 cm to 3 meters in right-lateral sense at several places. This field evidence implies that the significant surface faulting of right lateral strike-slip nature had occurred in and nearby Gerede. This is confirmed by the observation of 5,5 m right-lateral strike-slip offset of the line of Salix trees by the ground rupture of the 1944.02.01 Çerkeş – Gerede earthquake in the near east of Gerede County.

### 4.2.2. 1951 August 13 Kurşunlu Earthquake ($M_s$=6,7)

On August 13, 1951 an earthquake of $M_s$ 6,7 occurred along the N79$^0$E-trending master strand of the North Anatolian Fault System. The mainshock destroyed and damaged totally 3354 houses and resulted in 50 deaths. The earthquake is also felt over a wide region especially surrounding towns and counties and it was affective mainly in Kurşunlu.

The earthquake resulted in a 32 km long surface rupture on which 60 cm of dextral strike-slip offset was measured. Besides, the vertical displacement is observed to be 30 cm with downthrown northern block (Ambraseys and Jackson, 1998). Focal mechanism solution of this earthquake's mainshock indicated that the fault here is nearly vertical and displays a dextral strike-slip character fitting well with the field observations.

### 4.2.3. 1999 November 12 Düzce Earthquake ($M_w$=7,2)

In November 12, 1999 an earthquake of magnitude $M_w$ 7,2 occurred along the Kaynaşlı segment of the Karadere-Kaynaşlı-Mengen Fault Zone (central strand of the NAFS). This earthquake was felt over a very wide region and caused serious damage in settlements such as Gölyaka, Düzce and Kaynaşlı located on and nearby the Kaynaşlı segment. Although the epicenter of this earthquake is located away from the Eskipazar Basin, the aftershocks of this earthquake are located very close to the study area. The mainshock of this earthquake killed 792 people in total and severely damaged and destroyed totally 7850 houses, viaducs, roads and industrial buildings. The total length of the nearly E-W-trending surface rupture is ~60 km from the northern exit of the Bolu Tunnel in the east to Gölyaka in the west (Koçyiğit *et* *al.*, 2003b). The abundance of man-made features, such as roads and fences offset by the fault rupture, made it possible to measure the displacement very accurately and frequently. The rupture is confined in a generally narrow deformation zone (5-50 m). Considering its geometry and along the strike-slip distribution, the rupture is divided into four sub-segments by Çakır *et al.* (2003). Based on their observations, Çakır *et al.* (2003) reported that the three segments in the east show almost pure right-lateral slip up to 5,5 m in the middle one. Presence of aftershocks on the northern side of the fault, and the focal mechanism solution of the mainshock indicated that the fault has a significant northward dip.

Finally, based on the relationship between the epicentral distribution of small and moderate earthquakes ($3 \leq M \leq 5$) and the faults, it can be concluded that the Eskipazar Basin and its close vicinity is seismically active. In addition to seismic activities within this region, there is also aseismic slip (fault creep) going on at the İsmetpaşa region about 10 km east of Kapaklı (Aytun 1980). This fault creep is best indicated by the right-lateral offset of masonry wall of İsmetpaşa Maintenance Station at an average slip rate of 1 cm/year.

It is interesting that, within the frame of the study area and its close vicinity, the epicenter distribution is relatively sparse in the area between Yeniçağa and Eskipazar basins. Indeed, this lack of epicenter may be due to the lack of fore- and after-shocks of 1944 Gerede and 1951 Kurşunlu earthquakes, because of the fact that in that time the techniques and instruments for locating epicenters of minor earthquakes were relatively primitive or absent. Besides, the aseismic slip is taking place at İsmetpaşa station. This may be a factor, by which the elastic strain energy is regularly released in the form of continuous motion within the fault zone here, so the accumulation of elastic strain energy is prohibited partially by this regular release of energy and hence seismic activity along this portion of the North Anatolian Fault System may be hindered or reduced by this aseismic slip.

# CHAPTER V

# DISCUSSION AND CONCLUSIONS

One of the main aims of this thesis is to explain the neotectonic evolution of the Eskipazar Basin. In this part of the study, a tentative evolutionary model will be formulated for the Eskipazar Basin under the light of field and seismic data. In addition to this some other possible structural contributions to the evolutionary history of the Eskipazar Basin will be discussed.

## 5.1. Evolution of the Eskipazar Basin

New structural and stratigraphic data presented in foregoing chapters have allowed us to refine the age chronology and reconstruct the neotectonic evolution of the Eskipazar Basin. This Basin contains, indeed, two infills; one is the highly deformed paleotectonic unit, the Eskipazar formation and the other is the neotectonic unit, namely the Budaklar, Karkın and İmanlar formations.

The paleotectonic fill displays two distinct phases of deformation. The lower part of the Upper Miocene – Lower Pliocene Eskipazar formation is characterized by outcrop-scale growth faults and conjugate fractures. Their kinematic analysis yielded NW-SE directed extension and indicated that an extensional tectonic regime was present during the formation of these syn-depositional fractures and growth faults (Figure 29). During the Late Miocene-Early Pliocene time interval, the Eskipazar formation was actively deposited in a paleotectonic basin that is formed by the NW-SE directed extension as indicated by the widespread presence of growth faults all through the Eskipazar formation. Second phase of deformation took place after Early Pliocene and all the sequence of the

Eskipazar formation underwent a NE-SW directed compression, subsequently folded with axes trending in NW-SE; a direction perpendicular to the maximum compression direction ($\sigma_1$) (Figures 30 and 33). This compression was possibly due to the last phase of deformation that took place along North Anatolia, prior to the initiation of the neotectonic regime characterized by the formation of the North Anatolian Fault System. As a result of this compression the paleotectonic fill of the basin uplifted with the surrounding areas and it got thinner and thinner by erosion. These deformation and erosional activity distorted the configuration of the paleotectonic basin (Figure 55).

With the formation of the North Anatolian Fault System, and the onset of the neotectonic regime several basins formed along the NAFS with their long axes trending in E-W direction parallel to the fault system. The basins are indeed, formed due to the strike-slip complexities along the NAFS and considered to be pure strike slip basins (such as the İsmetpaşa, Yeniçağa and Bolu basins). However, the case is totally different for the Eskipazar Basin. The general characteristics of the Eskipazar Basin seriously diverge from the other pure strike-slip basins with its distinctive basin fill pattern, morphology and trend. The infill of the Eskipazar Basin displays a patchy distribution of the Plio-Quaternary units consisting of several sedimentary units such as the travertine deposits, terrace conglomerates, the Upper Quaternary floodplain deposits and alluvial fan deposits (Plate 1). However in the case of a typical pure strike-slip basin the infill generally displays a relatively continuous pattern and consists of floodplain, alluvial fan and apron deposits (e.g. The Yeniçağa Basin). In addition, the morphology of the Eskipazar Basin displays an irregular topography with deeply carved valleys and gently rolling hills which contradicts with the flat and smooth topography of the pure strike-slip basins. The Eskipazar Basin does not display a clear trend but the latest paleotectonic fill of the basin bounded in the east and west by oblique-slip normal faults and strike-slip faults, displays an NW-SE trend

(Plate 1). This trend looks like the trend of the basin, at a first glance but, as this unit is the latest paleotectonic fill of the basin it does not represent the neotectonic geometry and trend of the basin. Indeed this orientation of the paleotectonic basin fill does not represent the paleotectonic configuration of the basin either, as the original geometry and configuration of the paleotectonic basin is distorted and intensely deformed by the structures that are formed during the neotectonic period within the study area. The neotectonic character of the basin is only indicated by the neotectonic infill, overlying the paleotectonic infill exposing as patches, within the basin (Plate 1 and 3). Actually, the neotectonic trend of the basin can only be indicated by the trend of these patches, as these are formed under the control of the strike-slip deformation taking place during the recent strike-slip neotectonic regime. The trend of the patches exposing within the Eskipazar Basin at central and western parts displays nearly an E – W trend which fits well with the recent configuration and trend of the pure strike-slip basins located along the western part of North Anatolian Fault System; so the distribution of patches is controlled by active strike-slip faults can be considered as sub-basins exposing within the Eskipazar Depression.

The contradicting characteristics of infill pattern, morphology and trend of the Eskipazar Basin indicate that it is not a pure strike-slip neotectonic basin, such as the Yeniçağa or adjacent İsmetpaşa basins. Indeed, presence of nearly E–W-trending patchy outcrops of the neotectonic units (sub-basins of the Eskipazar Basin), overlying unconformably on the paleotectonic fill of the basin, suggests that this basin is a superimposed basin displaying extensive outcrops of latest paleotectonic infill, namely the Eskipazar formation (Plate 1). Nevertheless, this does not imply that the basin displays a totally paleotectonic character. The sub-basin controlled by, and located in between the Dibek, Karkın, İmanlar and Yeniköy faults is an actively growing basin that is indicated by the presence of the active İmanlar fissure ridge travertine deposits and recent food plain deposits of Çayır, Acısu and Kısık streams. The same situation is also true for the E –W-trending sub-basin in the west that is controlled by, and located in between the Budaklar fault set and Beytarla fault zone where there is a continuous sedimentation of flood plain deposits of the Göksu Stream. This indicates that the basin development is still going on within the Eskipazar Region, under the control of strike-slip neotectonic regime.

An important fault set that is exposing within the study area is the Kadılar fault set. It is possible that this fault has a pure neotectonic origin and control the development of sub-basins situated in the east of this fault set and thus this structure may be an important one that will control the future configuration of the Eskipazar Basin. Indeed, the Kadılar fault set is the major structure that deforms and distorts the preserved outline of the paleotectonic basin, making it very difficult to interpret the configuration of this basin during the paleotectonic period. On the other hand, this fault may be a reactivated oblique-slip normal fault that had possibly worked as a reverse fault during the latest phase of the paleotectonic regime, controlling the formation of tightly packed folds within the latest paleotectonic fill of the basin and thus, controlling the paleotectonic configuration of the basin.

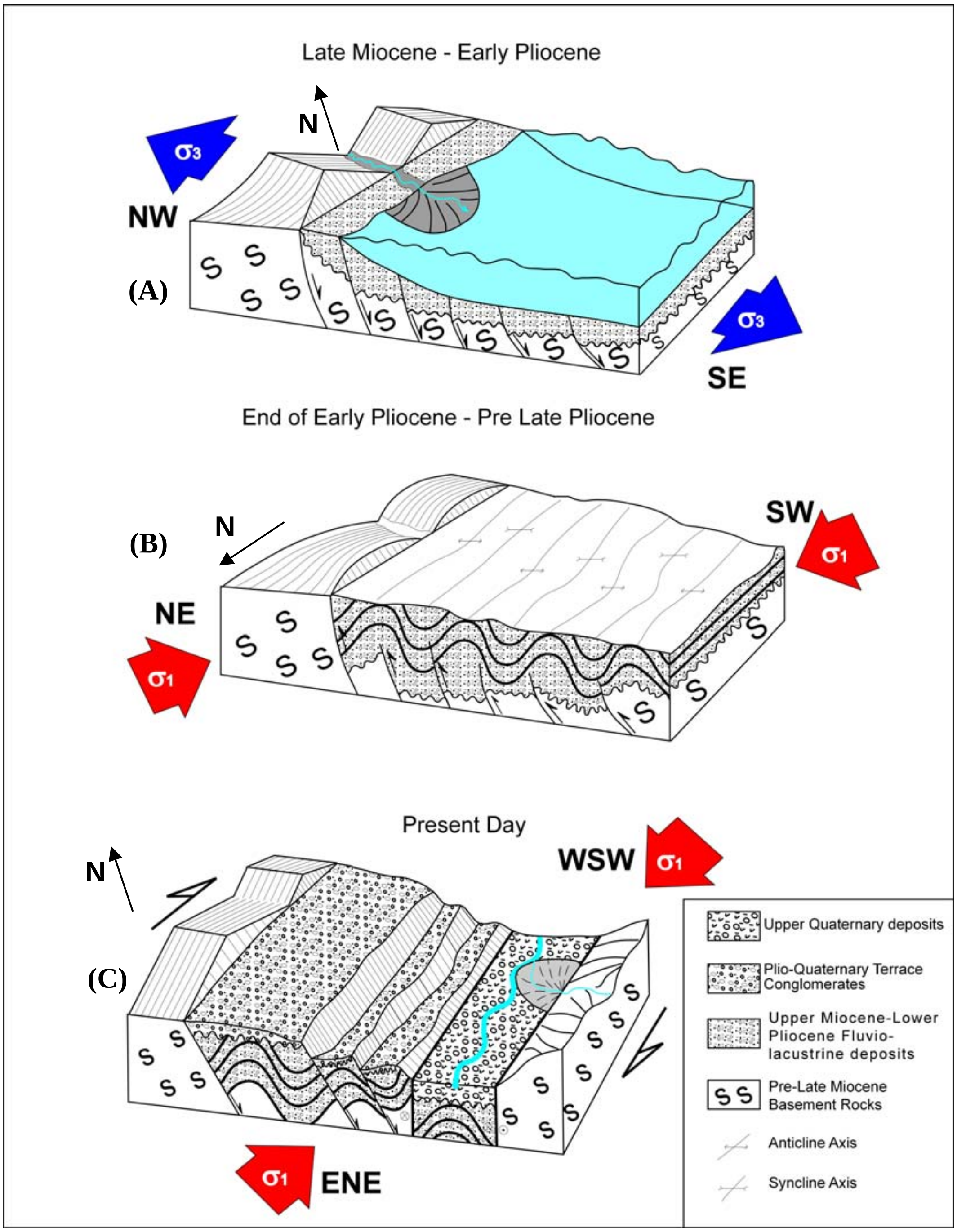


**Figure 55.** Sketch block diagrams depicting evolution of Eskipazar Basin. (A) Phase of extension during Late Miocene-Early Pliocene. (B) Phase of compression during end of Pliocene-Pre Late Pliocene. (C) Present day strike-slip neotectonic regime.

### 5.2. Conclusions

In the light of above mentioned discussion and the newly gathered field and laboratory data presented in the forgoing chapters, the followings are concluded.

**1.** Based on the analysis of data gathered during the field studies and geological mapping of the study area at 1/25.000 scale, the Eskipazar Basin is interpreted to be a superimposed basin composed of nearly E – W trending patches of Plio-Quaternary and Upper Quaternary units. These patches are considered to be sub-basins formed under the control of the strike-slip neotectonic regime and actively growing in the present-day.

**2.** In this study the neotectonic characteristics of the Eskipazar Basin is studied in detail. Indeed, neotectonic characteristics of this basin have never been studied in such a detailed way previously by any scientists.

**3.** This study was focused on the neotectonic characteristics of the Eskipazar Basin. However, one of the main aims of this study was to figure out the evolutionary history of the basin and for this purpose the latest paleotectonic unit exposing within the study area was also considered in detail. Results of the analysis of the slip plane data gathered from the syn-depositional shear fractures and growth faults of this unit indicated that it had experienced NW–SE directed extension during Late Miocene–Early Pliocene time interval, under the control of an extensional paleotectonic regime. In addition, the analysis of the trend of fold axes of this unit showed that, the extensional paleotectonic regime was than succeeded by a compressional paleotectonic regime as a last phase of paleotectonic period. Related NE–SW-directed compressional deformation resulted in folding of the latest paleotectonic infill with fold axes trending in NW – SE direction.

**4.** Geologically active nature of the faults, exposing within the study area is indicated by the down cutting of streams, development o marginal alluvial fans, well preserved fault scarps, fault terraces and presence of active and inactive fissure ridge travertine deposits, nearby the faults.

**5.** The topographical to morphological expressions of the faults and their geometrical relationships with the principal stresses indicate that these faults, exposing within the study area are generally strike slip faults with normal components. Here one exception is the Kadılar fault set whose morphological expression indicates that it is an oblique-slip normal fault with sinistral strike-slip component. This fault set is indeed a major one that bounds the basin in the west and serves as the main fault controlling the basin development.

**6.** In order to understand the long-term behavior of the potentially active sources of seismicity in and adjacent to the Eskipazar Basin, seismic data including both the historical and recent earthquakes were also examined. In the light of this compiled data, it is possible to suggest that the area surrounding the Eskipazar Basin is also seismically active. Nevertheless recently, the area remaining between the Yeniçağa and Eskipazar Basins is in a quiescence period since 1944 partially due to the continuous releasing of elastic strain energy by tectonic creep activity that is taking place at southern part of the study area at the Kapaklı–İsmetpaşa region. Nevertheless the slip-rate measured at the creep site is 1 cm/year and the slip rate along the North Anatolian Fault System is 2 cm/year, thus, this shows that the continuously released elastic strain energy is not enough to cause a total seismic quiescence within the region between the Yeniçağa and Eskipazar Basins. Therefore it is possible that, there exists a seismic gap at this portion of the NAFS, since 1944.

**7.** Most of the settlements are located on poorly consolidated fluvio-lacustrine deposits of the Eskipazar formation that is susceptible to landslides or nearby the active faults exposing within the basin (Plate 1). Therefore these settlements are open to earthquake hazard. Best solution of this problem is to construct structures at suitable places outside of the landslide susceptible Eskipazar formation and major active faults.

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# APPENDICES

**PLATE 1:** Geological map of the Eskipazar Basin

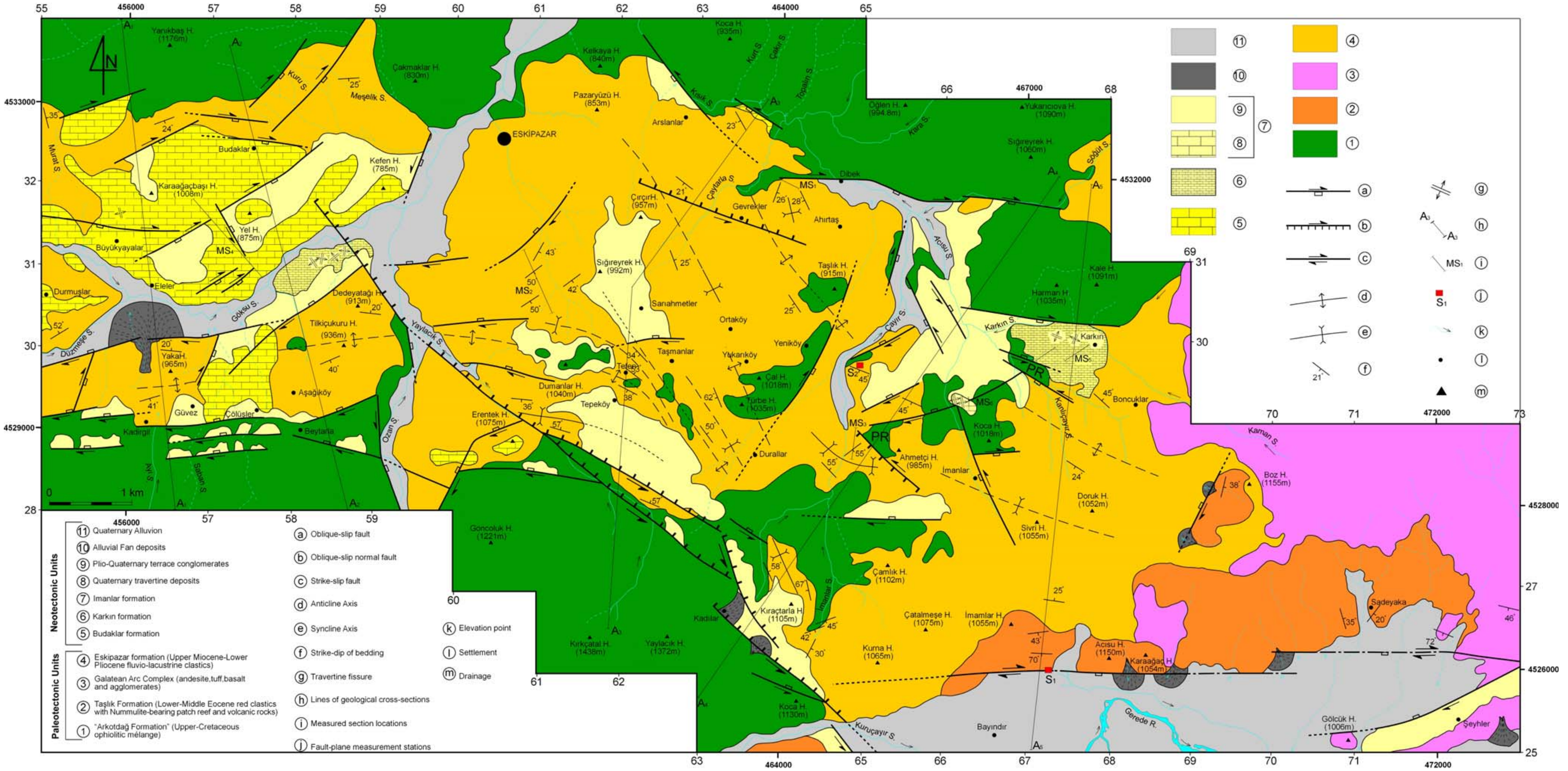

**PLATE 2.** Geological cross-sections showing geological structures, rock units and their relatioships to each other.

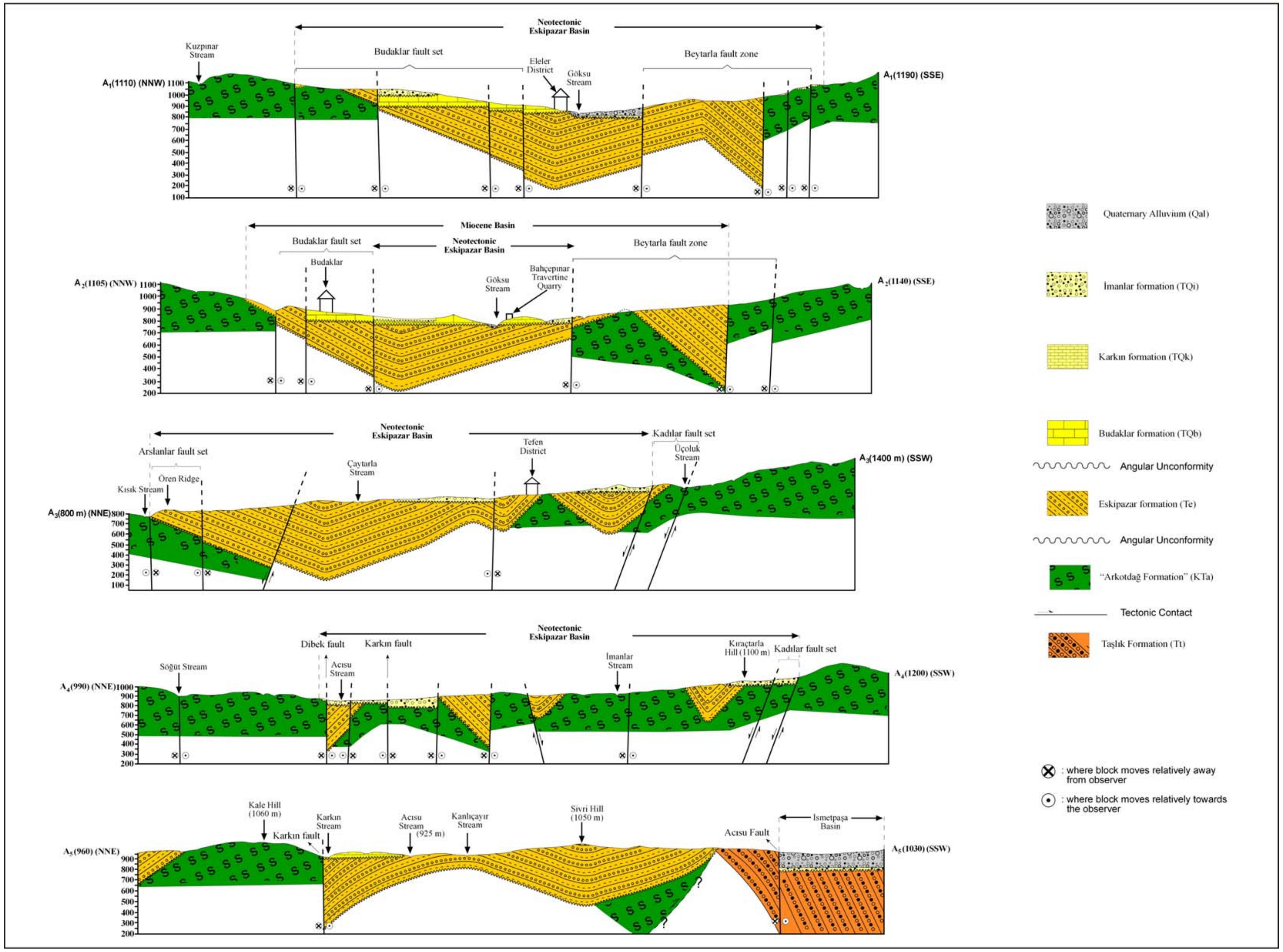

PLATE 3. Neotectonic map of the Eskipazar Basin

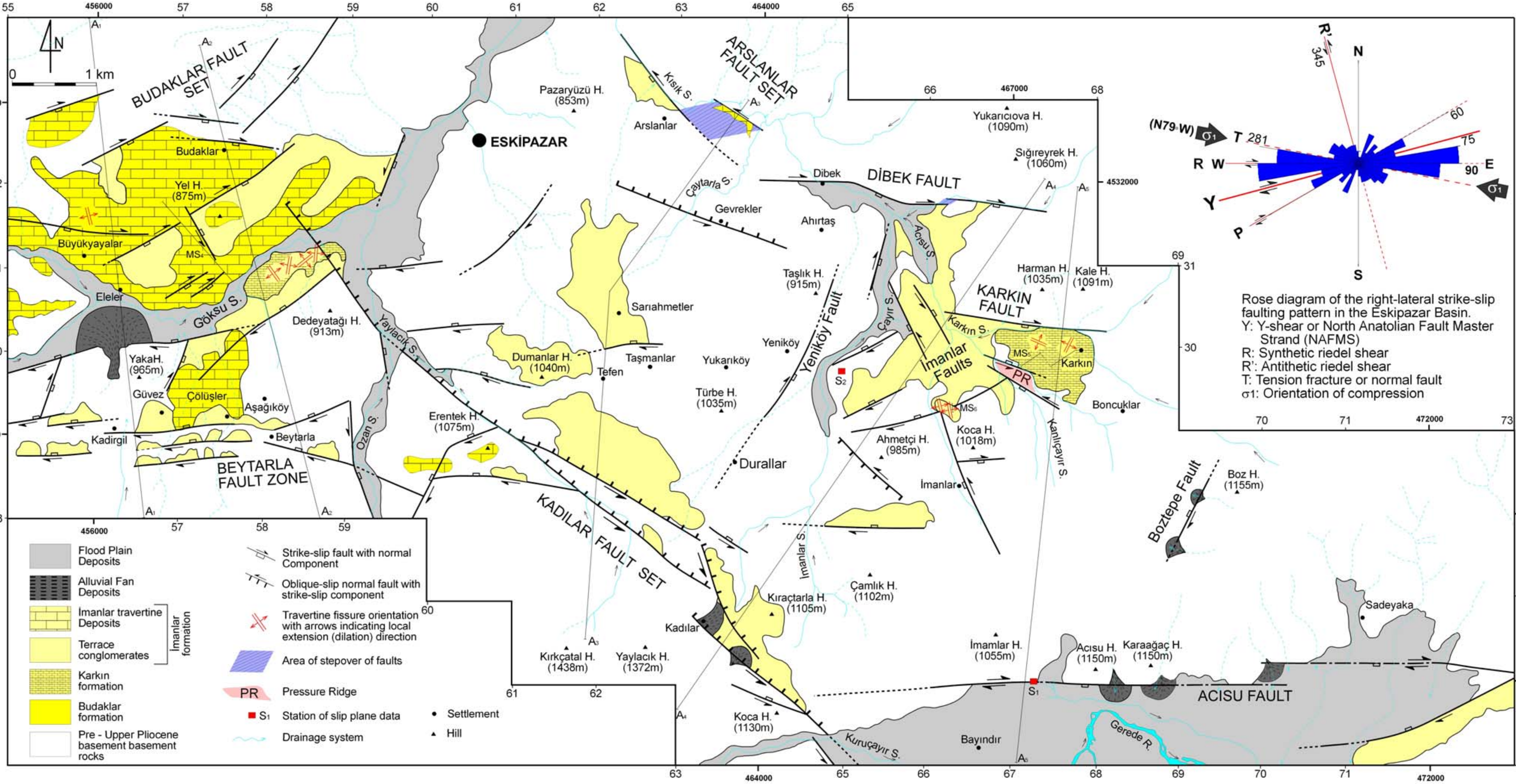

**Table 5.** Seismic parameters of the earthquakes occurred in the period of 1902-2003. Epicenter distribution of the Eskipazar-Gerede-Yeniçağa-Bolu region between 31,50-32,91N 40,45-41,40E coordinates. Data source: Kandilli Observatory & Earthquake Research Institute and General Directorate of Disaster Affairs-Turkey. (See Figure 53 for locations of epicenters)

| No. | Date | Origin (GMT) | Longitude (N) | Latitude (E) | Depth (km) | Magnitude |
|---|---|---|---|---|---|---|
| 1 | 1902.10.00 | 00:00:00 | 40,7 | 31.6 | 0 | 3,7 |
| 2 | 1929.04.08 | 01:12:01 | 41,2 | 32,2 | 33 | 4,2 |
| 3 | 1929.04.08 | 01:12:01 | 41,2 | 32,2 | 0 | 4,6 |
| **4*** | **1944.02.01** | **03:22:40** | **40,9** | **32,76** | **12** | **7,4** |
| **5**** | **1944.02.01** | **03:22:40** | **40,8** | **32,2** | **12** | **7,4** |
| 6 | 1944.02.10 | 12:05:27 | 41 | 32,3 | 10 | 5,3 |
| 7 | 1947.12.19 | 17:31:18 | 40,71 | 32,82 | 10 | 5,1 |
| 8 | 1949.05.13 | 20:14:01 | 40,74 | 32,71 | 20 | 5,1 |
| **9***** | **1951.08.13** | **18:33:34** | **40,88** | **32,87** | **10** | **6,9** |
| 10 | 1957.05.30 | 13:07:57 | 40,62 | 31,78 | 10 | 4,2 |
| 11 | 1959.01.05 | 04:54:02 | 40. 83 | 32,25 | 40 | 4,2 |
| 12 | 1961.12.05 | 01:21:15 | 40,62 | 32,62 | 1 | 1 |
| 13 | 1964.06.19 | 00:50:25 | 40,74 | 32,83 | 33 | 4,6 |
| 14 | 1971.05.16 | 10:23:31 | 40,9 | 31,8 | 0 | 3 |
| 15 | 1971.07.08 | 18:28:00 | 40,56 | 32,9 | 0 | 3,9 |
| 16 | 1973.10.21 | 22:50:31 | 40,7 | 32,4 | 5 | 3,1 |
| 17 | 1975.06.04 | 02:55:37 | 40,9 | 31,58 | 66 | 3,8 |
| 18 | 1975.06.04 | 02:57:05 | 41,09 | 32,3 | 0 | 4 |
| 19 | 1976.01.30 | 10:12:22 | 41,4 | 31,8 | 0 | 3,1 |
| 20 | 1976.02.19 | 02:42:46 | 41 | 32,1 | 0 | 0 |
| 21 | 1976.04.29 | 10:26:28 | 41,23 | 32,18 | 0 | 3,2 |
| 22 | 1977.11.15 | 22:16:51 | 41,1 | 32,2 | 23 | 3,6 |
| 23 | 1977.12.09 | 21:33:18 | 41,1 | 31,6 | 0 | 3 |
| 24 | 1978.06.11 | 03:16:13 | 40,5 | 31,6 | 0 | 3,3 |
| 25 | 1978.10.08 | 08:53:50 | 41,3 | 32,53 | 0 | 3,3 |
| 26 | 1978.11.03 | 09:35:03 | 40,91 | 32,35 | 10 | 4,2 |
| 27 | 1979.06.28 | 21:22:09 | 40,78 | 31,85 | 0 | 4,7 |
| 28 | 1980.08.03 | 15:17:42 | 40,6 | 31,5 | 0 | 3,1 |
| 29 | 1981.05.09 | 13:04:21 | 40,7 | 31,77 | 0 | 2,2 |
| 30 | 1981.09.18 | 05:24:33 | 40,64 | 32,8 | 0 | 2,6 |
| 31 | 1981.10.11 | 15:41:19 | 40,81 | 31,63 | 10 | 3,2 |
| 32 | 1981.10.12 | 08:05:21 | 40,74 | 31,7 | 10 | 3,4 |
| 33 | 1981.10.12 | 10:30:47 | 40,73 | 31. 69 | 0 | 2,6 |
| 34 | 1983.05.28 | 02:12:33 | 40,6 | 32,67 | 10 | 3,8 |

Continues →

| | | | | | | |
|---|---|---|---|---|---|---|
| 35 | 1986.10.17 | 10:33:06 | 41,2 | 32,39 | 12 | 4,4 |
| 36 | 1986.11.24 | 09:18:29 | 40,5 | 32,4 | 10 | 3,3 |
| 37 | 1986.12.15 | 18:12:02 | 41,6 | 32,49 | 10 | 1 |
| 38 | 1987.05.09 | 08:07:42 | 40,52 | 32,8 | 9 | 3,8 |
| 39 | 1990.02.09 | 18:20:00 | 41 | 31,9 | 10 | 3,7 |
| 40 | 1990.06.10 | 07:05:46 | 41,3 | 31,6 | 10 | 0 |
| 41 | 1990.11.11 | 22:06:00 | 40,6 | 31,74 | 14 | 3,2 |
| 42 | 1992.05.19 | 23:00:54 | 40,74 | 32,48 | 7 | 3,6 |
| 43 | 1992.07.01 | 11:29:09 | 40,8 | 32,5 | 6 | 1 |
| 44 | 1992.07.16 | 13:32:27 | 41,2 | 31,62 | 10 | 1 |
| 45 | 1992.07.20 | 07:46:23 | 40,72 | 31,7 | 10 | 1 |
| 46 | 1992.07.21 | 12:26:24 | 41,3 | 31,6 | 10 | 1 |
| 47 | 1993.03.15 | 13:24:19 | 41,23 | 31,86 | 10 | 3 |
| 48 | 1993.04.06 | 21:39:23 | 40,52 | 32,42 | 10 | 3,8 |
| 49 | 1993.07.18 | 16:29:12 | 40,72 | 31,72 | 10 | 3,1 |
| 50 | 1993.07.27 | 09:10:18 | 40,47 | 31,52 | 10 | 2,8 |
| 51 | 1993.07.31 | 20:45:51 | 40,8 | 31,84 | 10 | 3 |
| 52 | 1993.08.01 | 15:59:03 | 41,13 | 32,16 | 0 | 3,3 |
| 53 | 1995.11.10 | 05:22:36 | 40,89 | 32,66 | 0 | 3,4 |
| 54 | 1996.04.11 | 01:23:10 | 40,73 | 31,59 | 7 | 3,1 |
| 55 | 1996.04.22 | 22:17:30 | 40,54 | 32,78 | 9 | 3,6 |
| 56 | 1996.04.22 | 22:20:17 | 40,66 | 32,78 | 7 | 3,4 |
| 57 | 1996.07.02 | 06:25:59 | 40,56 | 32,68 | 10 | 3,5 |
| 58 | 1997.04.23 | 10:29:07 | 40,84 | 32,9 | 0 | 3,4 |
| 59 | 1997.06.09 | 13:59:31 | 41,35 | 31,57 | 4 | 3,8 |
| 60 | 1997.10.07 | 12:22:24 | 40,92 | 31,79 | 0 | 2,9 |
| 61 | 1997.12.09 | 08:02:05 | 40,56 | 32,37 | 0 | 3,2 |
| 62 | 1998.01.06 | 18:38:51 | 40,78 | 32,72 | 12 | 3,5 |
| 63 | 1998.01.06 | 18:38:51 | 40,78 | 32,72 | 12 | 3,5 |
| 64 | 1998.03.13 | 16:08:46 | 40,8 | 32,15 | 1 | 2,8 |
| 65 | 1998.03.13 | 16:08:46 | 40,8 | 32,15 | 1 | 2,8 |
| 66 | 1998.04.24 | 05:07:09 | 41,01 | 32,51 | 13 | 3,5 |
| 67 | 1998.04.24 | 05:07:09 | 41,01 | 32,51 | 13 | 3,5 |
| 68 | 1998.10.22 | 23:47:21 | 40,97 | 31,76 | 9 | 3,9 |
| 69 | 1998.10.22 | 23:47:21 | 40,97 | 31,76 | 9 | 3,9 |
| 70 | 1998.11.05 | 13:46:46 | 40,87 | 32,52 | 4 | 3,9 |
| 71 | 1998.11.05 | 13:46:46 | 40,87 | 32,52 | 4 | 3,9 |
| 72 | 1999.02.06 | 12:21 | 40,64 | 32,74 | 12 | 3,5 |
| 73 | 1999.03.17 | 21:19:02 | 40,67 | 31,97 | 18 | 3,6 |

Continues ⟶

| | | | | | | |
|---|---|---|---|---|---|---|
| 74 | 1999.04.02 | 01:18:03 | 40,66 | 31,92 | 0.8 | 3,4 |
| 75 | 1999.04.06 | 16:03:20 | 41,31 | 32,77 | 29 | 3,4 |
| 76 | 1999.05.19 | 21:11:14 | 40,78 | 32,35 | 0.2 | 3,4 |
| 77 | 1999.05.30 | 00:10:26 | 41,39 | 32,71 | 7.5 | 3,1 |
| 78 | 1999.07.07 | 13:09:39 | 40,8 | 32,35 | 5.6 | 3 |
| 79 | 1999.11.12 | 18:05:00 | 40,7 | 31,7 | 10 | 4,7 |
| 80 | 1999.11.13 | 00:15:00 | 40,73 | 31,5 | 10 | 4,3 |
| 81 | 1999.11.13 | 08:33:41 | 40,77 | 31,5 | 1 | 4,1 |
| 82 | 1999.11.13 | 10:10:34 | 40,82 | 31,57 | 8 | 4,3 |
| 83 | 1999.11.13 | 18:43:43 | 40,85 | 31,5 | 1 | 3,9 |
| 84 | 1999.11.14 | 14:42:14 | 40,78 | 31,6 | 5 | 3,1 |
| 85 | 1999.11.14 | 09:26:24 | 40,8 | 31,55 | 4 | 3,2 |
| 86 | 1999.11.14 | 13:42:08 | 40,8 | 31,52 | 5 | 3 |
| 87 | 1999.11.14 | 13:22:53 | 40,81 | 31,66 | 4 | 3,2 |
| 88 | 1999.11.14 | 17:05:40 | 40,85 | 31,67 | 2 | 3,2 |
| 89 | 1999.11.14 | 13:22:04 | 40,86 | 31,5 | 4 | 3,1 |
| 90 | 1999.11.14 | 16:00:42 | 40,87 | 31,73 | 4 | 3,1 |
| 91 | 1999.11.14 | 21:37:34 | 40,89 | 31,65 | 2 | 3,2 |
| 92 | 1999.11.14 | 06:45:31 | 40,91 | 31,83 | 4 | 3,3 |
| 93 | 1999.11.14 | 22:57:58 | 40,97 | 31,56 | 5 | 3,2 |
| 94 | 1999.11.15 | 00:58:13 | 40,79 | 31,6 | 5 | 3,1 |
| 95 | 1999.11.15 | 20:37:33 | 40,8 | 31,53 | 4 | 3 |
| 96 | 1999.11.15 | 15:44:57 | 40,82 | 31,5 | 4 | 3,1 |
| 97 | 1999.11.15 | 08:06:25 | 40,87 | 31,54 | 5 | 3,3 |
| 98 | 1999.11.16 | 07:49:39 | 40,7 | 31,63 | 4 | 4 |
| 99 | 1999.11.16 | 18:03:31 | 40,7 | 31,76 | 1 | 3,3 |
| 100 | 1999.11.16 | 14:09:16 | 40,71 | 31,73 | 10 | 3,1 |
| 101 | 1999.11.16 | 10:09:55 | 40,73 | 31,64 | 5 | 3,5 |
| 102 | 1999.11.16 | 05:13:54 | 40,74 | 31,5 | 12 | 3,2 |
| 103 | 1999.11.16 | 20:50:01 | 40,74 | 31,5 | 5 | 3,4 |
| 104 | 1999.11.16 | 17:51:17 | 40,79 | 31,6 | 1 | 4,9 |
| 105 | 1999.11.16 | 03:56:58 | 40,81 | 31,69 | 5 | 3,2 |
| 106 | 1999.11.16 | 06:44:07 | 40,83 | 31,52 | 4 | 3 |
| 107 | 1999.11.16 | 18:40:33 | 40,87 | 31,59 | 8 | 3,3 |
| 108 | 1999.11.16 | 15:14:49 | 40,9 | 31,58 | 1 | 3,2 |
| 109 | 1999.11.17 | 06:00:04 | 40,7 | 31,56 | 15 | 3 |
| 110 | 1999.11.17 | 14:28:41 | 40,86 | 31,57 | 5 | 3,2 |
| 111 | 1999.11.17 | 04:50:58 | 40,88 | 31,51 | 1 | 3,4 |
| 112 | 1999.11.18 | 23:15:56 | 40,75 | 31,6 | 1 | 2,6 |

Continues ⟶

| | | | | | | |
|---|---|---|---|---|---|---|
| 113 | 1999.11.19 | 08:28:37 | 40,95 | 31,52 | 4 | 2,8 |
| 114 | 1999.11.19 | 21:21:57 | 40,79 | 31,55 | 3 | 3,1 |
| 115 | 1999.11.19 | 22:09:48 | 40,88 | 31,59 | 1 | 3,1 |
| 116 | 1999.11.19 | 23:17:29 | 40,76 | 31,6 | 1 | 3 |
| 117 | 1999.11.20 | 00:24:55 | 40,79 | 31,69 | 4 | 3,2 |
| 118 | 1999.11.20 | 03:18:08 | 40,87 | 31,6 | 5 | 3 |
| 119 | 1999.11.20 | 09:35:40 | 40,95 | 32,08 | 3 | 3 |
| 120 | 1999.11.20 | 09:57:07 | 40,78 | 31,88 | 1 | 2,9 |
| 121 | 1999.11.20 | 11:17:04 | 40,73 | 31,61 | 1 | 3 |
| 122 | 1999.11.21 | 19:01:32 | 40,64 | 31,5 | 22 | 2,9 |
| 123 | 1999.11.21 | 20:40:19 | 40,86 | 31,54 | 5 | 2,9 |
| 124 | 1999.11.21 | 22:27:32 | 40,77 | 31,5 | 9 | 4,2 |
| 125 | 1999.11.21 | 23:18:04 | 40,81 | 31,68 | 5 | 3,1 |
| 126 | 1999.11.23 | 11:38:08 | 40,92 | 31,57 | 1 | 3,2 |
| 127 | 1999.11.24 | 10:56:06 | 40,77 | 31,54 | 12 | 2,9 |
| 128 | 1999.11.24 | 11:15:19 | 40,84 | 31,53 | 9 | 2,8 |
| 129 | 1999.11.24 | 11:43:10 | 40,79 | 31,57 | 12 | 2,7 |
| 130 | 1999.11.24 | 13:18:27 | 40,76 | 31,51 | 2 | 2,7 |
| 131 | 1999.11.25 | 05:30:53 | 40,85 | 31,55 | 1 | 3,1 |
| 132 | 1999.11.25 | 09:45:41 | 40,78 | 31,52 | 8 | 2,9 |
| 133 | 1999.11.26 | 11:26:50 | 40,83 | 31,66 | 8 | 3,1 |
| 134 | 1999.11.28 | 18:04:41 | 40,83 | 31,62 | 1 | 3,1 |
| 135 | 1999.11.29 | 08:41:15 | 40,88 | 31,52 | 5 | 2,9 |
| 136 | 1999.11.29 | 10:30:45 | 40,84 | 31,53 | 9 | 4 |
| 137 | 1999.11.29 | 10:32:11 | 41,05 | 31,71 | 1 | 2,9 |
| 138 | 1999.11.29 | 13:34:47 | 40,79 | 31,62 | 3 | 3,5 |
| 139 | 1999.11.29 | 22:08:38 | 40,67 | 31,67 | 1 | 3,1 |
| 140 | 1999.11.29 | 23:42:46 | 40,79 | 31,59 | 3 | 3 |
| 141 | 1999.12.021 | 13:17:12 | 40,64 | 31,6 | 1 | 3,3 |
| 142 | 1999.12.02 | 17:53:33 | 40,83 | 31,53 | 1 | 3,2 |
| 143 | 1999.12.02 | 19:40:50 | 40,74 | 31,57 | 1 | 3 |
| 144 | 1999.12.05 | 15:35:04 | 40,79 | 31,56 | 8 | 2,9 |
| 145 | 1999.12.05 | 23:52:12 | 40,73 | 31,51 | 5 | 3 |
| 146 | 1999.12.06 | 23:46:09 | 40,55 | 31,65 | 19 | 3 |
| 147 | 1999.12.11 | 21:21:09 | 40,87 | 31,57 | 1 | 2,8 |
| 148 | 1999.12.16 | 23:18:48 | 40,87 | 31,62 | 3 | 2,9 |
| 149 | 1999.12.17 | 12:16:57 | 40,74 | 31,67 | 1 | 2,9 |
| 150 | 1999.12.17 | 21:52:03 | 40,85 | 31,62 | 4 | 2,8 |
| 151 | 1999.12.17 | 23:58:59 | 40,76 | 31,6 | 4 | 2,6 |

Continues ⟶

| | | | | | | |
|---|---|---|---|---|---|---|
| 152 | 1999.12.18 | 04:03:41 | 40,78 | 31,5 | 1 | 3,2 |
| 153 | 1999.12.18 | 06:22:06 | 40,77 | 31. 55 | 12 | 2,6 |
| 154 | 1999.12.18 | 22:43:34 | 40,9 | 31,56 | 4 | 2,8 |
| 155 | 1999.12.22 | 09:40:44 | 40,91 | 31,64 | 5 | 2,8 |
| 156 | 1999.12.23 | 15:42:33 | 40,8 | 31,52 | 3 | 2,9 |
| 157 | 1999.12.23 | 18:39:05 | 40,77 | 31,57 | 1 | 2,9 |
| 158 | 1999.12.23 | 23:43:18 | 40,73 | 31,77 | 2 | 2,9 |
| 159 | 1999.12.24 | 14:05:59 | 40,79 | 31,59 | 16 | 2,7 |
| 160 | 1999.12.24 | 20:45:26 | 40,7 | 31,69 | 1 | 2,8 |
| 161 | 1999.12.24 | 21:58:32 | 40,7 | 31,51 | 3 | 3 |
| 162 | 1999.12.26 | 17:05:24 | 40,85 | 31,73 | 1 | 2,8 |
| 163 | 1999.12.26 | 19:39:06 | 40,81 | 31,62 | 4 | 2,8 |
| 164 | 1999.12.27 | 04:45:25 | 40,83 | 31,79 | 2 | 3,2 |
| 165 | 1999.12.29 | 19:58:36 | 40,84 | 31,5 | 4 | 3,2 |
| 166 | 2000.01.01 | 19:48:13 | 40,82 | 31,68 | 5 | 2,8 |
| 167 | 2000.01.09 | 20:44:27 | 40,72 | 31,62 | 14 | 2,7 |
| 168 | 2000.01.12 | 16:41:35 | 40,83 | 31,54 | 5 | 2,7 |
| 169 | 2000.01.12 | 20:34:35 | 40,72 | 31,75 | 9 | 2,7 |
| 170 | 2000.01.27 | 18:41:25 | 40,98 | 31,63 | 5 | 3 |
| 171 | 2000.01.29 | 09:48:15 | 40,91 | 31,91 | 1 | 3 |
| 172 | 2000.02.01 | 23:18:28 | 40,78 | 31,52 | 12 | 3,1 |
| 173 | 2000.02.06 | 15:21:47 | 40,83 | 31 .500 | 7 | 3,3 |
| 174 | 2000.02.14 | 06:56:36 | 40,9 | 31,75 | 15 | 5 |
| 175 | 2000.02.14 | 07:12:54 | 40,85 | 31,88 | 16 | 3,8 |
| 176 | 2000.02.14 | 22:30:00 | 41 | 31,61 | 1 | 3,1 |
| 177 | 2000.02.15 | 05:30:32 | 40,6 | 31,9 | 7 | 2,8 |
| 178 | 2000.02.15 | 07:53:38 | 40,96 | 31,58 | 1 | 3,5 |
| 179 | 2000.02.16 | 05:30:19 | 40,99 | 31,62 | 13 | 3,1 |
| 180 | 2000.02.17 | 08:57:19 | 41,13 | 31,61 | 5 | 3,2 |
| 181 | 2000.02.24 | 04:31:37 | 40,81 | 31,59 | 3 | 2,8 |
| 182 | 2000.02.26 | 12:39:46 | 40,9 | 31,56 | 4 | 2,9 |
| 183 | 2000.03.12 | 03:23:18 | 40,82 | 31,59 | 5 | 2,7 |
| 184 | 2000.03.31 | 13:04:34 | 40,89 | 31,69 | 5 | 3,7 |
| 185 | 2000.04.06 | 15:13:07 | 40,83 | 31,57 | 4 | 2,7 |
| 186 | 2000.04.12 | 23:01:56 | 41,2 | 32,73 | 15 | 3,5 |
| 187 | 2000.04.17 | 02:58:39 | 40,78 | 31,5 | 5 | 3 |
| 188 | 2000.04.22 | 20:35:23 | 40,81 | 31,61 | 5 | 2,9 |
| 189 | 2000.05.01 | 22:26:28 | 40,86 | 31,54 | 5 | 2,9 |
| 190 | 2000.05.11 | 08:57:34 | 40,84 | 31,6 | 4 | 2,9 |

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|---|---|---|---|---|---|---|
| 191 | 2000.06.07 | 18:49:11 | 40,9 | 31,73 | 6 | 3,2 |
| 192 | 2000.06.08 | 00:33:12 | 40,88 | 32,8 | 7 | 3,3 |
| 193 | 2000.06.08 | 02:46:06 | 40,82 | 31,64 | 6 | 3,2 |
| 194 | 2000.06.10 | 06:41:16 | 41,08 | 32,69 | 5 | 3,3 |
| 195 | 2000.06.12 | 06:18:25 | 41,15 | 32,78 | 5 | 3,4 |
| 196 | 2000.06.25 | 22:35:55 | 41,2 | 32,75 | 5 | 3,3 |
| 197 | 2000.08.25 | 10:44:17 | 40,74 | 31,81 | 7 | 3,2 |
| 198 | 2000.09.02 | 02:53:51 | 40,67 | 32,79 | 8 | 4 |
| 199 | 2000.09.11 | 23:11:10 | 40,67 | 31,83 | 14 | 3,2 |
| 200 | 2000.09.13 | 07:54:26 | 40,69 | 31,57 | 11 | 3,2 |
| 201 | 2000.09.17 | 07:05:25 | 41,2 | 32,77 | 5 | 3,3 |
| 202 | 2000.09.19 | 06:42:14 | 40,68 | 31,61 | 3 | 2,9 |
| 203 | 2000.10.19 | 05:06:20 | 40. 86 | 31,54 | 5 | 3,7 |
| 204 | 2000.12.12 | 10:20:12 | 40,65 | 32,09 | 0.2 | 3,2 |
| 205 | 2001.01.07 | 18:17:09 | 40,86 | 31,5 | 4.4 | 3 |
| 206 | 2001.01.10 | 10:19:02 | 41,201 | 31,947 | 9.9 | 3 |
| 207 | 2001.01.24 | 15:37:35 | 40,85 | 31,521 | 5.7 | 2,8 |
| 208 | 2001.01.24 | 15:39:45 | 40,837 | 31,506 | 2.2 | 2,8 |
| 209 | 2001.01.28 | 16:36:11 | 40,75 | 31,51 | 5.3 | 3,2 |
| 210 | 2001.02.05 | 13:41:45 | 40,97 | 31,79 | 4.8 | 2,9 |
| 211 | 2001.02.21 | 17:39:44 | 40,75 | 31,57 | 0.3 | 2,6 |
| 212 | 2001.03.13 | 04:57:33 | 40,61 | 31,76 | 7.7 | 2,8 |
| 213 | 2001.04.02 | 00:02:50 | 40,76 | 31,6 | 0.06 | 2,5 |
| 214 | 2001.04.02 | 00:29:53 | 40,78 | 31,52 | 1.1 | 2,6 |
| 215 | 2001.05.01 | 05:20:16 | 40,77 | 31,65 | 0.6 | 3 |
| 216 | 2001.05.10 | 02:17:47 | 40,86 | 31,85 | 5.3 | 2,8 |
| 217 | 2001.05.11 | 21:59:18 | 40,76 | 32,23 | 5.3 | 2,3 |
| 218 | 2001.05.14 | 21:13:53 | 40,78 | 32,24 | 7.7 | 3,1 |
| 219 | 2001.05.18 | 22:21:56 | 40,85 | 32,22 | 2.3 | 2,8 |
| 220 | 2001.05.21 | 07:26:14 | 40,63 | 31,63 | 3.2 | 2,8 |
| 221 | 2001.05.30 | 05:36:02 | 40,82 | 31,59 | 11.7 | 2,7 |
| 222 | 2001.07.09 | 22:52:40 | 40,63 | 31,81 | 9.1 | 3,1 |
| 223 | 2001.07.22 | 02:55:00 | 40,78 | 31,61 | 5 | 2,9 |
| 224 | 2001.08.26 | 00:41:00 | 40,95 | 31,57 | 7.8 | 4,6 |
| 225 | 2001.12.03 | 04:35:00 | 40,73 | 31,67 | 5 | 3,4 |
| 226 | 2001.12.07 | 15:41:00 | 40,68 | 31,63 | 5 | 2,3 |
| 227 | 2002.01.11 | 11:20:00 | 40,77 | 31,5 | 5 | 3,3 |
| 228 | 2002.01.30 | 23:33:00 | 40,94 | 31,59 | 5 | 2,9 |
| 229 | 2002.03.31 | 03:00:00 | 40,88 | 31,52 | 5 | 2,9 |

Continues →

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|---|---|---|---|---|---|---|
| 230 | 2002.05.01 | 15:56:00 | 40,92 | 31,64 | 5 | 2,8 |
| 231 | 2002.05.02 | 02:31:00 | 40,71 | 32,67 | 6.3 | 2,9 |
| 232 | 2002.05.04 | 13:09:00 | 40,75 | 31,65 | 6.7 | 3,3 |
| 233 | 2002.06.06 | 13:41:00 | 40,86 | 31,54 | 4.5 | 3,1 |
| 234 | 2003.08.17 | 10:32:25.00 | 41,14 | 32,05 | 9,90 | 3,7 |
| 235 | 2003.09.01 | 16:43:11.19 | 40,88 | 32,47 | 1.0 | 3,8 |
| 236 | 2003.02.13 | 10:26:17.60 | 40,73 | 31,55 | 8,30 | 2,7 |
| 237 | 2003.03.11 | 14:43:40.66 | 40,88 | 31,62 | 3,70 | 2,7 |
| 238 | 2003.07.25 | 07:26:42.87 | 40,86 | 31,62 | 6,10 | 3,1 |
| 239 | 2003.08.07 | 01:05:11.03 | 40,87 | 31,79 | 3,80 | 3,5 |
| 240 | 2003.08.12 | 20:05:38.34 | 41,34 | 32,09 | 11.0 | 3,8 |
| 241 | 2003.08.12 | 22:02:22.13 | 41,26 | 32,11 | 14.0 | 2,9 |
| 242 | 2003.08.12 | 23:47:53.00 | 41,2 | 32,01 | 9.0 | 2,9 |
| 243 | 2003.08.13 | 00:51:23.00 | 41,28 | 32,2 | 15.0 | 2,8 |
| 244 | 2003.08.15 | 07:51:03.09 | 41,16 | 32,1 | 10,40 | 3,3 |
| 245 | 2003.08.16 | 04:51:51.84 | 41,07 | 32,17 | 8,40 | 2,9 |
| 246 | 2003.09.07 | 11:37:09.56 | 41,2 | 32,04 | 6,70 | 3,8 |
| 247 | 2003.10.22 | 18:03:50.74 | 40,87 | 31,51 | 1.0 | 2,9 |
| 248 | 2003.12.23 | 22:34:13.38 | 40,65 | 32,22 | 7,50 | 2,6 |
| 249 | 2003.12.29 | 01:31:25.80 | 40,61 | 32,68 | 15,00 | 2,8 |

***** Gerede-Çerkeş earthquake ; Canıtez & Büyükaşıkoğlu, 1984
****** Gerede-Çerkeş earthquake ; Gençoğlu, 1990
******* Kurşunlu earthquake ; Canıtez & Büyükaşıkoğlu, 1984