NEOTECTONICS AND EVOLUTION OF THE YENİÇAĞA BASIN, BOLU - 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 YENİÇAĞA BASIN, BOLU – TURKEY

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Study area, the Yeniçağa Basin, is located in the western part of the North Anatolian Fault System. It is a 1-5-km-wide and 14-km-long WSW-ENE- trending depression bounded by a complex array of strike-slip faults.

The Yeniçağa Basin is interpreted to be a fault – wedge basin with the North Anatolian Fault's System Master Strand, namely the Gerede Fault, cutting across the basin itself. The basin and its surroundings contain mainly two groups of rock units namely the paleotectonic units and the neotectonic units. Paleotectonic units, which are deposited or formed during different phase(s) of tectonic regimes, comprise several formations. The most important one of these formations is the Upper Miocene – Lower Pliocene Eskipazar formation which plays an important role in understanding the evolutionary history of the basin. Neotectonic unit deposited under the control of today's tectonic regime is the Plio-Quaternary Betemürlü formation.

Betemürlü formation unconformably overlies the paleotectonic Eskipazar formation throughout the study area and the unconformity separating these two units corresponds to the time interval during which the paleotectonic stress regime changed into the neotectonic stress regime. 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 Yeniçağa Basin are, the Aşağı Kuldan fault, the Aksu fault, the İzmirli fault set, the Sarayçalı fault, the Değirmen fault set and the Hamzabey fault set. They display well-preserved fault scarps in places. Morphological expressions of these faults and their geometrical relationships with the local stress regime indicate that these faults are mainly strike-slip and oblique-slip faults.

Morphotectonic expressions of the faults exposing within the study area indicate that these faults are active. Most of the settlements within the study area are located on water-saturated loose basin fill nearby the active faults. Hence, these are open to future earthquake hazards. Therefore, structures and settlements have to be constructed on strong grounds away from the active faults.

Keywords: neotectonics, Yeniçağa basin, North Anataolian Fault System, stress distribution, fault-wedge basin

ÖZ

YENİÇAĞA HAVZASI'NIN NEOTEKTONİĞİ VE OLUŞUMU, BOLU – TÜRKİYE

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Çalışma alanı, Yeniçağa Baseni, Kuzey Anadolu Fay Sistemi'nin batısında yer almaktadır. Basen; 1-5 km genişlikte ve 14 km uzunlukta BGB-DKD yönelimli bir çöküntü alanı olup, karmaşık düzendeki yanal atımlı faylarla sınırlanmıştır.

Gerede Fayı olarak isimlendirilmiş Kuzey Anadolu Fay Sistemi'nin ana kolu tarafından kesilen Yeniçağa fay kaması baseni olarak yorumlanmıştır. Basen ve çevresi başlıca paleotektonik birimler ve neotektonik birimler olmak üzere iki farklı kaya grubunu içerir. Tektonik rejimlerin farklı fazları sırasında çökelmiş ya da oluşmuş paleotektonik birimler birçok formasyonu kapsarlar. Bu formasyonlardan en önemlisi basenin evrimsel tarihini açıklamakta önemli rol oynayan Geç Miosen – Geç Pliyosen yaşlı Eskipazar formasyonudur. Neotektonik birimse günümüz tektonik rejimi kontrolünde çökelen Plio-Kuvaterner yaşlı Betemürlü formasyonudur.

Betemürlü formasyonu çalışma alanında paleotektonik Eskipazar formasyonunu uyumsuzlukla örter ve bu iki birim arasındaki uyumsuzluk paleotektonik stres rejiminin neotektonik stres rejimine dönüşmesi sırasındaki zaman aralığına denk gelmektedir. Böylece, yanal atımlı neotektonik rejimin çalışma alanındaki başlangıç yaşı Geç Pliyosen (~2,6 My) olarak belirlenmiştir.

Yeniçağa Baseni'nin en önemli kenar sınırı fayları Aşağı Kuldan fayı, Aksu fayı, İzmirli fay seti, Sarayçalı fayı, Değirmen fay seti ve Hamzabey fay setidir. Bu faylar yer yer iyi korunmuş fay sarplıklarına sahiptirler. Fayların morfolojik özellikleri ve yerel gerilme (sıkışma) ekseni ile olan ilişkileri, fayların başlıca yanal atımlı ve verev atımlı olduklarını göstermektedir.

Bu fayların çalışma alanındaki morfotektonik özellikleri, fayların aktif fay olduklarını belirtir. Çalışma alanı içindeki çoğu yerleşke aktif fayların yakınındaki suya doygun gevşek havza dolgusu üstünde yer almaktadır. Dolayısıyla, bu bölgeler gelecekteki depremlerde de tehlikelere açıktırlar. Bu sebepten, yapı ve yerleşkelerin aktif faylardan uzak, sağlam zeminlere inşa edilmesi önerilir.

Anahtar sözcükler : yenitektonik, Yeniçağa havzası, Kuzey Anadolu Fay Sistemi, yerel gerilme sistemi, fay kaması havzası

To My Family

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I would like to express my gratitude to Assist.Prof.Dr.Nuretdin Kaymakçı for his theoretical support in using "TECTOR" software developed by Angelier (1989) and suggestions about the evolution of the Yeniçağa Basin, Prof.Dr. Erdin Bozkurt for his support in compiling the literature review, Assoc.Prof.Dr. Bora Rojay for his support in compiling the literature review and suggestions about the evolution of the Yeniçağa Basin and Prof.Dr. Vedat Toprak for his support in organizing the format of the thesis.

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INTRODUCTION

1.1. Purposes and Scope

The North Anatolian Fault System is one of the world's well-known dextral intra-continental 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 this 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 in the west. 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 the 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 style of deformation and relevant features are recorded and well-preserved. In order to contribute to the neotectonic characteristics and evolution pattern of the North Anatolian Fault System, neotectonic characteristics of the NE-SW trending Yeniçağa Basin, which is located within the western portion of North Anatolian Fault System, was analysed under the light of new stratigraphical, structural and seismic data.

1.2. Method of Study

In order to achieve the above mentioned purpose, 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, available literature were collected and reviewed at first. Later on, available borehole data were compiled and used for assessment of Plio-Quaternary sedimentary pile.

At the stage of field work, field geological mapping is carried out at 1/25000 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 and morphological properties. In addition, structural data these faults as well as other shear planes and Planar-linear elements were measured for the use of kinematic analysis. Apart from these, detailed stratigraphy and deformational features of the latest paleotectonic infill of the basin (Miocene rocks) were studied in order to make a distinction between paleotectonic and neotectonic periods. For these purposes, the latest paleotectonic unit and the neotectonic units are studied and analysed in terms of measured type sections.

In the next stage of this research, which is laboratory to office work, field data on the kinematic properties of the faults are. The data 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 a computer a computer programme ‘Tector’ developed by Angelier (1989) which provides stereographic plots of fault planes and orientations of principle stress axes.

For the purpose of determining operation direction of the stress at the time of sedimentation and at the time of deformation some stereographic pole plots were prepared by using measured planar attitudes of the bedding planes within the sedimentary rocks. In addition, recent seismic events that occurred in the study area were compiled and evaluated to find out the earthquake hazard risk in the region.

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

1.3. Location and Accessibility

The study area, the Yeniçağa Basin, is located between 40.75^0 – 40.82^0 latitudes and 31.93^0 – 32.12^0 longitudes in the southern part of the Arkot Mountain (Figure 1). It falls in the Bolu G28-a4, G27-b3 quadrangles and covers an area of more than 30 km^2. The Yeniçağa Basin is about NE-SW - trending depression with the maximum relief of 992 m between the lowest basin floor and the height peak of the margin-bounding highlands.

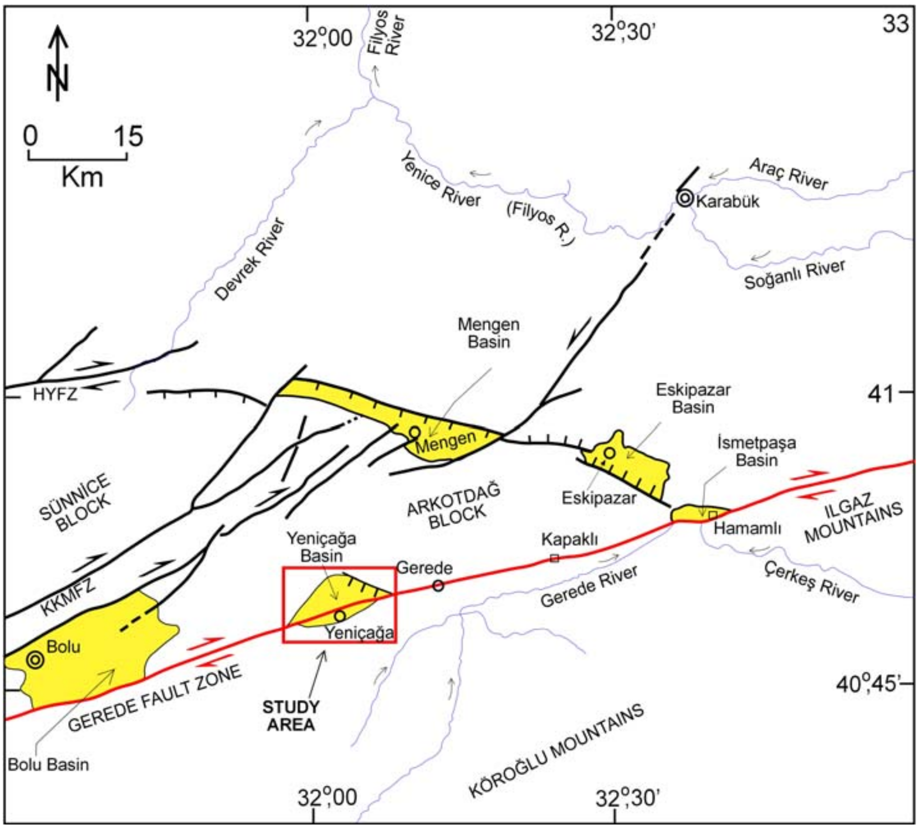

Figure 1. Simplified neotectonic map of the study area and its close vicinity showing major neotectonic structures and basins. HYFZ: Hendek - Yığılca Fault Zone (Northern strand of the NAFS), KKMFZ: Karadere -Kaynaşlı - Mengen Fault Zone (Central strand of the NAFS).

The accessibility to the study area is provided by Gerede-Bolu highway running through the study area. Yeniçağa county is located about 12 km west of Gerede. There are also some other asphaltic, stabilized and earthy roads cutting or joining to the main road. By using these roads both northern and southern margins of the basin are accessible.

1.4. Previous Works

The Yeniçağa 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 Yeniçağa Basin was carried out by Lahn (1948). He claimed that Lake Yeniçağa and the basin surrounding it, has a tectonic origin.

Erinç *et al*. (1961) carried out some studies about Çağa stream, Çağa Lake and Çağa (Yeniçağa) depression. He reported information about the geometry of this depression and emphasized the importance of the major fault which is the North Anatolian Fault Master Strand that controls the southern margin of the depression. He also briefly described the rock units that are exposed in northern and southern parts of the North Anatolian Fault Master Strand. They also attracted attention to the geomorphology of the basin and its margins, and stated significance of tectonic activity in forming morphological features surrounding the depression. They also focused on recent and past geometry of Lake Çağa (Yeniçağa) and defined it as a basin formed by accumulation of water at depression center. In addition, they dealt with the Çağa stream and stated that this stream is the one which mainly drains the basin and Lake Çağa and flows toward North through a deep, narrow valley.

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 and/or fault sets exposed within the study area or and its vicinity.
He documented some important information about the characteristics, geometrical relations and properties of these faults as well as their recent or past activities. The faults are namely Ulusu Fault, Gerede, Çerkeş, Dikmen, Kızılibrik, Yılanlı faults. He explained that these faults are comprising the Gerede-Ilgaz portion of the North Anatolian 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 margin-structures within the Gerede-Ilgaz portion of the fault system however, other faults such as the Çerkeş, Dikmen, Kızılibrik and Yılanlı are the ones determining both northern and southern walls of the zone of deformation controlling the morphology. He also dealt with the seismotectonics of the region and seismicity along the fault zone. In conclusion, he evaluated the previous models on origin of the NAFS and discussed their reliability based on his own observations.

Şengör *et al*. (1985) identified Yeniçağa Basin as a tectonically controlled depression and claimed that this basin is located at the point of bifurcation of North Anatolian Fault System, and stated that this depression may be an extensional fault wedge basin.

Öztürk *et al*. (1984, 1985) identified the Yeniçağa Basin as a tectonically controlled depression and claimed that this basin is located at the point of bifurcation of the North Anatolian Fault System.

They identified the deformational structures under two categories which are the paleotectonic structures and the neotectonic structures. Besides, they also identified the rocks exposed within their study area as paleotectonic and neotectonic units. They summarized the major extensional and compressional phases prevailed in this region during the paleotectonic and neotectonic periods. Several fold axis orientations in each rock unit pointing out the time – dependent change in the compression direction acting on the region was also documented.

They named mainly twelve faults of neotectonic origin, namely the Hacigüzel, Kayserler, İslamlar, Çukurviran, Çakmaklar, Karamanlar, İkizler, Dereceviran, Musalar, Nallar, Rüzgarlar and the Akçaalan faults. Based on field observations, they stated that the age of the North Anatolian Fault System is of post Late Miocene.

Serdar and Uğur (1990) studied the Mengen-Bolu-Abant portion of the North Anatolian Fault System. They reported the detailed description of rock units exposed within this area. They also stated the structural geology of this region and gave some information mainly on folds and faults. They have also explained the geological evolution of the area based on their observations and gave information about the petroleum potential of the area.

Şaroğlu *et al*. (1995) mapped the geology of the area located between Yeniçağa and Eskipazar at a scale of 1/25.000. They studied several rock units within the study area and subdivided these rock units into two categories based on their position with respect to the North Anatolian Fault System. These categories are, the units on the northern block and those on the southern block of the North Anatolian Fault System. They identified the structures exposed within the study are in the same manner, as the structures belonging to the northern part of the North Anatolian Fault and those on the southern block of the North Anatolian Fault System.

In addition to this, they also focused on the geomorphology and the economic geology of the region. Based on their analysis and observations, the North Anatolian Fault System is Late – Pliocene in age.

Yiğitbaş and Elmas (1997, 2001) studied the Bolu-Eskipazar-Devrek-Çaycuma region and they divided this region based on the stratigraphical and tectonic characteristics of the rock units exposing within the belt into mainly seven subareas, namely the Sakarya Continent, the Bolu-Eskipazar Zone, the Karabük Basin, the Sünnice High, the Ulus Basin, the 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 Apalar 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 composed mainly of fluvio-lacustrine deposits. In addition to these, they identified Quaternary units as 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 the Sünnice high to the north.

1.5. Regional Tectonic Setting

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

The Dextral North Anatolian intracontinental transform fault system formes the contact between the Eurasian Plate in the north and the Anatolian platelet in the south. This fault system is conjugate to the sinistral East Anatolian Intracontinental transform fault system and they are Pliocene in age. They may have formed as a natural response to the post-collisional north-south directed convergence between the Arabian Plate and the Eurasian Plate (Koçyiğit *et al*., 2001a). At eastern Anatolia, this convergence produces N-S orientated compression.

Today, the westward escaping Anatolian platelet moves onto the oceanic lithosphere of the eastern-Mediterranean Sea, and the African Plate has been subducting northwards beneath the Anatolian platelet with a rate of 35 mm/yr (McKenzie 1972 ; Le Pichon and Angelier 1979 ; Meulenkamp *et al*. 1988 ; 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 the North Anatolian intracontinental transform fault continues since the Late Pliocene, therefore, Late Pliocene is accepted to be the initiation time 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. 1997, Stein *et al*. 1997; Kahle *et al*. 1998, 2000; McClusky et al., 2000).

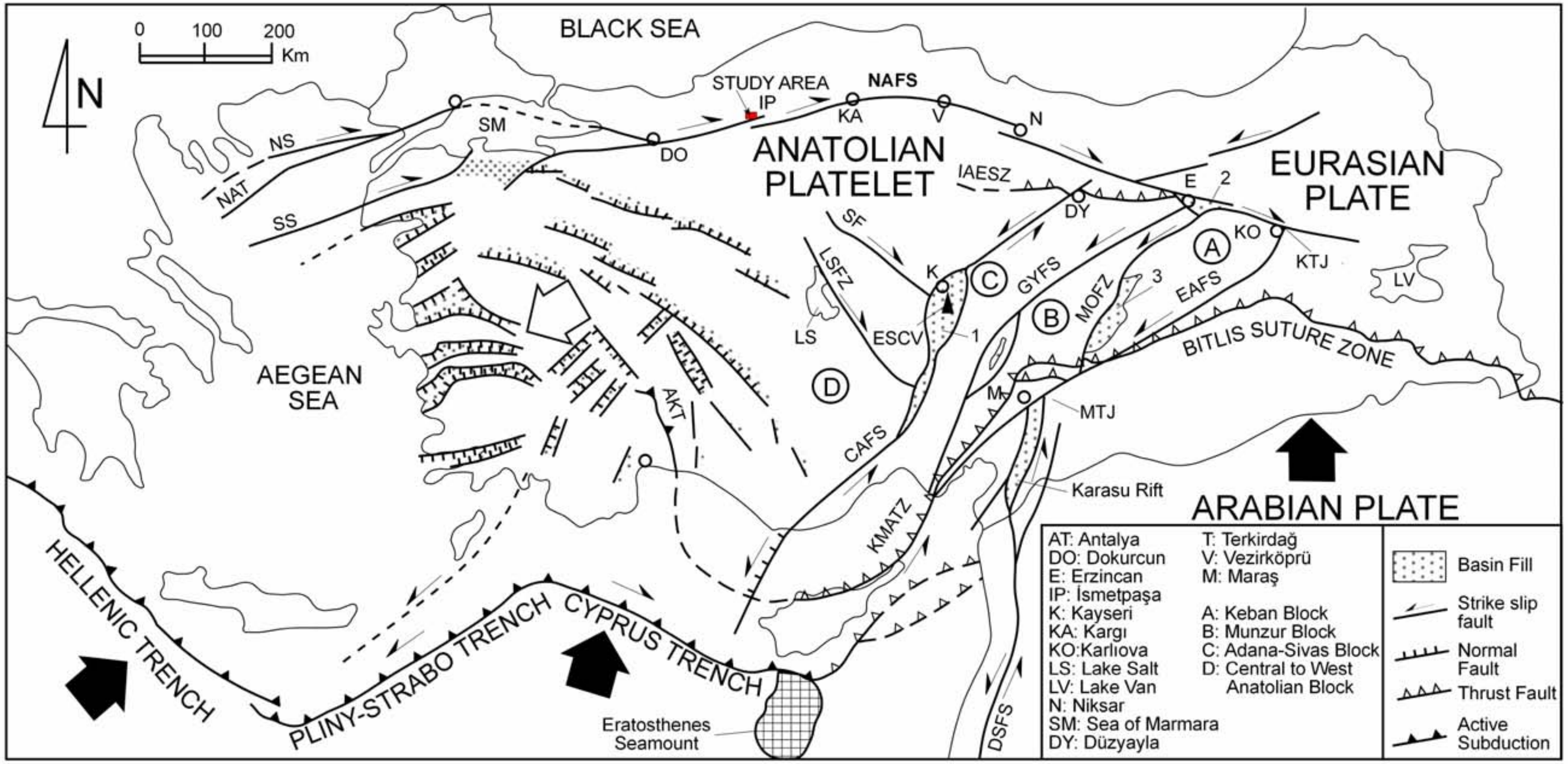

Figure 2. Simplified map showing the study area and major tectonic structures in Turkey and adjacent regions. AKT: Aksu Thrust, CAFS: Central Anatolian Fault Sysyem, DSFS: Dead Sea Fault System, EAFS: East Anatolian Fault System, ESCV: Erciyes andesitic-basaltic stratovolcano complex, GYFS: Göksu-Yakapınar Fault System, IAESZ: Izmir-Ankara-Erzincan Suture Zone, KMATZ: Kyrenia-Misis-Andrın Fold-Thrust Fault Zone, KTJ: Karlıova Triple Junction, MTJ: Maraş Triple Junction, LSFZ: Lake Salt 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 (Koçyiğit 1996).

In addition, the Anatolian platelet is divided into four blocks by the intracontinental transcurrent faults, Lake Sault, 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 100-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 northwestern part of the fault system has a trend of NE-SW, and characterized by a number of fault zones, fault sets, isolated faults and anastomosing and splay-type geometry and 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 with long axes parallel to the general trend of the NAFS.

The Yeniçağa Basin is located on southern side of the Arkotdağ Tectonic Block. At close proximity to this basin, Mengen Basin, and Bolu Basin are present in the NE and W, respectively (Figure 1). The Yeniçağa Basin is about 14-km-long, 1-5-km-wide and ENE-WSW-trending actively growing depression controlled by the strike-slip faults. Within the Yeniçağa Basin, two groups of rock units are exposed. They are the Paleotectonic and the neotectonic units. These units will be described in Chapter 2. A crucial emphasis will be given to the stratigraphy of the latest palaeotectonic unit and the neotectonic units to understand the evolutionary history of the Yeniçağa Basin.

CHAPTER 2

STRATIGRAPHY

The rock units exposed in the study area are divided into two groups. the basement and cover units. The neotectonic unit comprise the cover units, whereas older rocks unconformably beneath the neotectonic units are categorized into basement units. The distribution of units exposed within the study area are plotted on a geological map at 1/25.000 scale, and the generalized stratigraphic columnar section of the study area is given in Plate 1 and Figure 3, respectively. The basement rocks are outside of this work scope; therefore they will not be described in detail. But detailed descriptions of the youngest paleotectonic unit and the neotectonic units are given below.

2.1. Basement Units

The basement units comprise Jurassic–Cretaceous dolomitic limestones (Soğukçam Limestone), the Upper Cretaceous ophiolitic mélange ("the Arkotdağ Formation"), the Lower–Middle Eocene red-clastics (Taşlık Formation) which laterally grades into Lower – Middle Eocene volcanics of the Galatean Arc Complex, the Upper Miocene–Lower Pliocene fluvial clastics (Eskipazar formation) which comprises the youngest paleotectonic unit in the study area.

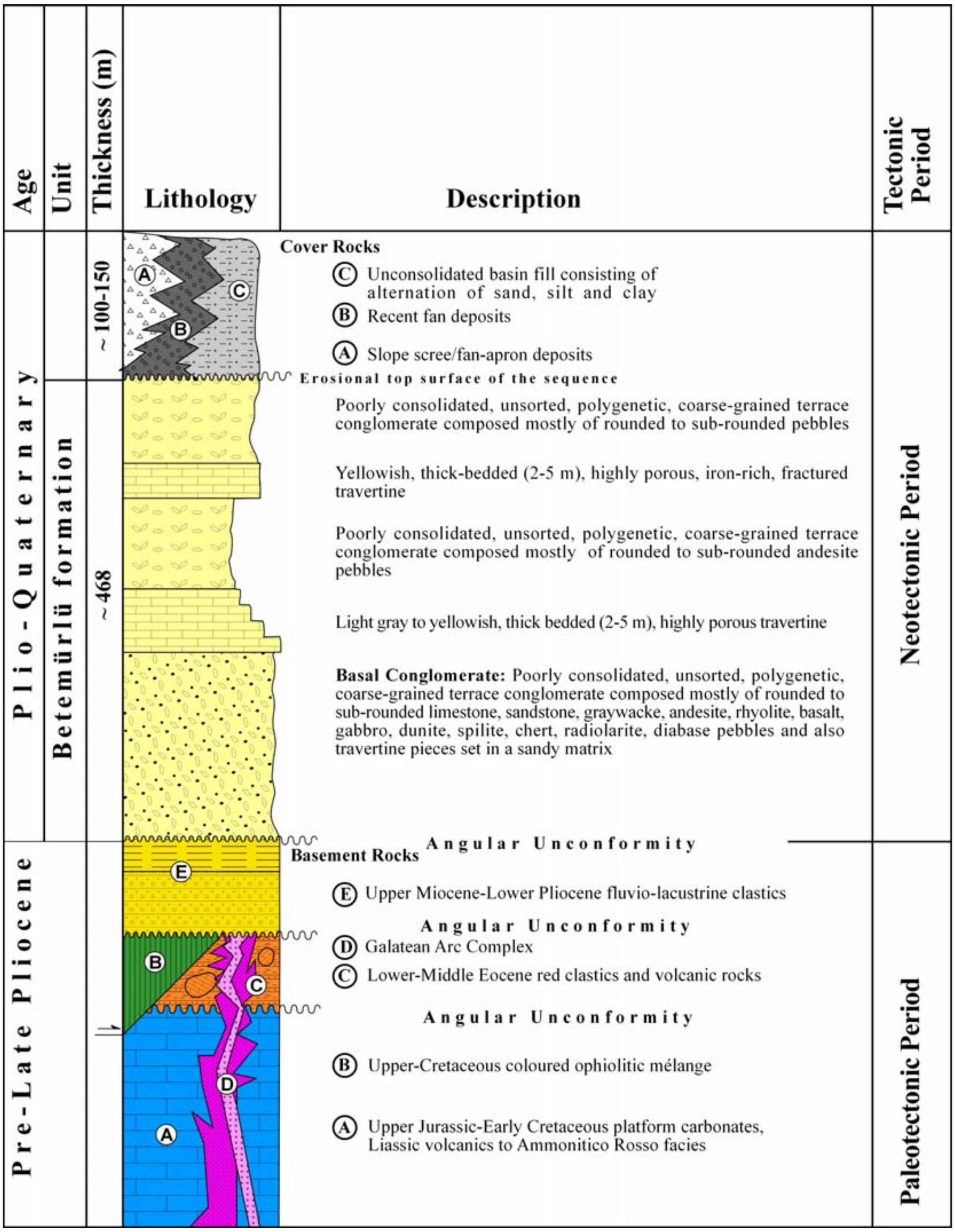

Figure 3. Generalized stratigraphic columnar section showing both the paleotectonic and the neotectonic units.

2.1.1. Soğukçam Limestone (JKs)

The Soğukçam Limestone was first named by Altınlı (1973). It is characterized by middle to thick bedded, monotonous, cream or pinkish bioclastic levels are pelletic, oolitic and fossilferous packstones and grainstones containing Tubiphytes and dasyclad algae with interbeds of laminated mudstones or wackestones (Figure 4).

The formation is exposed mainly in the southern parts of the study area on the southern block of the North Anatolian Fault System Master Strand (Plate 1). The bottom boundary of the formation is not exposed within the study area. It is unconformably overlain by the Galatean Arc Complex. In addition, it has tectonic contact relationship with the clastics of Plio-Quaternary Betemürlü formation.

The Soğukçam Limestone is characterized by light gray, massive shallow marine platform carbonates, i.e. limestones and dolomites in places, in the study area (Figure 5). Micro-fossils are present abundantly in this formation. The major fossils identified by Altıner *et al*. (1991) are; "*Conicospirillina"* basiliensis, *Protopeneroplis trochoangulata*, *Protopeneroplis* sp., *Earlandia? Conradi*, *Ammobaculites* sp., *Reophax* sp., *Siphovalvulina* sp., *Valvulina* sp., *Ataxophragmiidae*, *Textularia* sp., *Belorussiella* sp., *Verneuilina polonica*, *Dobrogelina* sp., *Montsalevia salavensis*, *Haplophragmoides joukowskyi*, *Nautiloculina cretacea*?, *Nautiloculina* sp., *Charentia* sp., *Everyticyclammina* sp., *Pseudocyclammina lituus*, *Miliolidae*, *Ophthalmidium* sp., *Trocholina elongate*.

According to this fossil assemblage, the age of this formation is Late Jurassic-Early Cretaceous.

2.1.2. “Arkotdağ Formation” (KTa)

The “Arkotdağ Formation” was first named by Tokay (1973). It is composed of 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 and it does not show a well defined top and bottom boundaries. Besides, it does not have any certain type section. 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.

Figure 4. General view of the Soğukçam Limestone (Location: ~250 m NE of Şahnalar village, view towards SW), Berk for scale.

Figure 5. Close up view of the Soğukçam limestone (Location: ~250 m SW of Aşağı Kuldan Village), hammer for scale.

The “Arkotdağ Formation” is exposed mainly in the northern and the centralwestern parts of the study area (Plate 1). Its bottom boundary is not exposed within the study area. It is unconformably overlain by the Eskipazar formation (Figure 6) and the younger units. It tectonically overlies the Taşlık Formation of Early–Middle Eocene age in the western and northwestern parts of the study area (Plate 1). Besides, the serpentine blocks (Figures 7, 8) are unconformably overlain by basalts of the Galatean Arc Complex in the eastern part of the study area. In addition, it has a tectonic contact relationship with the Plio-Quaternary and Quatenary units in places along the active faults.

The “Arkotdağ Formation” is characterized by various limestone blocks originally deposited in both the neritic and pelagic depositional settings. These blocks are set in a finer-grained matrix characterized by sandstone, siltstone and mudstone.

The matrix is intensively deformed, sheared, folded and faulted (Figure 9). In most of the places, the matrix has no its primary structures, and locally, it shows evidence for metamorphism with development of protomylonites and evidence for incipient greenschist facies along the discrete zones of deformation owing to the intensive deformation and frictional heating resulted in local elevated temperatures.

These units are part of the Late Cretaceous Ophiolitic Mélange (Tokay, 1973) and extensively exposed all around Turkey (Şengör and Yılmaz, 1981; Koçyiğit, 1991a).

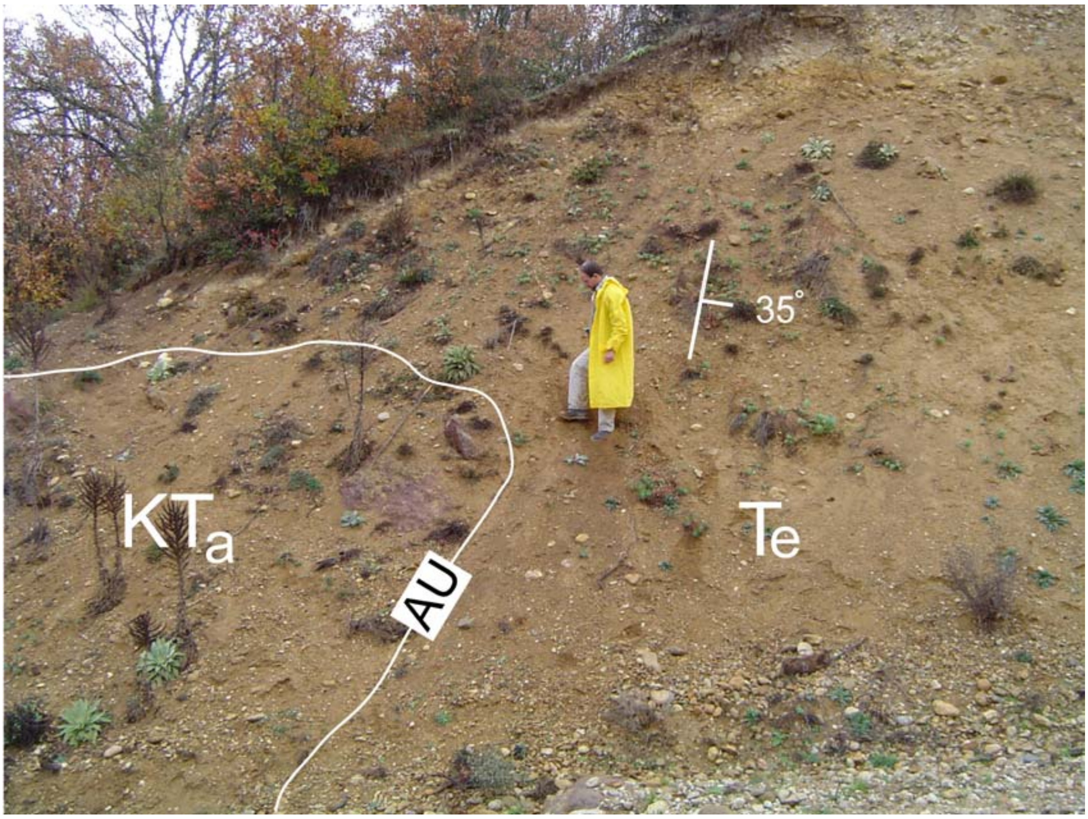

Figure 6. General view of the unconformable contact between the “Arkotdağ Formation” (KTa) and the Eskipazar formation (Te) where polygenetic basal conglomerates including pebbles to cobbles derived from the underlying “Arkotdağ Formation” (KT_a) rest on the erosional surface (AU. Angular Unconformity) (Location: ~ 500 m SSW of Kındıra village), Berk for scale.

Figure 7. General view of the highly deformed serpentinite blocks of the “Arkotdağ Formation” (Location: ~ 300 m North of Selek Hill), hammer fro scale.

Figure 8. Close-up view of the higly deformed Serpantinite blocks of the “Arkotdağ Formation” (Location : ~ 300 m North of Selek Hill), pencil for scale.

Figure 9. Close up view of the intensely deformed “Arkotdağ Formation”. (Location: ~ 1 km South of Eskiçağa County), Berk for scale.

2.1.3. Taşlık Formation (Tt)

The Taşlık Formation was first named by Şaroğlu *et al*. (1995). It is characterized by the alternation of red clastics and volcanic rocks. This formation was defined based on the 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 same name, the Taşlık Formation, is used for this rock unit.

The formation is exposed mostly in the northwestern, western and eastern parts of the study area (Plate 1). Its bottom boundary is not exposed within the study area, but its top is unconformably overlain by the Miocene– Lower Pliocene Eskipazar formation and the clastics of the younger Betemürlü formation and Quaternary Alluvion. It tectonically underlies the “Arkotdağ Formation” of Early-Middle Eocene age in the western and northwestern parts of the study area. The formation laterally grades into volcanics of the Galatean Arc Complex of the same age (Figure 3). In addition, it has also a tectonic contact with the same volcanics and Quaternary units, in places, along the faults.

The Taşlık Formation is characterized by conglomerate, sandstone and siltstone alternation within the study area (Figure 10). At about 2 km south of Nallar village the dominant lithology is thickly bedded, polygenetic conglomerate composed of mainly pelagic micritic limestone and radiolarite pebbles set in a sandy matrix (Figure 11). In some certain sandstone beds of this formation *Nummulites* sp., *Assilina* sp., *Orbitolites* sp., *Asterigerina* sp., Rotalidae, Miliolidae, Valvulinidae are identified by Şaroğlu *et al*., 1985). Hence, the age of this formation can be specified as Early-Middle Eocene.

Figure 10. General view of the clastic portion of the Taşlık Formation (Location: ~ 2 km NW of Aşağıkuzören village), Berk for scale.

Figure 11. Close-up view of the clastic level of the Taşlık formation (Location: ~ 2 km SE of Cevekkeller village), pencil for scale.

2.1.4. Galatean Arc Complex (KT_g)

The sequence of volcanic rocks exposing in the Bolu – Ankara – region between İzmir – Ankara – Erzincan Suture Zone (IAESZ) in the south and the 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 *et al*. 1970; Öngür 1977; Ach 1982; Akyürek *et al*. 1984; Kazancı and Gökten 1988; Tankut *et al*. 1990; Türkecan *et al*. 1991; Koçyiğit 1991a, b; Keller *et al*. 1992; Gökten *et al*. 1996; Toprak *et al*. 1996; Wilson *et al*.1997). 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 the 'Köroğlu (Galatia) Volcanic Complex'. However, Koçyiğit (1991a) and Koçyiğit *et al*. (2003a) carried out some detailed studies in the southern parts of this sequence. They determined the top and bottom of the sequence, measured several stratigraphical sections to define and describe these rock units and pointed out the tectonic significance of both the presence and spatial distribution of these rocks. Koçyiğit *et al*. (2003a) pointed out that these rocks have formed under the multi-phase magmatic arc evolution, and then named this sequence of volcanic rocks as the Galetean Arc. 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).

The part of the Galatean Arc Complex is exposed mainly in the southern part of the study area (Plate 1).

It unconformably overlies the Soğukçam Limestone, but it is unconformably overlain by the Betemürlü formation in the southern parts of the study area. The formation laterally grades into Lower-Middle Eocene Taşlık Formation (Figure 3). In addition, it has a tectonic contact relationship with the Quaternary units, in places, along the active faults in the southern parts of the study area (Figure 12).

Figure 12. Tectonic boundary relationship between the underlying Galatean Arc Complex (KT_g) and the overlying Betemürlü formation (TQ_b) (Location: ~100 m SE of Aşağıkuldan village, view to NW).

Within the study area, the small portion of the Galatean Arc Complex, is characterized and dominated by the massive agglomerates mainly composed of andesite and basalt cobbles set in a tuffaceous matrix (Figure 13). They also occur as thinly bedded tuff layers in places closer to the southern margin of the study area (Figures 14, 15). Besides, some basaltic layers of this formation outcrops at eastern part of the study area (Plate 1).

No fossil have been found in the unit, 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 (1991a) and Koçyiğit *et al*. (2003a).

The Galatean Arc Complex comprises the Upper Cretaceous to Lower Pliocene volcanic rocks mainly produced by pre- and post-collisional magmatic events. This magmatic activity is indeed related to the northward subduction of the floor of the northern branch of Neotethys (Şengör and Yılmaz 1981), and represents the development of the Galatean Magmatic Arc at the northern active margin of the subduction zone. Nevertheless, this subduction-related volcanic activity (Galatean arc activity) did not took 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 the 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*. 2003).

Figure 13. General view of massive agglomerates of the Galatean Arc Complex (Location: ~ 1 km SW of Kısırbayır Hill), hammer for scale.

Figure 14. Close-up view of massive agglomerates and tuffaceous layer of the Galatean Arc Complex (Location: ~ 1 km SW of Kısırbayır Hill), hammer for scale.

Figure 15. General view of the layered basalts belonging to the Galatean Arc Complex (Location : ~ 50 m W of Toshacı Stream), hammer for scale.

2.1.5. Eskipazar formation (Te)

The Eskipazar formation is named for the first time in this study. It is characterized by fluvio-lacustrine red clastics. This formation was previously named as Pazarbaşı formation by Şaroğlu *et al*. (1995). However, the "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).

The Eskipazar formation is extensively exposed in the northwestern part of the study area (Plate 1). It unconformably overlies the "Arkotdağ Formation" and Taşlık Formation in the northwestern part of the study area (Figure 6). The Eskipazar formation is unconformably overlain by the clastics of the Plio-Quaternary Betemürlü formation in the northwestern parts of the study area. In addition, it has also tectonic contact relationship with the Quaternary units along the active faults.

The Eskipazar formation is the youngest paleotectonic unit exposed in the study area and thus it has an important role in understanding the evolutionary history of the Yeniçağa Basin. For this reason the Eskipazar formation will be explained here in more detail.

This formation can be subdivided, based on variations in its lithological characteristics, into three parts. Each is analyzed and documented by three measured sections (MS), namely MS_2, MS_3 and MS_4 (see Plate 1 for their locations). MS_2 constitutes the oldest and lowermost part of the formation while MS_4 constitutes the youngest and the uppermost part of the formation.

The type locality of MS_2 is ~2.5 km NW of Hasanallar Village (Plate 1). At this locality bottom portion of the Eskipazar formation is well exposed and here this formation unconformably overlies the Arkotdağ Formation (Figure 6).

The lowermost part of the section starts with poorly consolidated, unsorted, polygenetic, massive boulder-block basal conglomerate consisting of sub-rounded to rounded components such as silty sandstone, micritic limestone of dark-gray to light gray tones, claystone and marl clasts (Figure 16, 17). Moreover, andesite, basalt, rhyolite, gabbro, graywacke, diabase, and radiolarite pebbles are also present. The components are set in a silty matrix. This basal conglomerate is succeeded by alternations of grayish to light-gray, thick-bedded (2-5 m), coarser-grained sandstone and poorly consolidated, unsorted, polygenetic, thickly-bedded, grayish boulder-block fluvial conglomerate. Towards the top of the section, there is an alternation of coarser-grained, matrix-supported sandstone with thin beds of claystone intercalations of conglomerate lenses, in places. Towards the top, the sequence consists of polygenetic and poorly consolidated fluvial conglomerate, displaying a fining-upward succession and containing interclations of sandstone lenses, in places. At the top, light-gray, medium-bedded (1-2 m) sandstone alternates with thin beds of claystone (Figure 18).

Figure 16. General view of the basal part of the Eskipazar formation. (Location: ~ 500 m SSW of Kındıra village), Berk for scale.

Figure 17. Close-up view of the basal portion of the Eskipazar formation (Location : ~ 500 m SSW of Kındıra village), pencil for scale.

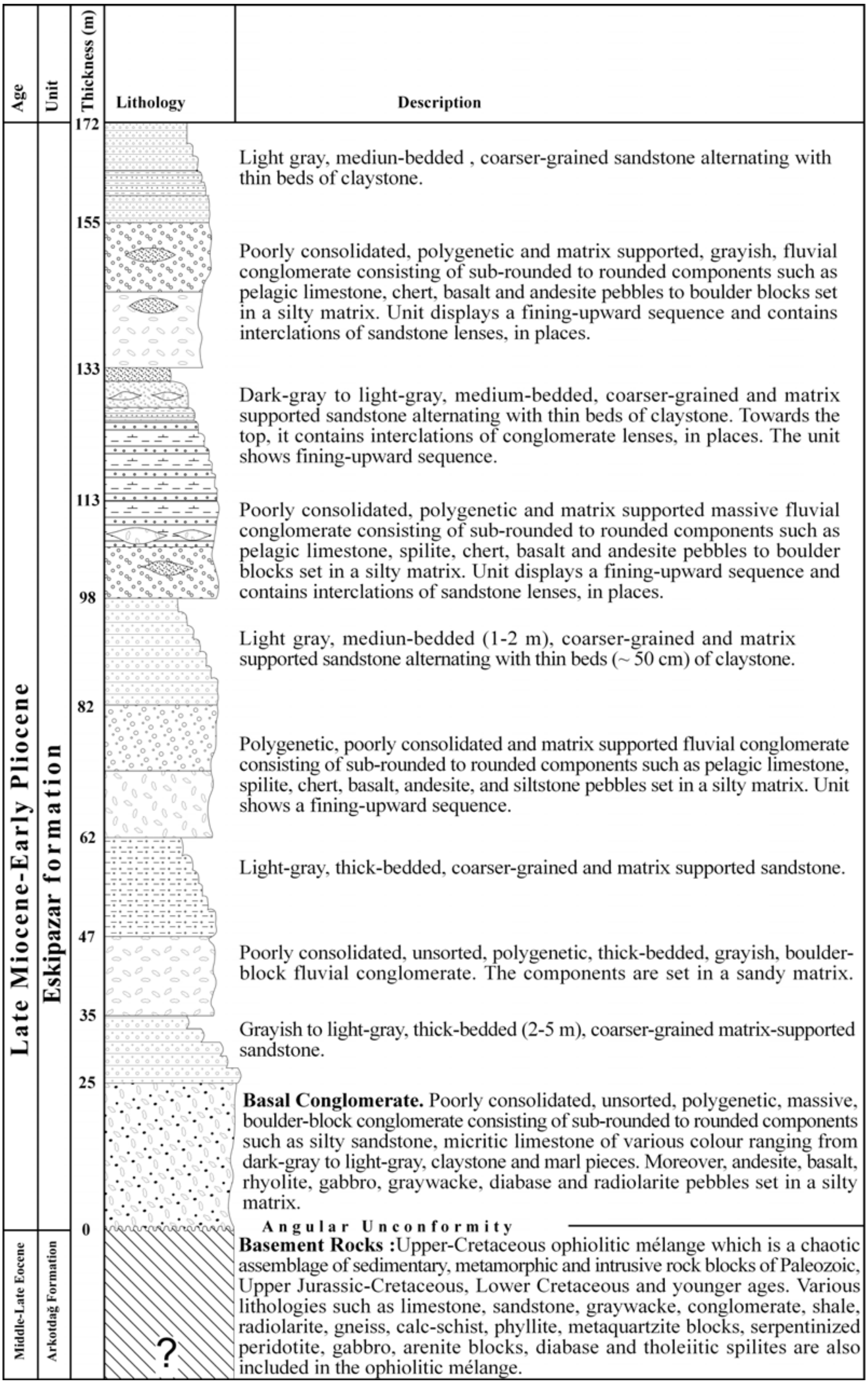

Figure 18. Measured section (MS2) of the basal part of the Eskipazar formation (type locality: 500 m SSW of Kındıra village, for location see MS2 in Plate 1).

Type locality for MS_3 is near Hasanallar Village (Plate 1). At this locality middle portion of the Eskipazar formation is exposed. Dominant lithology is poorly consolidated, polygenetic, matrix-supported and massive fluvial conglomerate, consisting of sub-rounded to rounded components such as pelagic limestone, spilite, chert, basalt, andesite, and siltstone pebbles set in a silty matrix (Figure 19, 20). It displays a fining-upward sequence and contains interclations of sandstone lenses, in places. This section is characterized by the presence of organic-rich sandy siltstone alternating with dark-brown laminae of coal, finer-grained, medium-bedded (10-30 cm), iron-rich cross-bedded sandstone alternating with thin laminae of yellowish, hydrothermally altered siltstone and brownish to dark-brown, thin-bedded (3-10 cm) claystone containing local intercalations of chalk lenses. At the top, the measured section terminates with poorly consolidated, polygenetic, massive fluvial conglomerate consisting of sub-rounded to rounded components such as pelagic limestone, spilite, chert, basalt, andesite and siltstone pebbles set in a silty matrix. It displays a fining-upward sequence and contains intercalations of sandstone lenses, in places (Figure 21).

Figure 19. General view of the middle part of the Eskipazar formation. (Location: eastern vicinity of Hasanallar village), hammer for scale.

Figure 20. Close-up view of the middle part of the Eskipazar formation. (Location: eastern vicinity of Hasanallar village), hammer for scale.

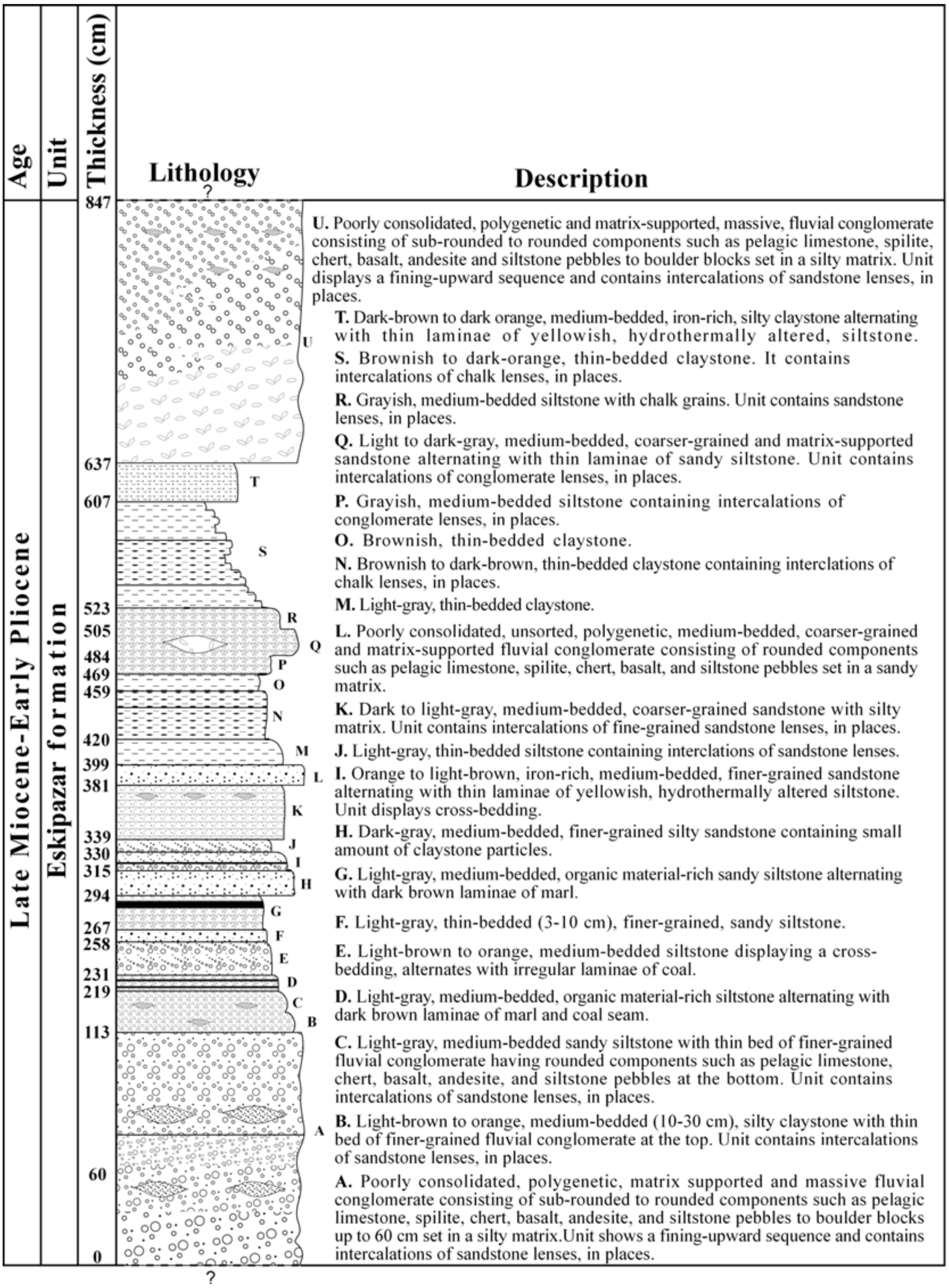

Figure 21. Measured section (MS3) of the middle part of the Eskipazar formation (Type locality: eastern vicinity of Hasanallar village, for location see MS3 in Plate 1).

Type locality for MS_4 is about 5.5 km WNW of Gölbaşı village (Plate 1). At this locality upper part of the Eskipazar formation is exposed (Figures 22, 23). The unit here starts with poorly consolidated, polygenetic and medium-to coarse-grained fluvial conglomerate, composed mostly of rounded to sub-rounded limestone, andesite, rhyolite and basalt pebbles set in a sandy matrix.

The measured section MS_3 is characterized by brownish, medium-bedded (10-30 cm) silty sandstone, dark-brown, organic material-rich, plant debris-bearing thin-bedded (3-10 cm) mudstone alternating with thin beds of sandstone, and light-brown, thin-bedded mudstone containing intercalations of sandstone lenses. At the top, the section terminates with poorly consolidated, polygenetic, thickly-bedded and coarser-grained fluvial conglomerate composed mostly of limestone, andesite, chert, spilite, basalt, and siltstone pebbles set in a sandy matrix. Unit shows first fining-upward sequence, later coarsening-upward nature (Figure 24).

The combined thickness of the Eskipazar formation is about 196 m and contains micro- and macro mammalian fossil assemblages as mentioned by Şaroğlu *et al*. (1995). Based on the fossil content of fossils of *Miyomimus* sp., Spalacidae gen. et sp. indet, Talpidae gen. et sp. indet (Desmana or Dibolia) found in this formation, Şaroğlu *et al*. (1995) assigned a Late Miocene-Early Pliocene age to the "Pazarbaşı Formation", i.e. to the Eskipazar formation of this study. This formation is dominated by fluvial deposits of conglomerate, cross-bedded sandstone and mudstone. Under the light of these findings it is proposed that the Eskipazar formation was deposited in a fluvio-lacustrine environment.

Figure 22. General view of the upper part of the Eskipazar formation (Localition: ~5.5 km WNW of Gölbaşı Village), hammer for scale.

Figure 23. Close-up view of the upper part of the Eskipazar formation (Locality: ~ 5.5 km WNW of Gölbaşı Village), hammer for scale.

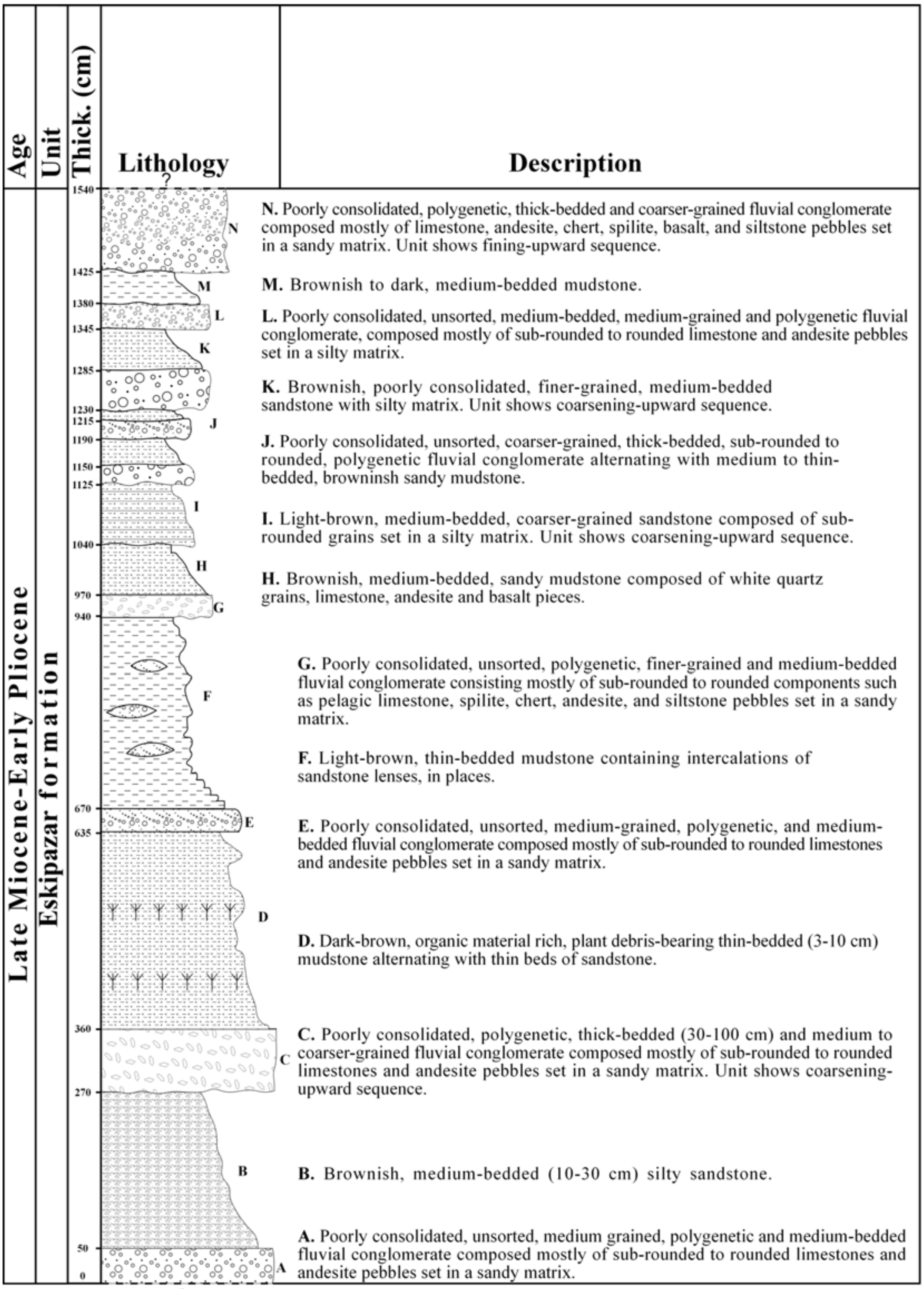

Figure 24. Measured section (MS4) of the upper part of the Eskipazar formation (Type locality: 5.5 km WNW of Gölbaşı Village, for location see MS4 in Plate 1).

2.2. Neotectonic Units

The neotectonic units comprise the Plio-Quaternary travertine deposits and their lateral correlatives of terrace and fluvial conglomerates (Betemürlü formation). Recent alluvial fans and unconsolidated basin fill consisting of alternation of sand, silt and clay are also classified in the framework of neotectonic units. These lithologies show both vertical and lateral gradations to each other and rest on erosional surface of the deformed (folded and thrust faulted) paleotectonic units with an angular unconformity.

2.2.1. Betemürlü formation (TQ_b)

This formation is named for the first time in this study. It is characterized by the travertine-conglomerate alternation and extensively exposed in the northwestern and western parts of the study area (Plate 1). Clastics of this formation unconformably overlies the Eskipazar, the "Arkotdağ" and Taşlık formations in the northwestern, western and eastern parts of the study area. Besides, in the southern parts of the study area, it unconformably overlies the volcanic rocks of the Galatean Arc Complex (Plate 1).

The Betemürlü formation is analyzed and documented in measured section MS_1 (Figure 25) At this type locality, the bottom portion of the Betemürlü formation is well exposed, and here, this formation unconformably overlies the Lower-Middle Eocene red clastics of the Taşlık Formation.

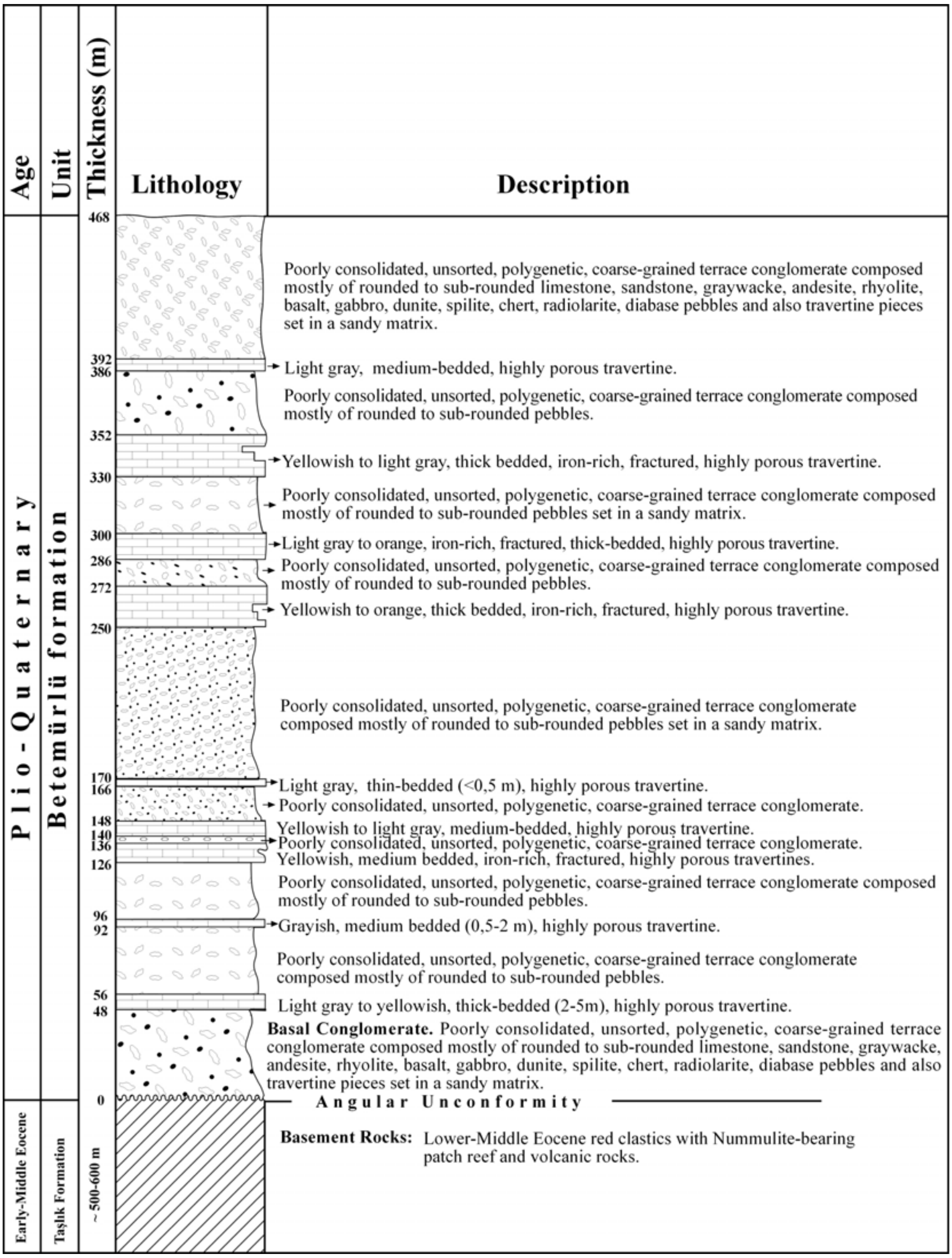

Figure 25. Measured section (MS1) of the Plio-Quaternary Betemürlü formation (TQb) (Type locality: Betemürlü Hill, for location see MS1 in Plate 1).

Type locality for the Betemürlü formation (MS_1) is about 100 m east of the Betemürlü Hill (Plate 1). At this locality the Betemürlü formation is characterized by poorly consolidated, coarser-grained, thickly – bedded, unsorted, polygenetic terrace conglomerates alternating with grayish to yellowish, medium (0,5-2 m) to thick bedded (2-5 m), iron-rich, fractured, highly porous travertine horizons (Figure 26). The polygenetic terrace conglomerate is mainly composed of rounded to sub-rounded limestone, sandstone, graywacke, andesite, rhyolite, basalt, gabbro, dunite, spilite, chert, radiolarite, diabase pebbles and also travertine clasts set in a sandy matrix (Figure 27). Based on measured stratigraphic sections, the total thickness of the Betemürlü formation is 468 m (Figures 3 and 25).

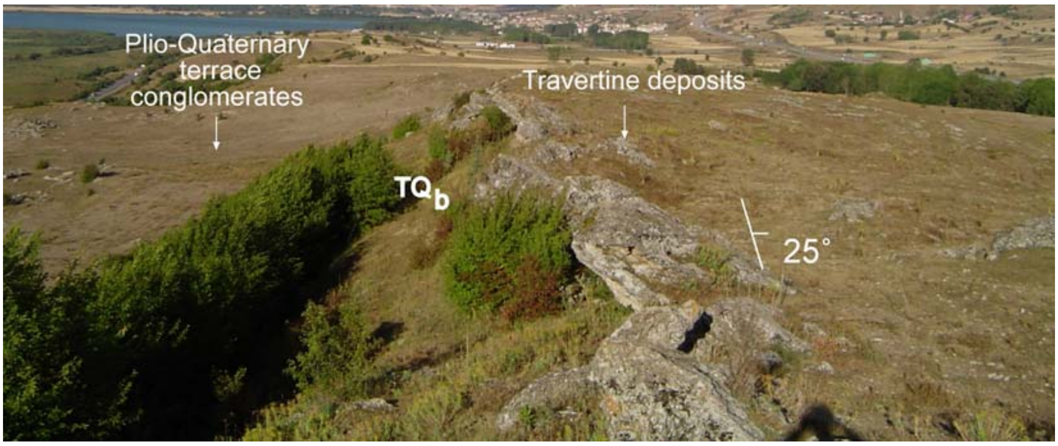

Figure 26. Generel view of the Plio-Quaternary Betemürlü formation (TQ_b) where the Plio-Quaternary terrace conglomerates and travertine deposits alternate each other (Location: ~20 m E of Pantların Hill, view to E).

No fossils could be found in the Betemürlü formation during the field studies, however, based on stratigraphical relationship with underlying units and overlying unconsolidated Upper Quaternary sediments, it is concluded that the age of this formation is Plio–Quaternary.

Clastic portions of this formation are deposited at continental environment in the form of terrace conglomerates as indicated by their unsorted, nature and present day positions.

Figure 27. Close-up view of the Plio-Quaternary Betemürlü formation (TQb) (Location : Betemürlü Hill), pencil for scale.

2.2.2. Upper Quaternary Deposits (Qal)

Upper Quaternary deposits consist mainly of coarser-grained marginal and finer-grained depocentral sediments resting unconformably on the erosional surface of various pre-Quaternary rocks within the present-day configuration of the Yeniçağa Basin.

Marginal sediments constitutes coarser-grained, recently developing alluvial fan deposits that change from a few hundreds m^2 to 2 km^2 in size on the map and occur in places where streams enter into the floor of the basin and their transportation capacity is decreased. A series of diverse-sized alluvial fans with their apices adjacent to the basin margin-bounding faults are well exposed (Plate 1).

The fans indicate sudden change in the slope related to the Recent activity of the basin-bounding faults. For example, the alluvial fan which is observed about 2 km SW of Yukarıkuldan Village, near Dağtarla Hill (Plate 1) is perched on a flat topography and could not reach the flood plain floors. This indicates the activity of one of the segments of the Yukarı Kuldan Fault Set.

Depocentral sediments occur in a wide area across the basin floor and consist of unconsolidated, fine-grained, organic-rich silt, peat, clay, mud, sand and lensoidal pebbles. These are mostly the meandering river, sheet flow and swamp deposits. At the eastern and western ends of the basin, depocentral sediments are confined to a narrow zones parallel to stream beds flowing into the basin. However, towards the central part of the basin, they widen and cover an area of 5 km wide and 15 km long (Plate 1).

Thickness of fine-grained depocentral sediments range from 30 to 125 m. However, borehole drilled by Turkish Hydrolic Works (DSİ) in the basin floor penetrated 89 m of unconsolidated sediments in south of Adaköy located in the Yeniçağa basin floor (Yücel, 1969) (Plate 1).

CHAPTER 3

STRUCTURAL GEOLOGY

This chapter deals with the description and analysis of the geological structures observed within the study area. Structural elements include syn-depositional growth faults and shear fractures, beds, unconformities, folds and faults. Based on tectonic period during which they formed, these structures are grouped into two major categories: (1) paleotectonic structures, (2) neotectonic structures. The deformation of pre-Neogene basement rocks lies outside the scope of this study. But, paleotectonic structures deforming the latest paleotectonic unit of the Upper Miocene-Lower Pliocene Eskipazar formation will be described similar to neotectonic structures; this is important to determine the stress-regime during the latest paleotectonic period. The structures formed by the deformation of Eskipazar formation and the neotectonic structures shaping the present day configuration and outline of the Yeniçağa Basin will be described and analysed in detail.

The database for the structural analysis is obtained during geological field mapping. In the field, attitudes of various planar and linear structures such as strike, dip, trend-plunge and rake were measured; later on, these raw data-sets were analyzed by using pole plots, histograms and a computer software named as Data Base for Tectonic Orientations (Tector) (Angelier, 1989).

Basically, “Tector” allows us to find the relationship between faults and principal stress directions. This program simply processes the data based on three sub-programs. Mesure, Tensor and Diagra are the computer softwares provide the user principle stress directions. The software ‘Diagra’ presents the results of the processed data on stereographic projection which includes slip-planes and principle stress axes.

3.1. Paleotectonic Structures

In the study area, paleotectonic structures are mainly subdivided into two categories: (1) structures deforming pre-Neogene basement rocks and (2) structures affecting the latest paleotectonic unit, the Upper Miocene-Lower Pliocene Eskipazar formation.

3.1.1. Structures Deforming Pre-Neogene Basement Rocks

The study area is located within the Intra-Pontide Suture Zone (Okay *et al*. 1997) which straddles the Rhodope-Pontide Fragments (Pontide Zone) in the north and the Sakarya Zone (or Continent) in the south. The Pontide Zone is represented mainly by the İstanbul-Zonguldak Unit while the Sakarya Zone is situated to the south of the İstanbul-Zonguldak Unit that is bounded on its southside by the İzmir-Ankara Suture (Elmas and Yiğitbaş, 2001). According to Şengör and Yılmaz (1981), this Zone is thought to represent a suture belt of a sea way, the Intra-Pontide Ocean, which existed during Late Cretaceous time and closed by northward-directed subduction. This produced an ophiolitic mélange (the "Arkotdağ Formation" of Tokay 1974).

In the study area, the "Arkotdağ Formation" is thrust over the Lower-Middle Eocene Taşlık Formation along the Hamzaköy and Nallar thrust faults.

3.1.1.1. The Hamzaköy Thrust Fault

The Hamzaköy thrust fault is exposed in the NW corner of the Yeniçağa Basin around Hamzaköy village and Akbayır Hill (Figure 28 and geological cross-section A_1-A_1 in Figure 29). It is about 3 km long and displays a curved to curvilinear fault trace; it is well exposed within the Değirmen stream valley where no fault plane is observed. Nevertheless, according to elevation change along the trace of the thrust fault, on the map, the dip of the Hamzaköy thrust fault should be less than 20°. In the SW end, the Hamzaköy thrust fault is displaced by one of the faults of the Değirmen fault set (Plate 1). The Hamzaköy thrust fault is overlain unconformably by the Upper Miocene-Lower Pliocene Eskipazar formation (cross-section A2-A2 on Figure 29). Therefore, the age of the thrusting must be younger than Middle Eocene but older than Late Miocene.

3.1.1.2. The Nallar Thrust Fault

The Nallar thrust fault is exposed in the western corner of the Yeniçağa Basin around Nallar village and Kanlı Stream. It is about 3 km long and displays a curvilenar fault trace and convex pattern in SE direction, indicating NW to SE-directed tectonic transport (Plate 1 and geological cross-section A1-A1 in Figure 29).

Along the Hamzaköy and the Nallar thrust faults the Upper Cretaceous “Arkotdağ Formation” is thrust over the Lower Middle Eocene Taşlık Formation. The Nallar thrust fault contact is sealed by the Plio-Quaternary Betemürlü formation along the Kanlı Stream (Plate 1). In additon, the Hamzaköy thrust fault is displaced by the Değirmen fault set and overlain unconformably by the Upper Miocene-Lower Pliocene Eskipazar formation. According to this information, the Hamzaköy and Nallar thrust faults were active in the period of post-Middle Eocene and Early Pliocene.

Figure 28. General view of the Hamzaköy thrust fault (HTF). KTa. "Arkotdağ Formation", T_t. Taşlık Formation (Location: ~1,5 km SW of Hamzaköy village, view towards SE).

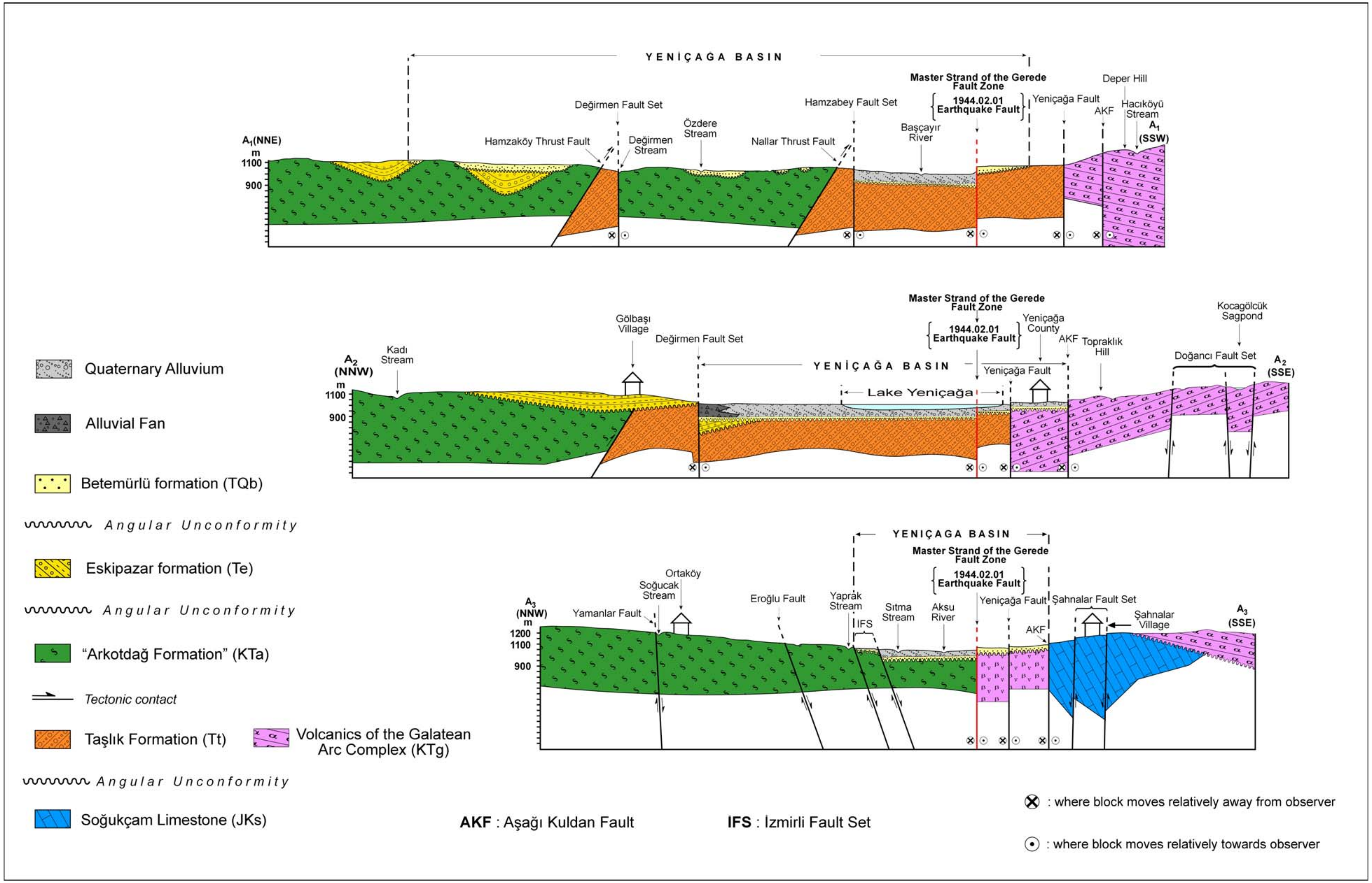

Figure 29. Geological cross-sections showing geological structures, rock units and their relationships to each other.

3.1.2. Syn-depositional Growth faults and Shear fractures: Tectonic regime coeval with sedimentation

Paleotectonic structures are hosted by the 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. The analysis of the geological structures will enlighten the tectonic history, namely the tectonic regime coeval with sedimentation.

Upper Miocene-Lower Pliocene Eskipazar formation was deposited in a lacustrine to fluvial depositional system under the control of an extensional tectonic regime recorded by a number of minor growth faults and shear fractures (Figure 30). These shear planes and growth faults display well-developed slickenlines at station 2 (S_2 on Plate1). Data was gathered from these syn-depositional minor structures for kinematic analysis and dip amounts, dip directions, rakes and slickenlines are documented during the field studies at station 2 (Table 1). These slip plane measurements of shear fractures indicated that the sense of motion was generally oblique to the strike of the fracture plane. Data gathered at field studies were kinematically analysed by using the computer software named as 'Tector' (Angelier, 1988). Kinematic analysis of slip planes yielded, approximately NW-SE directed paleotectonic extension with a nearly vertical maximum stress axis (σ_1) nearly (Figure 31). Nearly vertical orientation of maximum stress axis (σ_1) supports the idea of normal faulting and extensional paleotectonic regime dominating the study area and the surrounding region during the Late Miocene. This idea is also supported by the presence of growth faults (Figure 30) at the lower-middle parts of the Eskipazar formation. To sum up, results of the analysis indicate that during the deposition of this formation in Late Miocene, NW-SE directed extension was taking place within the study area and its vicinity.

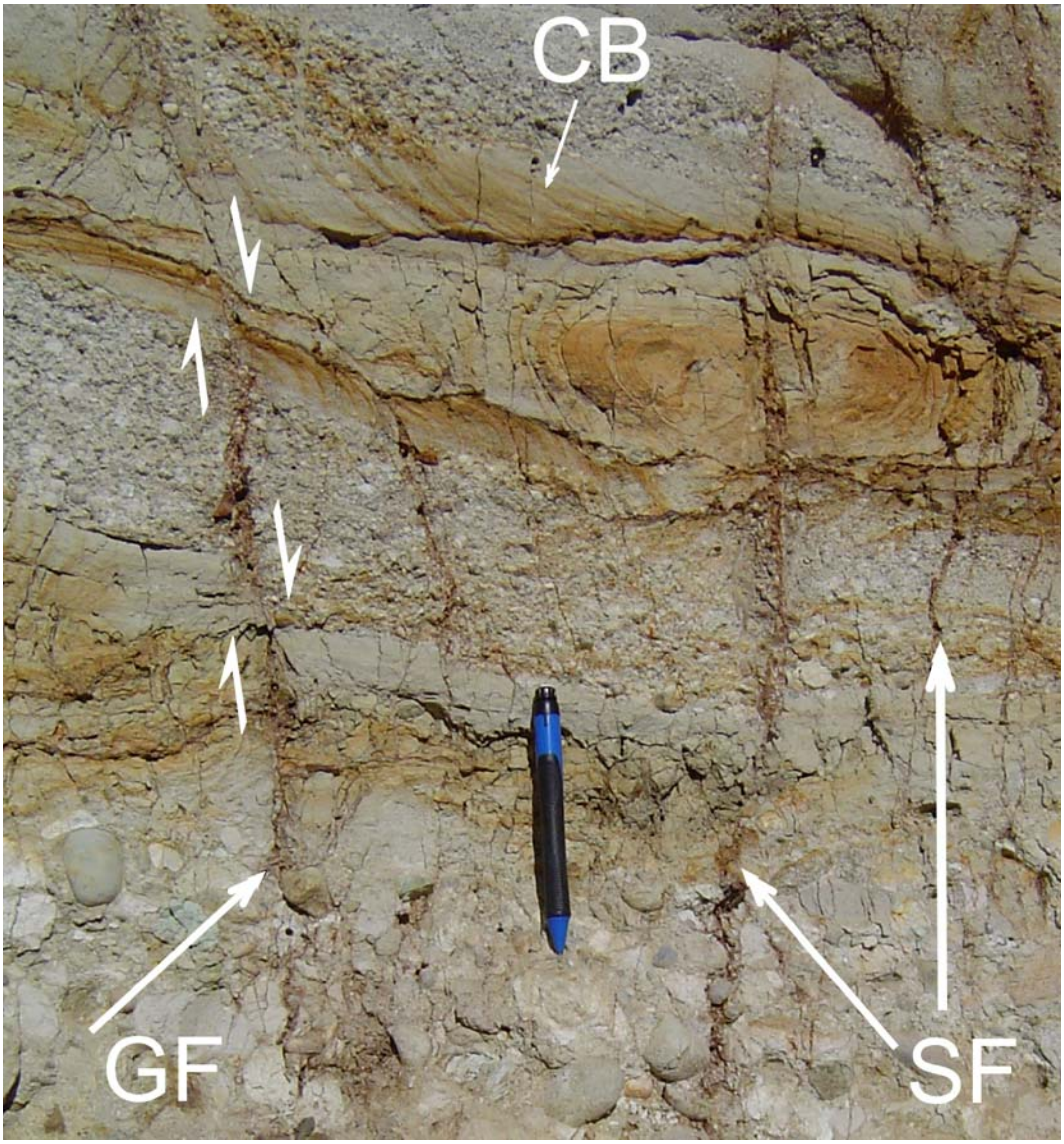

Figure 30.Close-up view of the syn-depositional structures in the middle portion of the latest paleotectonic unit, the Eskipazar formation. GF: Growth faults, CB: Coss-bedding pointing out a paleoflow direction from WNW to ESE, SF: Shear fractures (Location : ~ 250 m ESE of Hasanallar village)

Table 1. Growth faults and shear fractures data measured from the Eskipazar formation (see Plate 1 for location of station 2)

Station 2	Shear Fracture (Strike and Dip)	Rake
1	N13° W, 60° W	50° N
2	N16° W, 48° SW	49° N
3	N40° E, 57° NW	70° S
4	N60° E, 48° NW	55°W
5	N48° E, 42° NW	70°S
6	N08° W, 39° SW	73° S
7	N10° E, 70° SE	45° S
8	N38° E, 70° SE	65° S
9	N13° E, 50° NW	58° N
10	N10° W, 55° SW	45° N
11	N03° W, 45° NW	63° S
12	N70° E, 45° NW	60° W
13	N60° E, 45° NW	77° SW
14	N85° W, 55° N	56° W
15	N38° E, 63° SE	58° W
16	N55° E, 60° NW	65° W
17	N28° E, 55° NW	75° S
18	N58° E, 53° NW	82° N
19	N45° E, 45° NW	70° S
20	N38° W, 55° SW	48° NW
21	N82° E, 55° NW	54° W

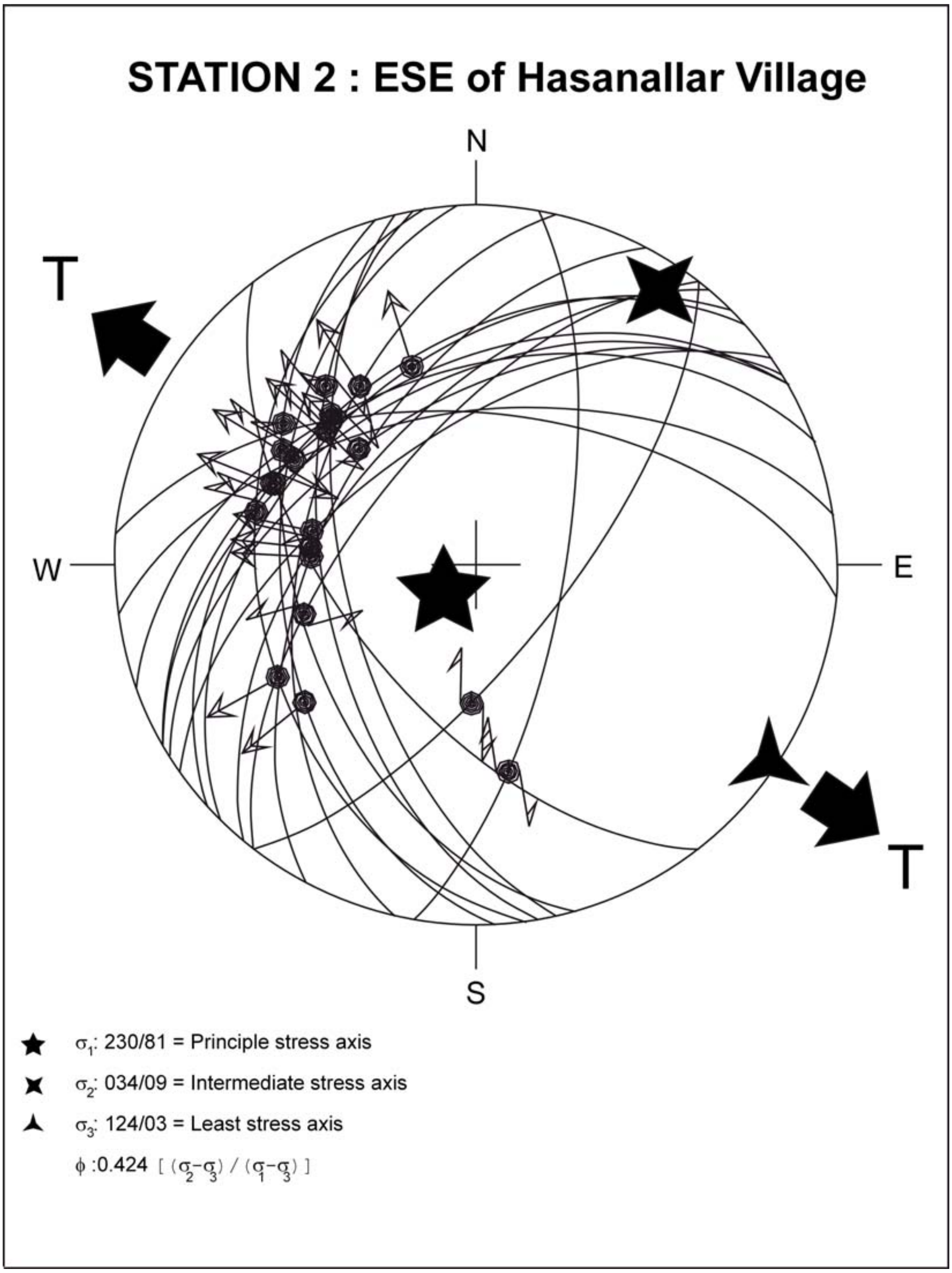

Figure 31. Kinematic analysis within the Eskipazar formation at Station 2 (see Plate 1 for location) (Location: ~ 500 m ESE of Hasanallar Village). The diagram shows the streographic plots of syn-depositional growth faults and the shear planes with orientations of slip lines. The orientation of these structures strongly reveal an extensional tectonic regime dominated by normal faulting and related fractures during the sedimentation of the Upper Miocene-Lower Pliocene Eskipazar formation. T: extension direction.

3.1.3. Structures Deforming Latest Paleotectonic Unit

Paleotectonic structures are hosted by the Upper Miocene-Lower Pliocene Eskipazar formation. 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.

3.1.3.1. Tilted Beds

The outcrops of the Eskipazar formation exposed at road cuts and quarry benches within the study area projecting the well-developed beds and bedding planes with thicknesses ranging from few tens of centimeters to tens of meters. The attitudes of these bedding planes, located in the northern part of the study area (Plate 1) are documented and mapped at 1/25.000 scale by measuring their dip directions and dip amounts.

Observations related to these measurements within the study area showed that dip amounts of these beds vary from 25^0 up to 45^0, in average dip amounts are within the range of 31^0-43^0 (Figure 32, Dip amount histogram). In the study area, the "Arkotdağ Formation" is thrust over the Lower-Middle Eocene Taşlık Formation along the Hamzaköy thrust fault. When considered spatially, it is observed that dip amounts of the beds are relatively higher, closer to the thrusting in the NW corner of the Yeniçağa Basin (Plate 1). As a result, it can be interpreted that the amount of paleotectonic deformation of this unit is relatively higher in this part of the study area due to the intense deformation by thrusting. As far as dip directions are concerned, they vary greatly within the range of 190^0-270^0 in azimuth, (Figure 33, dip direction histogram), and this again implies the intensity of paleotectonic deformation of the Eskipazar formation.

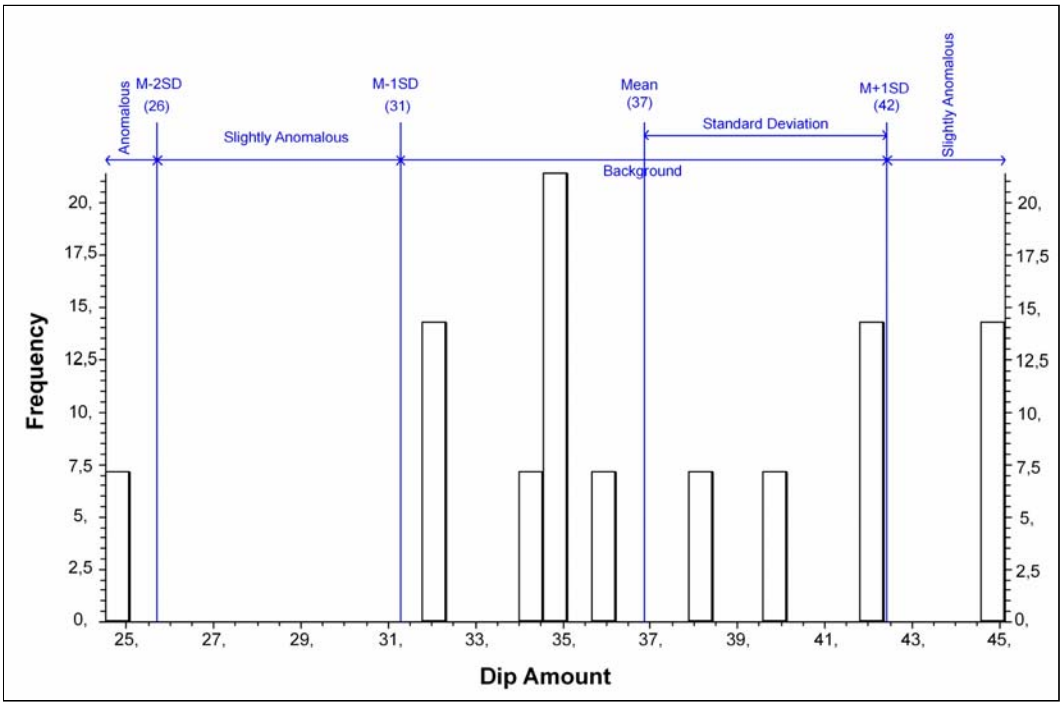

Figure 32. Histogram showing predominant dip amounts of bedding planes belonging to Eskipazar formation.

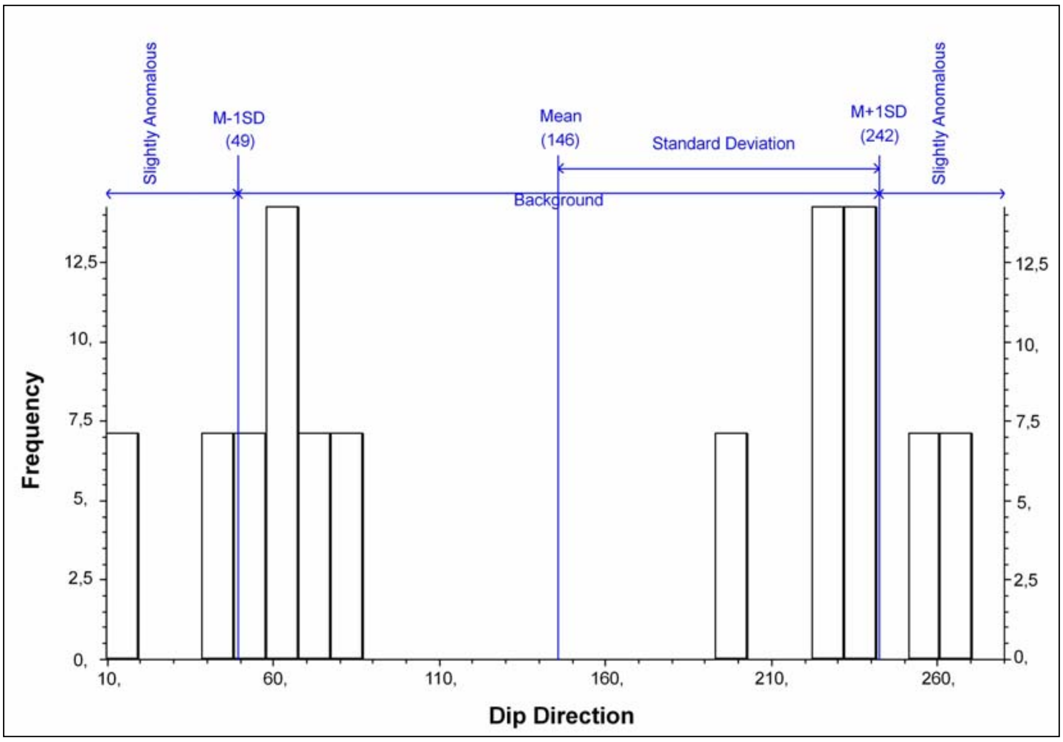

Figure 33. Histogram showing predominant dip directions of bedding planes belonging to the Eskipazar formation.

3.1.3.2. Folds

According to field geological mapping and strike-dip measurements taken at 1/25.000 scale, the bedding planes revealed several synclines and anticlines with different tightness at different localities of the Eskipazar formation within the study area. The fold axes of these folds are plotted on geological map of the study area (Plate 1) by the help of the strike and dip measurements.

The folds hosted by the Eskipazar formation differ in tightness from place to place within the study area. In the northern part of the study area (southwestern part of the Körükyanı Hill, Plate 1) these folds occur as tight folds with interlimb angles (Ramsay 1967) ranging from 55° to 89° (section A_1-A_1 in Figure 29). On the other hand, in northern part of the study area, near Aliağa village, Eskipazar formation constitutes open fold with interlimb angle around 130° (Figure 34, cross-section A_2-A_2 in Figure 29). This analysis of tightness of folds may imply to that the paleotectonic deformation of the Eskipazar formation was relatively more intense compared with the other parts of the formation constituting an open fold.

The axes of the anticline and syncline display a parallel-subparallel pattern with a NW-SE- to NNW-SSE- direction. The folds become tightly packed resulting in closely spaced fold axes in the southwestern and northwestern parts of the Eskipazar formation and this is well observed in geological map of the study area (cross-section A_1-A_1 in Figure 29). The length of the fold axes range from few hundreds of meters to kilometres.

Based on the NW-SE to NNW-SSE trends of the fold axes, it can be interpreted that these folds are formed by nearly NE-SW directed (Figure 34) compressional stress, which is nearly perpendicular to the trend of the fold axes. In addition to this, stereographic pole plots of 14 bedding planes from the Upper Miocene-Lower Pliocene Eskipazar formation confirmed the above mentioned paleotectonic compressional stress direction (Figure 35).

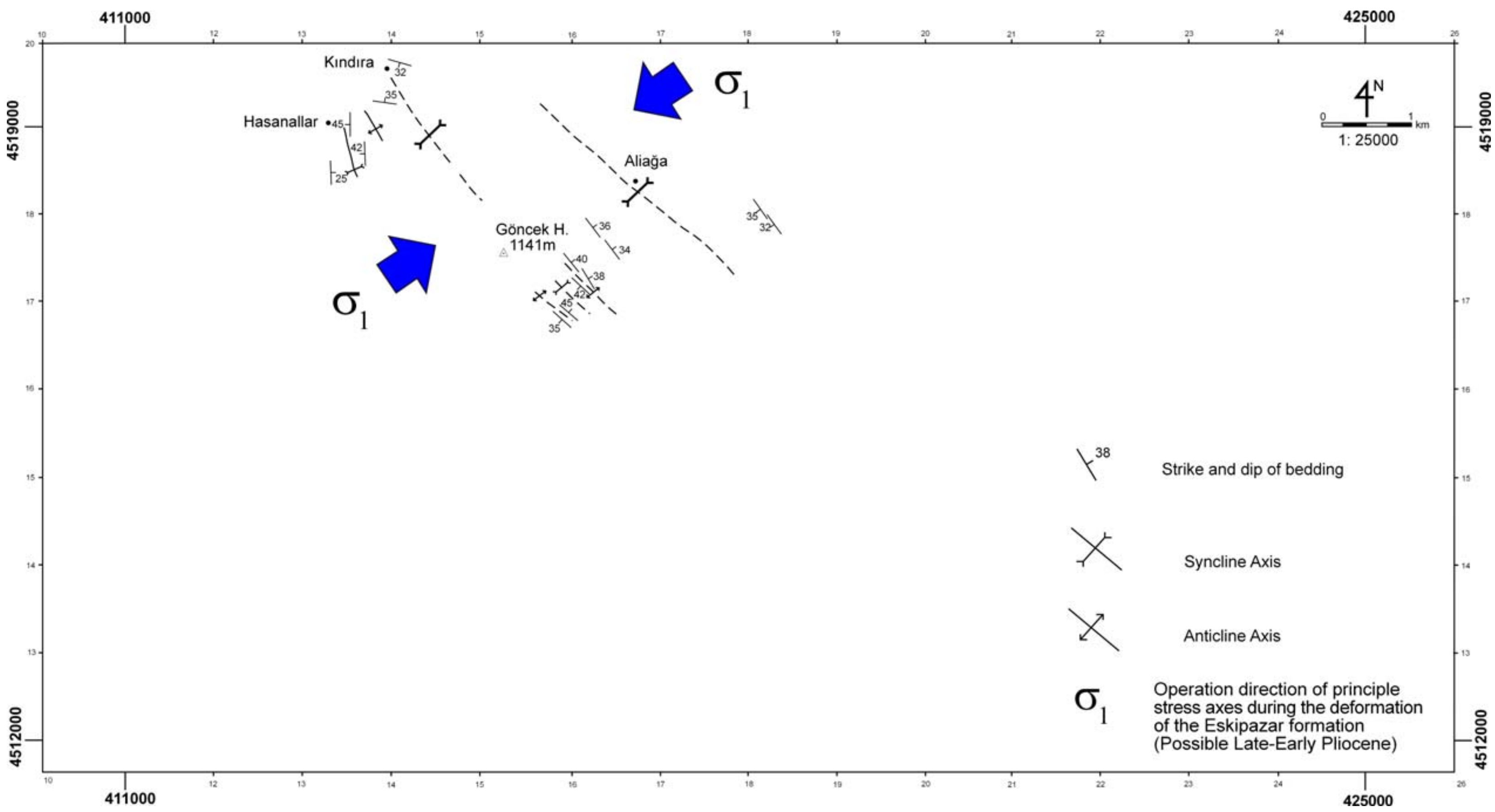

Figure 34. Fold map of the study area showing orientations and positions of major fold axes and the strike-dip of bedding planes of the latest paleotectonic unit, the Eskipazar formation.

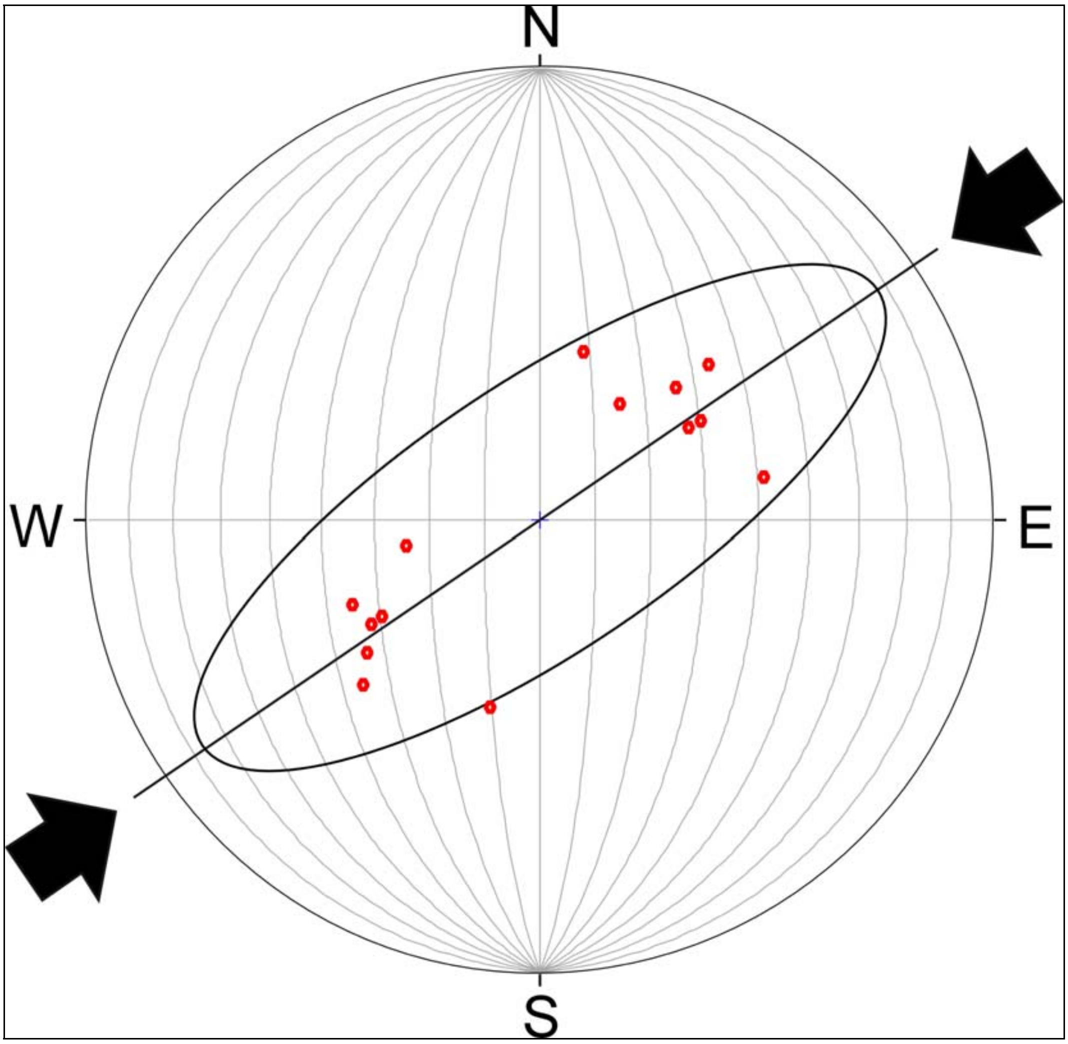

Figure 35. Stereographic pole plots to bedding planes of the Eskipazar formation (Black arrows indicate the average operation direction of the compressive stress during the deformation by folding).

3.2. Neotectonic Structures

In this section, the neotectonic structures that are exposed within the study area will be discussed. Meanwhile, the term “Neotectonic” is considered as a period of time elapsed since the last major wholesale tectonic reorganization in a region of interest (Şengör, 1980). According to this definition, the structures developed under the present day strike-slip tectonic regime in the study area are defined as the Neotectonic structures which constitute beds, unconformities and faults. The analysis of these structures will enlighten the characteristics of the present-day deformation taking place within the study area and will aid the interpretation of the final stage evolution of the Yeniçağa Basin.

3.2.1. Beds

Undeformed younger infill consists of the Plio-Quaternary Betemürlü formation and Holocene sediments. The Betemürlü formation is characterized by well-bedded terrace conglomerates alternating with medium to thick-bedded, highly porous travertines. Original dip of the beds are nearly horizontal within the major parts of the study area, but it reaches up to 36° in places, in and nearby the elongated hill bounded by the Gerede Fault in the north, and Yeniçağa Fault in the south.

Bedding with thickness ranging from 0.5 m to 5 m is well observed along the pressure ridge near the Betemürlü Hill and the Pantların Hill (Plate 1) (Figure 26). In contrast, the Quaternary deposits are represented by unconsolidated alluvium containing silt, clay, peat, mud and sand.

3.2.2. Unconformities

The Neotectonic units overlie the deformed paleotectonic basement rocks including also the Upper Miocene-Lower Pliocene Eskipazar formation with anguar unconformity. In addition, in certain parts of the study area, the angular differences between nearly flat-lying unconformity surfaces and the underlying Eskipazar formation range from 15° to 30° (Figure 29). The age of angular the unconformity between the Eskipazar formation and overlying Betemürlü formation is Late-Early Pliocene.

On the other hand, in several parts of the study area, the “Arkotdağ Formation” is unconformably overlain by the terrace conglomerates of the Plio-Quaternary Betemürlü formation (Figure 29).

In addition, an erosional surface, which is a short-term time gap in the nature of disconformity occurs between the Betemürlü formation and the Upper Quaternary alluvial fill. It is important to note that these units are nearly horizontal and undeformed. The age of this disconformity is probably Late Pleistocene.

3.2.3 Faults

Based on trends, faults observed and mapped within the study area are classified into four categories : (1) ENE-WSW-trending faults , (2) NE-SW-trending faults, (3) NW-SE-trending faults, and (4) E-W- trending faults. They occur as nearly vertical strike-slip faults and high-angle (> 75^0) oblique-slip normal faults. The southern margin, northeastern and northwestern ends of the Yeniçağa Basin are controlled by the active strike-slip faults. The southern margin of the Yeniçağa Basin is bounded by the WSW-ENE- trending Aşağı Kuldan fault (~16 km) belonging to the Gerede Fault Zone.

Another fault belonging to this fault zone is generally WSW-ENE- trending Gerede Fault Zone Master Strand (GFZMS) (Gerede Fault) (~17 km) and it partly controls the southwestern and eastern margins of the Yeniçağa Basin, and E-W- to WSW-ENE-trending Yeniçağa Fault (~14 km). Beyond these faults, the nearly SW-NE-trending Şahnalar fault set (~5,5 km), the WNW-ESE-trending Doğancı fault set (~2 km) and the nearly SW-NE-trending Yukarı Kuldan fault set (~ 3 km), comprise the Gerede Fault Zone, and play an important role in the morphologic evolution of the southern parts of the Yeniçağa Basin. In the northern parts of the basin, the SW-NE-trending Hamzabey fault set (~ 4 km) and the nearly E-W-trending Değirmen fault set (~ 5 km) control the nothwestern margin of the Yeniçağa Basin. On the other hand, the northern and the northeastern margins of the basin is bounded by the nearly N-S-trending Çağa fault (~ 2 km), the NW-SE trending İzmirli fault set, and the nearly NE-SW trending Sarayçalı fault (~2 km). In addition to this, the morphology of the northeastern part of the Yeniçağa Basin is controlled by the E-W- to NW-SE- trending Eroğlu fault (~ 4,5 km) and the E-W- trending Yamanlar fault (~ 3 km) (Figure 36).

Within the study area, the existence and activeness of the faults are indicated by sudden break in slope, well-preserved fault-scarps with or without slickensides, downcutting of streams, widespread development of marginal alluvial fans, and terraced Plio-Quaternary conglomerates of the Betemürlü formation.

The basin margins and the morphology of the basin are controlled by the active strike-slip faults and oblique-slip normal faults with minor amount of dextral or sinistral strike-slip components (Figures 37, 38). Within the study area, several strike-slip related features are present, such as the pressure ridges and sagponds nearly parallel to the general trend of the basin.

Major faults taking part in the neotectonic evolution of the Yeniçağa Basin will be explained in more detail in the following sections.

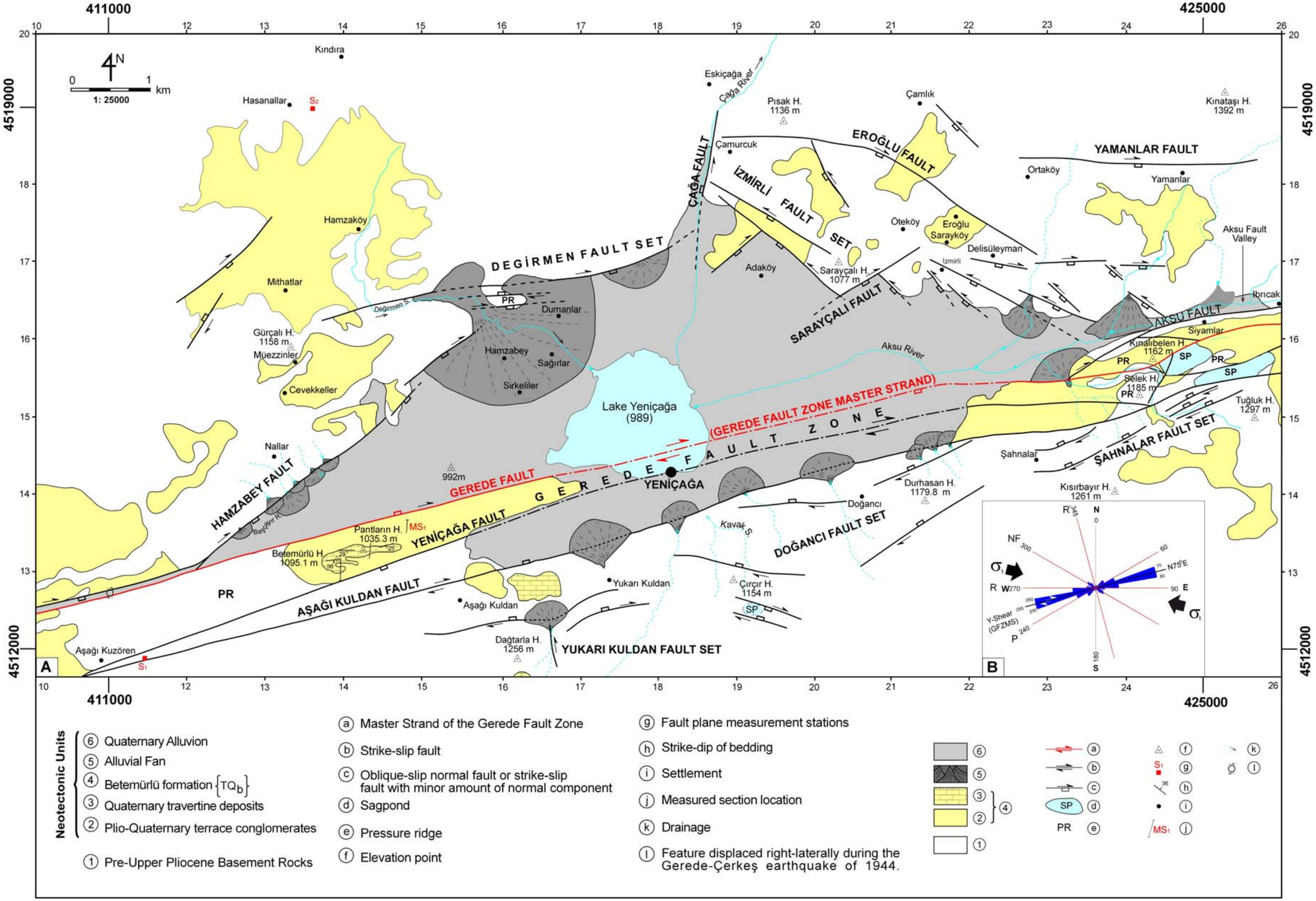

Figure 36. A. Neotectonic map of the Yeniçağa Basin**. B**. Rose Diagram of the right-lateral strike-slip faulting pattern in the Yeniçağa Basin. Y : Y shear or North Anatolian Fault Master Strand (NAFMS); R: Synthetic Riedel shear; R': Antithetic Riedel shear; P: P shear; NF: Oblique-slip normal fault, and σ_1: orientation of the local principle stress axis.

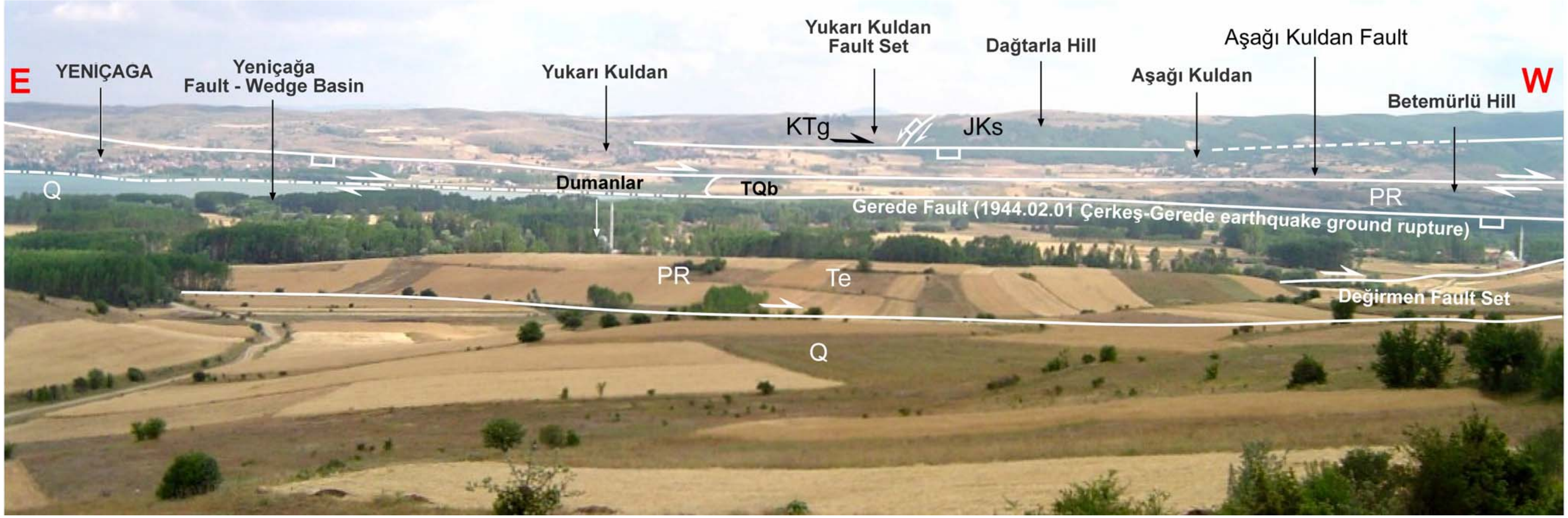

Figure 37. General view of the northern and southern margin – bounding faults of the Yeniçağa fault-wedge basin. JKs: Upper Jurassic-Lower Cretaceous Soğukçam Limestone, KTg: Upper Cretacous – Upper Miocene Galatean Arc Complex, Te: Upper Miocene-Lower Pliocene fluvio-lacustrine deposits (Eskipazar formation), TQb: Plio-Quaternary terrace conglomerates (Betemürlü formation), Q: Quaternary Alluvial sediments, PR: Pressure Ridge. (Location ~ 500 m ESE of Akbayır Hill, view to S)

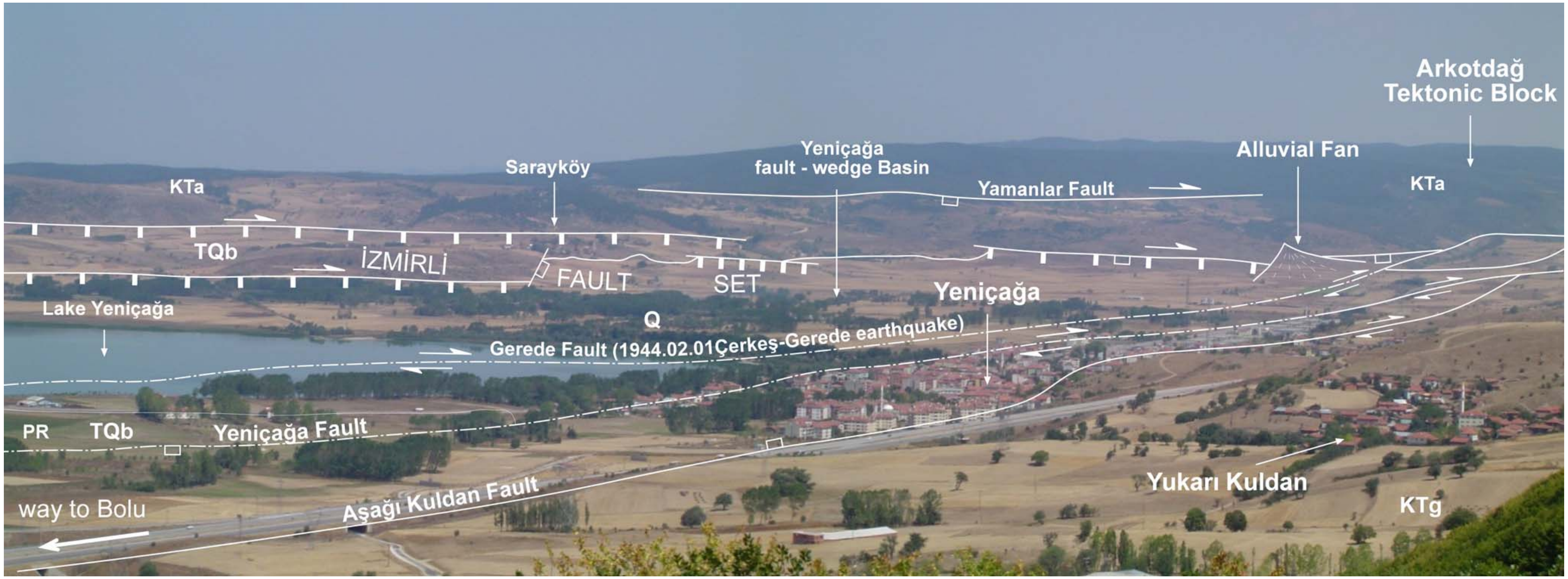

Figure 38. General view of the eastern half of the Yeniçağa fault-wedge basin and its margin – bounding faults. KTa: Upper Cretaceous ophiolitic mélange (the "Arkotdağ Formation"), KTg: Upper Cretaceous – Upper Miocene Galatean Arc Complex, TQb: Plio-Quaternary Betemürlü formation, Q: Quaternary Alluvial sediments, PR: Pressure Ridge (Location: Dağtarla Hill, view from SSW to NNE)

3.2.3.1. Gerede Fault Zone (GFZ)

The Gerede Fault Zone is first named by Koçyiğit (2003b). It consists of the NE-SW- to ENE-WSW- trending dextral strike-slip faults (Figure 36). The width of the fault zone ranges between 1 to 3 km throughout its course. It is characterized by the several pressure ridges and sagponds (Figure 39). The faults of the Gerede Fault Zone pass through several villages, such as Şahnalar, Doğancı and Yukarı Kuldan. One of the major faults which passes through the Yeniçağa County is the Yeniçağa Fault (Plate 1) (Figures 36, 38). The faults comprising the Gerede Fault Zone are the Aksu Fault, the Gerede Fault (Master Strand), the Yeniçağa Fault, the Aşağı Kuldan Fault, the Şahnalar Fault Set, the Doğancı Fault Set and the Yukarı Kuldan Fault Set (Plate 1). These faults will be described in detail in the following sections.

3.2.3.1.1. Aksu Fault

The Aksu fault is first named in this study. It is located at the eastern most of the Yeniçağa Basin (Figures 36, 39). The Aksu Fault comprises a dextral strike-slip fault with minor amount of normal component, displaying a nearly WSW-ENE- to SW-NE-trending curvilinear pattern. The fault runs near Siyamlar and Ibrıcak villages and then it joins with the Gerede Fault Zone Master Strand at the eastern tip of the Yeniçağa Basin.

Through its course, it bounds the pressure ridge situated 500 m WSW of Kınalıbelen hill from the north (Figure 39). This pressure ridge is bounded by another subsidary splay fault passing through 250 m NE of Kınalıbelen Hill at east. This subsidary fault splays off from the Gerede Fault Zone Master Strand (GFZMS) in the south and joins with the Aksu Fault in the northwest (Plate 1).

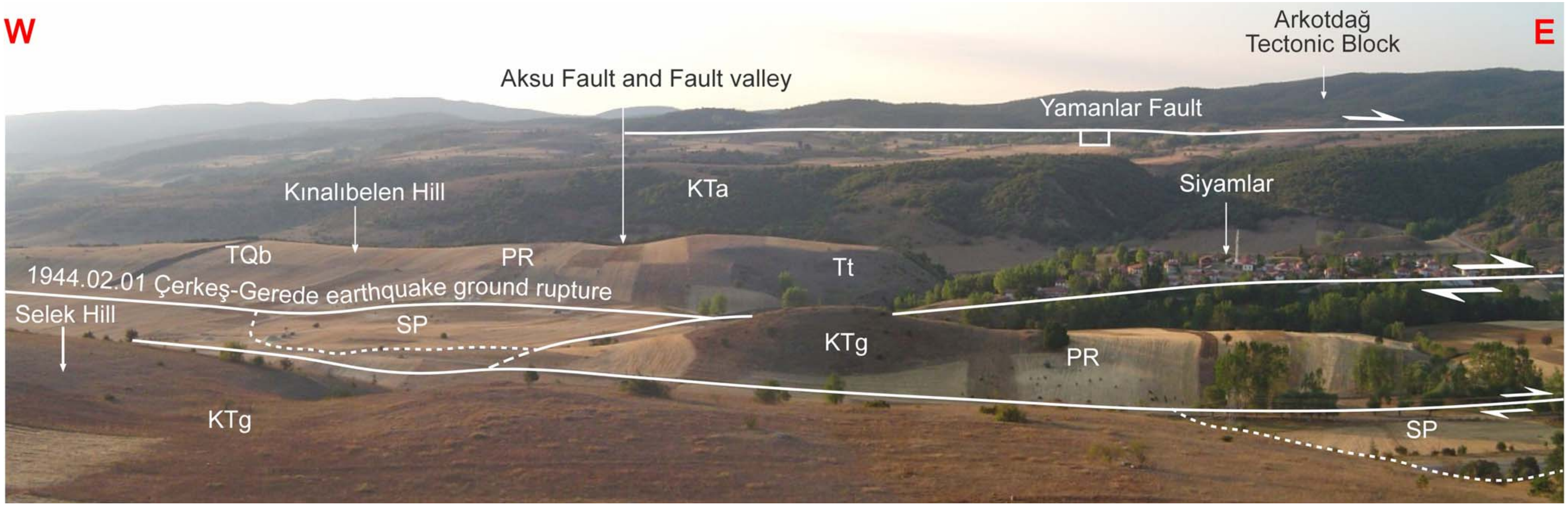

Figure 39. General view of the Siyamlar section of the Gerede Fault Zone and the Master Fault indicated by the 1944.02.01 Çerkeş-Gerede earthquake ground rupture. KTa: Upper Cretaceous ophiolitic mélange (the "Arkotdağ Formation"), KTg: Upper Cretaceous – Upper Miocene Galatean Arc Complex, Tt: Lower-Middle Eocene Taşlık Formation, TQb: Plio-Quaternary Betemürlü formation, PR: Pressure Ridge, SP. Sag Pond (Location ~ 500 m S of Siyamlar Village, view from S to N)

The length of the Aksu fault within the study area is 3 km, and it juxtaposes the Taşlık Formation with the “Arkotdağ Formation” in the east, but in further west it juxtaposes again the Taşlık Formation with Quaternary fill of the Yeniçağa basin (Figure 36) (Plate 1).

The Aksu fault displays poorly developed fault scarps where it cuts through the Taşlık Formation and morphologically it is followed through by the deeply carved valley of the Aksu River within and outside of the study area. The development of this deeply carved valley is due to the presence of the weakness zone which is created by the Aksu fault.

In the study area, the existence and the activeness of the Aksu Fault are indicated by sudden break in slope, fault scarp exposed at northern part of outcrop of the Taşlık Formation, tectonic juxtaposition of units of dissimilar age, origin, lithofacies and internal structure, the downcutting of the Aksu River (a fault valley) and development of quite large alluvial fans at its western part.

3.2.3.1.2. Gerede Fault (Master Strand of the Gerede Fault Zone)

This fault is first defined by Tokay (1973) as the “Gerede I” fault. In this study it is referred to as the Gerede Fault (Master Strand). It partly controls the eastern margin of the Yeniçağa Basin (Figure 36). It comprises a curvilinear to linear dextral strike-slip fault, displaying generally ENE-WSW trend. Starting from the eastern part of the study area, the fault runs in nearly E-W- direction and curves to southwest, and at 250 m south of Kınalıbelen Hill, it makes a restraining bending and curves towards west. From this point, it runs nearly in E-W- trend for about 3 km and at 1 km west of the restraining bend, it is joined by the Aksu Fault. In the further west, the fault continues in an ENE-WSW trend and approximately 1,7 km NE of Aşağıkuzören village, it is joined by the Hamzabey Fault Set (Figure 36).

Throughout its course, the fault bounds several pressure ridges and sagponds. In near south of Kınalıbelen Hill it separates two adjacent pressure ridges (Figure 39). They are the Selek Hill in the south and the Kınalıbelen Hill in the north. There is a sagpond between these two pressure ridges. The sagpond here is bounded in its NW part by the Gerede Fault Zone Master Strand. In the western part of the study area, this fault bounds another pressure ridge located between Aşağıkuzören and Lake Yeniçağa (Figures 36, 40). The part of Gerede Fault that is exposed within the study area has a length of nearly 17 km. In the west, it juxtaposes the Plio-Quaternary Betemürlü formation and the Lower-Middle Eocene Taşlık Formation with the Quaternary fill of the Yeniçağa Basin (Plate 1).

The Gerede Fault is a dextral strike-slip fault, it does not display any distinct fault scarp and consequently no slickensides could be observed on this fault. However, the Gerede Fault is the most active strand of the Gerede Fault Zone, and it is the source of the ground rupturing earthquake, such as the 1944.02.01 Çerkeş-Gerede Earthquake. One of the maximum offset of 7.28 m was measured along the line of older salix trees displaced by the 1944.02.01 Çerkeş-Gerede earthquake (Figure 41).

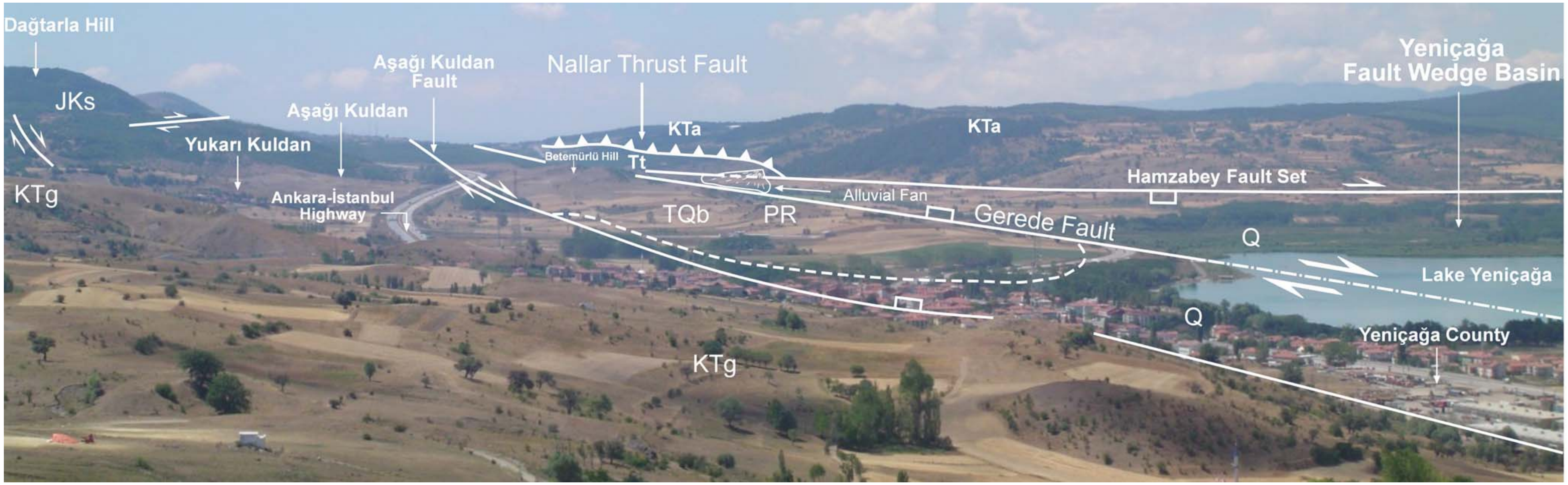

Figure 40. General view of the western half of the Yeniçağa fault-wedge basin and its margin – bounding faults. JKs: Upper Jurassic-Lower Cretaceous Soğukçam Limestone, KTa: Upper Cretaceous ophiolitic mélange (the "Arkotdağ Formation"), KTg: Upper Cretaceous – Upper Miocene Galatean Arc Complex, Tt: Lower-Middle Eocene Taşlık Formation, TQb: Plio-Quaternary Betemürlü formation, Q: Quaternary Alluvial sediments, PR: Pressure Ridge (Location ~ 2 km E of Yukari Kuldan Village, view from SE to NW)

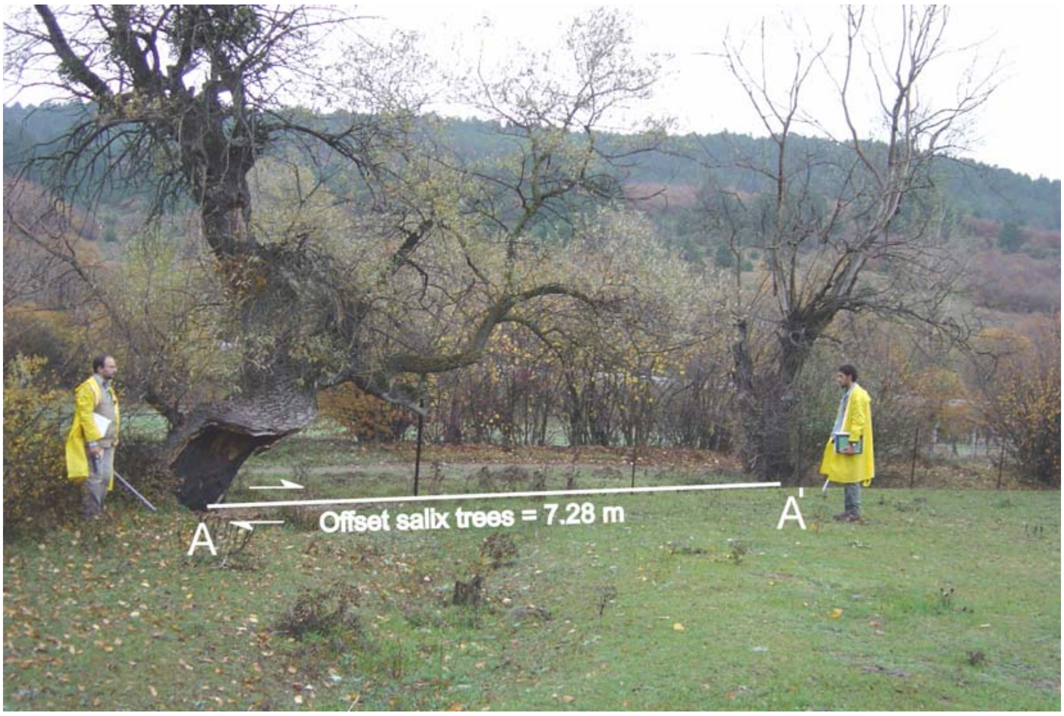

Figure 41. Line of older salix trees displaced (A-A' = 7,28 m) in right-lateral direction by the Gerede Fault (Master fault) during the 1944.02.01 Gerede-Çerkeş earthquake (Location: west tip of the Yeniçağa Basin, see Figure 36 for location, view to NNW).

3.2.3.1.3. Yeniçağa Fault

This fault is first named in this study. It partly defines the southern-southeastern margin of the Yeniçağa Basin and passes across the Yeniçağa County (Figures 36, 38). The fault comprises a dextral strike-slip fault, displaying a general trend of ENE-WSW with a linear to curvilinear pattern. The fault bifurcates from the Aşağı Kuldan fault at about 150 m SSE of the Selek hill and runs in E-W trend for about 2,5 km and then curves towards WSW and continues in this trend until it reaches the southern part of the study area (Figure 36). The fault partly runs through the Yeniçağa county and Aşağı Kuzören villages. Through its course it bounds the pressure ridges such as the Selek Hill in the east and the Betemürlü hill in the western part of the study area (Figures 36, 39)

The part of the Yeniçağa fault exposed within the study area has a length of approximately 14 km, and it mainly juxtaposes the Betemürlü formation and the Taşlık Formation with the volcanics of the Galatean Arc Complex (Plate 1)

Based on the morphological markers, the Yeniçağa fault is a dextral strike-slip fault, but it displays no distinct fault scarps, and no slickensides on this fault could be observed.

The existence and the activeness of the Yeniçağa Fault are indicated by the tectonic juxtaposition of different units, and some morphological indications such as the pressure ridges along its trace.

3.2.3.1.4. Aşağı Kuldan Fault

This fault is first named in this study. It determines the southern margin of the Yeniçağa Basin (Figures 36, 37) and comprises dextral strike-slip fault with minor amount of normal component. The downthrown block of the fault lies in the north, and the upthrown block lies in the south (Figure 29). In the eastern part of the basin, it runs to west nearly in an E-W trend and then curves slightly to SW, approximately 750 m east of Selek hill, and continues in this trend for about 1 km. In the further west, it re-bends to E-W direction and runs in this direction for about 2 km. Approximately 1 km NE of Durhasan Hill, it starts to curve slightly to WSW direction and continues in this direction until it reaches the western end of the study area. This fault possibly joins with the Yeniçağa fault in the further southwest nearby the Aşağı Kuzören village (Figure 36)

Through its course, it bounds the southern margin of a sagpond that is located approximately 750 m north of Tuğluk hill. In the further west, it is characterized by diverse-sized alluvial fans with apices adjacent to the fault itself.

The total length of the Aşağı Kuldan Fault is approximately 16 km. This fault juxtaposes the Soğukçam limestones, the Betemürlü formation, the Quaternary infill of the Yeniçağa Basin and the agglomerates of the Galatean Arc Complex to each other (Plate 1). In other parts of the study area, it juxtaposes volcanics of the Galatean Arc Complex with the Quaternary sediments along its course (Plate 1).

The Aşağı Kuldan Fault dislays partly well-developed fault scarps, where it cuts through the Soğukçam Limestone and partly the volcanics of the Galatean Arc Complex (Plate 1).

The existence and the activeness of this fault are indicated by sudden break in slope, fault scarps, tectonic juxtapostion of different units, presence of straigthly alligned alluvial fans with apices adjacent to a fault, and the presence of sagpond along its trace (Plate 1, Figures 36, 38)

3.2.3.1.5. Şahnalar Fault Set

Şahnalar fault set is first named in this study. It controls the morphology of the eastern margin of the study area and comprises a parallel to sub-parallel, closely-spaced basinward facing, linear to curvilinear dextral strike-slip faults with minor amount of dip-slip component. The fault set starts at approximately 500 m NNW of Tuğluk Hill in the form of three NE-SW-trending closely spaced sub-parallel strands and then continues to west in the form of single to two discontinues strands. At approximately 250 m north and south of Şahnalar village, the faults of this set curves towards E-W direction resulting in a restraining bend where spacing of the faults increases and fault set comes to end.

In the eastern part, the Şahnalar fault set creates a well-developed step-like morphology (cross-section A_3-A_3 in Figure 29). In the further west, as the faults of this set become more widely spaced, the steps get wider.

At the western end of the Şahnalar fault set, the right-lateral offset of faults are indicated by the outcrops of the Soğukçam Limestone with the Galatean Arc Complex. The westward bending of the faults may be due to the rheological control here, where the two faults of this fault set enter the Soğukçam Limestone. Besides this, the termination of the fault set at this locality may be due to the same rheological control here working together with the restraining bending at this locality (Plate 1).

The Şahnalar fault set has a width ranging from approximately 250 m to 400 m from east to west, meaning that the fault set widens in westward direction. The longest fault of this fault set measures approximately 1 km (Figure 36). The fault set mainly juxtaposes the Soğukçam Limestone with volcanic of the Galatean Arc Complex in its western parts (Plate 1)

The Şahnalar fault set displays well-developed fault scarps at localities where it creates a step-like morphology. Unfortunately, these fault scarps do not display any slickensides indicating characteristics of the faults. The scarps of the faults and offset of lithological boundaries along these faults indicate that the fault set is made up of dextral strike-slip faults with minor amount of dip-slip component.

3.2.3.1.6. Doğancı Fault Set

Doğancı Fault Set is first named in this study. It controls the morphology of the southern margin of the Yeniçağa basin and comprises a set of parallel to sub-parallel, linear to curvilinear, generally basinward-facing, widely spaced dextral strike-slip faults with minor amount of dip-slip components. The fault set starts at approximately 1 km NE and ENE of Durhasan hill in the form of two parallel strands, and then continues to the west in an NE-SW-trend. In the west of the Doğancı village, the faults of Doğancı fault set changes their trend into nearly E-W to WNW-ESE.

The northern fault at this locality has a nearly E-W trend and the southern three faults have WNW-ESE trend. This fault set extends up to about 1 km WNW of Çırçır hill and comes to an end at this locality (Figure 36).

All along its trace, Doğancı fault set creates a step-like morphology. In the SE of Çırçır hill, one of the faults of this fault set faces towards south and another one that is closely spaced with the first one faces towards the basin (cross-ection A_2-A_2 in Figure 29). In between these adjacent faults which are facing towards each other, there is a sagpond which is bounded and created by these faults. The presence of this sagpond indicates that by the activity of these two faults, there developed an extension at this locality and created a depression. This lead to the development of the sagpond (Plate 1). At approximately 250 m NNE of Çırçır hill, the Kavak stream seems to be offset right laterally by about 50 m by one of the faults of the Doğancı fault set (Plate 1). Nevertheless, such an offset is not observable another streams. Indeed, this offset, sudden change in course of Kavak stream may be due to the weakness zone created by the fault, so for some distance of 50 m the stream flowed within this weakness zone and after that it turn back to its original course.

The Doğancı fault set has a width ranging from approximately 700 m to 1,5 km from east to west. Like Şahnalar fault set, it also widens towards westward direction. The longest fault of this fault set measures approximately 2 km in length (Figure 36). No juxtaposition of different lithologies along this fault set could be observed during the field observations and it is evident that this fault set cuts through only the volcanics of the Galatean Arc Complex (Plate 1, cross-section A_2-A_2 in Figure 29).

The Doğancı fault set displays well-developed fault scarps all through its extend but no slickensides could be observed on these fault scarps. Nevertheless, morphological expression of the faults making up the fault set indicates that this fault set is composed of dextral strike-slip faults with minor amount of dip-slip components.

In the study area, the existence and the activeness of the Doğancı fault set is indicated by the presence of step-like morphology, and the sudden break in topographical slope, and presence of sagpond along its extend.

3.2.3.1.7. Yukarı Kuldan Fault Set

Yukarı Kuldan fault set is first named in this study. It controls the morphology of the southern to southwestern margin of the Yeniçağa Basin and comprises parallel to nearly orthogonal, curvilinear dextral strike-slip faults with minor amount of dip-slip components. The fault set is composed of mainly three faults namely northern, the southern fault and the orthogonal western segments. In general, the fault set has a NE-SW trend, but as its trace is highly curvilinear, the trend of the faults of this set changes from place to place. The fault set starts at approximately 250 m south of Yukarı Kuldan village and both of the northern and southern faults have nearly WSW-ENE trend at this locality. Further to the west, both faults curve towards SW direction and continues in the same manner for about 600 m. where, the southern strand terminates and the northern strand curves westward by 40^0 to gain a E-W trend. Then, towards westward, it gently bends towards WSW again creating a restraining bend, and 750 m south of Aşağı Kuldan village it rebends to westward direction. In the south, 500 m east of the Dağtarla hill, there is another fault which is relatively short and has a trend of nearly N-S direction; It displays a relatively linear pattern and possibly joins to the northern fault.

The Yukarı Kuldan fault set displays well-developed step-like morphology at its eastern parts and characterized by the offset of the boundary between Soğukçam Limestone – agglomerates of Galatean Arc Complex (Plate 1). The most evident offset is observed along the N-S-trending segment of this fault set (Figure 42). This boundary seems to be offset right laterally by about 400 m along the N-S-trending fault (Plate 1).

Also, the outcop of the Soğukçam Limestone located at near SW of Yukarı Kuldan village seems to be offset right-laterally; the small patch of outcrop was displaced eastward and separated from the main body of outcrop, that is situated in the southern part of the northern fault. It is also observed that within the Soğukçam Limestones, no morphological features are present which may be due to the rheological control of the Soğukçam Limestone. Thus the propagation of the southern fault is limited and terminated possibly by these intact limestones. Also, there is an alluvial fan with its apice adjacent to the northern fault of this fault set; the fan occurs in a perched pattern.

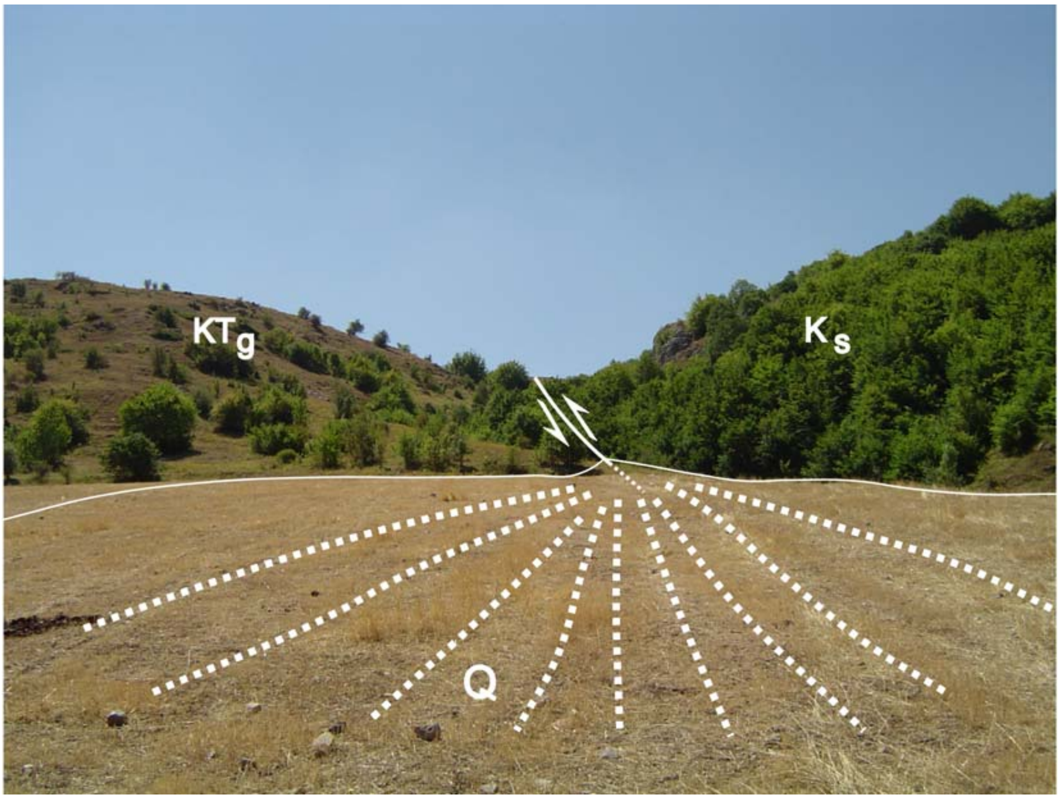

Figure 42. General view of the N-S trending fault juxtaposing the volcanics of the Galatean Arc Complex and the Soğukçam Limestone, an alluvial fan formed. Ks: The Soğukçam Limestone, KTg: Galatean Arc Complex, Q: Alluvial fan deposits (Location:~ 500 m SW of Yukarı Kuldan Village, view to S).

The Yukarı Kuldan fault set displays well-developed fault scarps indicated by the sudden break in slope along its trend.
However, no slickensides could be observed on these scarps. The morphological expression of the fault set indicates that the Yukarı Kuldan fault set is made up of dextral strike-slip faults with minor amount of dip-slip components.

In the study area, the existence and the activeness of Yukarı Kuldan fault set are indicated by a series of morphological markers such as sudden break in slope, presence of step-like morphology, juxtaposition of the Soğukçam Limestone and agglomerates of the Galatean Arc Complex, and presence of a perched alluvial fan with its apice adjacent to the northern fault of the fault set.

3.2.3.2. Hamzabey Fault Set

The Hamzabey fault set is first named in this study. It determines the western margin of the Yeniçağa Basin and comprises NE-SW-trending linear, closely-spaced basinward-facing dextral strike-slip faults with minor amount of dip-slip components. The fault set starts at its junction with the Gerede Fault (Master Strand), and continues towards northeast as a single fault in a straight pattern up to approximately 1,2 km ESE of Cevekkeller village, where it jumps to the west and continues for about 600 m in the same trend up to 500 m NW of Hamzabey village (Figure 36). In its southwestern parts, a series of alluvial fans with apices adjacent to the southern margins bounding Hamzabey fault set occur. This is an indication of sudden break in slope towards the basin located on the downthrown block of the fault. This fault cuts and displaces the Nallar thrust fault at approximately 1,2 km SE of Cevekkeller village (Plate 1 and Figure 40).

About 1,5 km east of Cevekkeller village, the fault makes a jump to the left where it creates a restrained area between overlapping faults of this set. This small area of overlap is characterized by a gentle and small hill made up of “Arkotdağ Formation”. This gentle, small hill is possibly formed by the up-heave of the surface by compressional forces acting on this small area due to the overlap of the bounding dextral strike-slip faults.

The Hamzabey fault set has a width of approximately 250 m and the longest fault of this fault set measures approximately 3 km. Along this fault, mainly the Taşlık Formation, the “Arkotdağ Formation” and the clastics of the Betermürlü formation are tectonically juxtaposed with the Quaternary infill of the basin (Plate 1 and cross-section A1-A1 in Figure 29).

The Hamzabey fault set displays well-developed scarps indicated by the sudden break in slope along its trend, but, no slickensides could be observed on these scarps. Indeed, the morphological expression of the faults and their geometrical relationship with the regional principle stresses indicate that Hamzabey fault set is dextral strike-slip faults with minor amount of normal components.

In the study area, the existence and the activeness of the Hamzabey fault set is indicated by sudden break in slope near by the fault scarps, tectonic juxtaposition of different unit and allignment and coallesence of alluvial fans with apices adjacent to the fault.

3.2.3.3. Değirmen fault set

The Değirmen fault set is first named in this study. It determines the northern margin of the Yeniçağa Basin (Plate 1) and controls the morphology of this part of the study area (Figure 43). It comprises ENE-WSW-trending parallel to sub-parallel, linear to curvilinear, generally basinward-facing dextral strike-slip faults with minor amount of dip-slip

components. The longest fault of the fault set starts at approximately 600 m NNE of Müezzinler village and continues in ENE trend.
The shorter faults of this fault set having WSW-ENE trend appear in the south of the longest fault and bound the pressure ridge located at 750 m NW of Dumanlar village (Figure 37). The Değirmen fault set terminates in approximately 1 km west of Gölbaşı village, near by the southern part of the Çağa Fault (Figure 36).

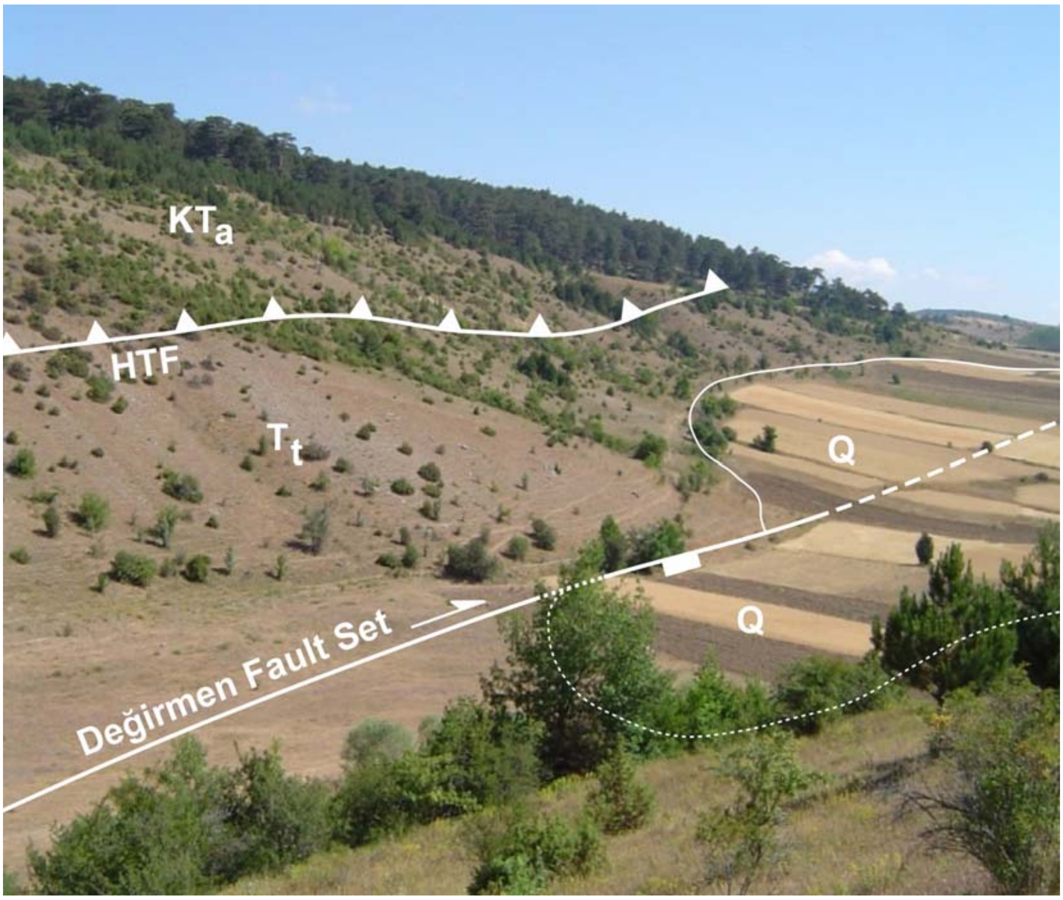

Figure 43. General view of the northern margin-bounding Değirmen fault set (DFS) and the Hamzaköy thrust fault (HTF). KTa: "Arkotdağ Formation", Tt: Taşlık Formation, Q: Quaternary deposits (Location: ~ 2 km N of Hamzaköy Village, view to NE)

The longer northern fault segment of the Hamzabey fault set cuts and displaces the Hamzaköy thrust fault. It indicates that the Hamzabey fault set fault is younger than the paleotectonic thrust fault (Plate 1).

In further east, a very large alluvial fan (~ 2,5 km^2), on which Dumanlar, Sağırlar, Hamzabey and Sirkeliler villages are situated, is bounded by the longest fault of this fault set at its northeastern area (Figure 36). In the northern part of this alluvial fan, between two faults of the fault set, that are dipping in opposite directions, a pressure ridge is present (Figure 37).
The dominant lithology of the this ridge is the red clastics of the Upper Miocene-Lower Pliocene Eskipazar formation, and the reason for this pressure ridge to be smooth and rounded may be the rheological property of this formation. In further east, near its eastern termination point, the Değirmen fault set comes closer to the Çağa fault and disappears under the Quaternary units. The longest fault of this fault set is followed through by the deeply carved Değirmen stream flowing in the valley carved within the zone of weakness created by the fault itself.

Değirmen fault set has a width of nearly 250 m and the longest fault of this fault set measures approximately 5 km (Figure 36). Through the western trace of this fault set, mainly Betemürlü formation and the Taşlık Formation are tectonically juxtaposed with the “Arkotdağ Formation”. In the further eastern parts, the Taşlık Formation and the Eskipazar formation together are tectonically juxtaposed with the Quaternary units and infill of the Yeniçağa Basin.

The Değirmen fault set’s longest strand displays well-developed fault scarps all through its extend but no slickensides could be observed on them. Indeed, the morphological and expression of this fault set indicate that the fault set comprises dextral-strike slip faults with minor amount of dip-slip components.

In the study area, the existence and the activeness of Değirmen fault set is indicated by the sudden break in slope in basinward direction, presence of deeply carved valley, juxtaposition of different units, presence of fault-parallel alligned large to extensive alluvial fans and the pressure ridge with long axis parallel to the margin-bounding faults.

3.2.3.4. Çağa Fault

Çağa fault is first named in this study. It controls the morphology of the northern margin of the Yeniçağa Basin (Figure 44) and comprises nearly NNE-SSW-trending linear to curvilinear, westward-facing, sinistral strike-slip fault with minor amount of dip-slip component. It plays an important role in the evolution of the Yeniçağa Basin.

It starts at approximately 400 m south of Eskiçağa village and runs towards the south and terminates or disappears under the Quaternary infill of the Yeniçağa Basin approximately 750 m west of Adaköy (Figure 36). The Çağa fault has an extraordinary trend relative to the other faults exposing throughout the study area, and it separates the NW margin of the basin from its NE margin. In addition to this, it is delineated by the straight and deeply carved valley of the Çağa River which is carved within the zone of weakness of this fault (Plate 1).

The length of this fault is approximately 2 km; it juxtaposes mainly the "Arkotdağ Formation" with the Quaternary infill of the Yeniçağa Basin.

The Çağa fault displays a well-developed fault scarps at localities where it cuts the "Arkotdağ Formation". But, no slickensides on this fault scarps could be observed. Indeed, the morphological expression of the fault indicates that it is sinistral strike-slip fault with minor amount of dip-slip component.

In the study area, the existence and the activeness of the Çağa fault is indicated by the deeply carved Çağa valley, tectonic juxtaposition of different units and the sudden break in slope.

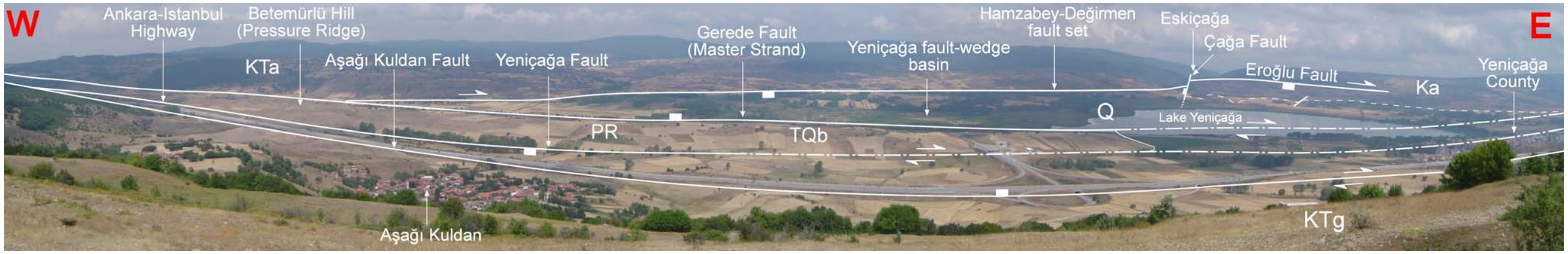

Figure 44. General view of the Yeniçağa fault – wedge basin and its margin – bounding faults. KTa: Upper Cretaceous ophiolitic mélange (the "Arkotdağ Formation"), KTg: Upper Cretaceous – Upper Miocene Galatean Arc Complex, TQb: Plio-Quaternary Betemürlü formation, and Q: Quaternary Alluvial sediments, PR: Pressure Ridge. (Location ~ 200 m SSE of Aşağı Kuldan Village, view from S to N).

3.2.3.5. İzmirli Fault Set

This fault zone is first named in this study. It determines the northeastern to eastern margin of the Yeniçağa Basin (Figure 36) and comprises linear basinward facing, closely-spaced parallel to sub-parallel, relatively short and discontinues oblique-slip normal faults with dextral to sinistral strike-slip component (Plate 1, Figure 36). It starts 500 m SW of Çamurcuk village, near by the upthrown block of Çağa fault and continues to the eastward in a nearly WNW-ESE trend until it reaches to the Aksu fault and, approximately 500 m west of Siyamlar village, it comes to an end. The faults comprising this fault zone generally trend in NW-SE direction in the southern parts of the fault zone; however in the northern parts of the fault zone, the trends of the discontinuous short fault become nearly E-W. The fault zone passes through İzmirli and Delisüleyman villages (Plate 1, Figure 36).

The İzmirli fault set displays a step-like morphology all along its extend as the faults comprising this set are oriented side by side nearly parallel to each other (Figure 38 and cross-section A_3-A_3 in Figure 29). The faults exposed in the west of the set are relatively long and form longer steps. On the other hand, the faults to the east of the fault set are relatively short and discontinuous. In the eastern parts, two different trends are observable. In the northern parts of the fault set, the trends of the faults are nearly E-W, and these short and discontinuous northern group of faults comprise dextral strike-slip faults with minor amount of amount of dip-slip components, and this character is different from any other fault that is exposed within this fault set. This difference in character is mainly due to the different orientation of these northern faults with respect to the orientation of the principle stress axes (Figure 36).

The width of the İzmirli fault set differs from place to place and ranges between 250 m and 1 km. Towards the eastern parts, the fault set widens and reaches to a width of 1 km (Figure 36). The longest fault of the İzmirli fault set measures approximately 2 km and the fault zone juxtaposes mainly the Betemürlü formation and Quaternary infill of the basin with the “Arkotdağ Formation” (Figure 38).

Faults of the İzmirli fault set displays well-developed scarps especially in the NE corner of the Yeniçağa Basin. In other parts, fault scarps are more smoothened and gentle. No slickensides could be found on these fault scarps but morphological expressions of the faults comprising the İzmirli fault set indicate that this fault zone comprises oblique-slip normal faults with minor amount of strike-slip components.

The existence and the activeness of the İzmirli fault set is indicated by the presence of alluvial fans (Figure 38) with apices adjacent to faults, sudden break in slope, presence of the Plio-Quaternary perched terrace conglomerates on downthrown blocks of the faults and tectonic juxtaposition of different units.

3.2.3.6. Sarayçalı Fault

The Sarayçalı fault is first named in this study. It determines the northeastern margin of the Yeniçağa and comprises a NE-SW trending, straight, southeastward-facing, dextral strike-slip fault with minor amount of dip-slip component. It starts approximately 350 m SSE of Öteköy in the NE and trends towards SW for about 1,7 km and disppears under the Quaternary infill of theYeniçağa Basin (Plate 1, Figure 36). Based on the cross-cutting relationship between this fault and two faults of the İzmirli fault set exposed nearby the Sarayçalı hill, it can be said that the Sarayçalı Fault is younger than other two faults of the İzmirli fault set.

The length of the Sarayçalı fault is about 1,7 km and it mainly juxtaposes the “Arkotdağ Formation” with the Quaternary infill of the Yeniçağa Basin (Plate 1).

The Sarayçalı fault displays well-developed scarp, in places, where it cuts through the “Arkotdağ Formation”, but no slickensides could be observed on this scarp. The morphological expression of the fault and its geometrical relationship with the principle stress indicate that this fault is a dextral strike-slip fault with minor amount of dip-slip component.

In the study area, the existence and the activeness of the Sarayçalı fault is indicated by the tectonic juxtaposition of different units and sudden break in slope towards the basinward direction.

3.2.3.7. Eroğlu Fault

This fault is first named in this study. It controls the morphology of the northern-northeastern margin of the Yeniçağa Basin (Figure 44). It is a curvilinear, basinward-facing and, NW-SE- to E-W-trending dextral strike-slip fault with minor amount of dip-slip component (cross-section A3-A3 in Figure 29). The downthrown of the fault takes place on the southern side of it. The fault starts approximately 500 m east of Delisüleyman village and runs towards northwest for about 2,5 km and 750 m southwest of the Çamlık hill it bends in westward direction, later on it runs in nearly E-W trend until approximately 250 m northwest of Çamurcuk village where it comes to end.

The Eroğlu fault meets with another subsidiary fault approximately 500 m southeast of Pısak hill.

The length of the Eroğlu fault is about 4,5 km and it mainly cuts through the “Arkotdağ Formation”. This fault juxtaposes mainly the Plio-Quaternary Betemürlü formation and the “Arkotdağ Formation” (Plate 1).

The Betemürlü formation is limited generally on downthrown block of this fault, but in the middle parts of this fault, the Betemürlü formation is not confined to the downthrown block of the fault, and its exposure extends to the upthrown block of the fault.

The Eroğlu fault displays smoothened and relatively low fault scarps. The fault scarps are more evident in the place where the fault determines the boundary of the outcrops of the Betemürlü formation. No slickensides could be observed on these fault scarps. On the other hand, morphological expression of the fault and its geometrical relationship with the principle stress indicate that the Eroğlu fault is a dextral-strike-slip fault with minor amount of dip-slip component.

The existence and the activeness of the Eroğlu fault is indicated by the sudden beak in slope, presence of Plio-Quaternary perched terrace conglomerates on downthrown block of the fault as well as juxtaposition of different units.

3.2.3.8. Yamanlar Fault

The Yamanlar fault is first named in this study. The fault controls the morphology of the northeastern margin of the basin. It is a relatively straight, E-W-trending, and southward facing dextral strike-slip fault with minor amount of dip-slip component (Plate 1, Figures 36, 38, 39, and cross-section A3-A3 in Figure 29). It starts approximately 250 m NNW of Ortaköy and continues eastward for about 3 km. The fault comes to end approximately 1 km SE of Kınataşı hill (Figure 36).

Morphologically, the fault defines a boundary between northern higher lands on the upthrown block and southern gently sloping low land areas on the downthrown block of the fault, and this is best indicated by the presence of nearly flat-lying, large Plio-Quaternary perched terrace conglomerates on the hanging block of the fault (Plate 1).

The length of the Yamanlar fault is about 3 km and it only cuts through the "Arkotdağ Formation". No units are juxtaposed along the trace of this fault and this is due to the fact that this fault is exposed at a location relatively far from the active margins of the Yeniçağa Basin (cross-section A_3-A_3 in Figure 29).

The Yamanlar fault displays a well-developed fault scarp along its trend, but no slickensides could be observed on this fault scarp. Indeed, the morphological expression of this fault indicates that the fault is a dextral strike-slip fault with minor amount of dip-slip component.

The existence and the activeness of this fault is indicated by the sudden break in slope and the presence of fault scarp all along its trend.

3.3. Pattern of Neotectonic Structures

The study area is a well-defined zone of deformation dissected by the closely-spaced strike-slip faults (Figure 36). As shown in Figure 36, within the zone of deformation, two groups of structures, the transtensional and the transpressional structures are originated. The sagponds (light blue area in Figure 36) and the pressure ridges with their axes parallel to the Gerede Fault (Master Strand) are the transtensional and transpressional features, respectively.

The whole of the neotectonic structures are superimposed in Figure 36B, which reflects a well-developed right-lateral strike-slip faulting pattern. By using both the strike-slip fault terminology of Wilcox *et al*. (1973) and the Riedel shear terminology modified by Tchalenko & Ambrasseys (1970), this fault pattern can be interpreted as the Master fault (Y-shear), the synthetic shear (R), antithetic shear (R'), the secondary synthetic shear (P) and the extension fracture, or oblique-slip normal faulting (NF) (Figure 36B).

The predominant members of the dextral strike-slip fault system defined in the study area are the Y-shear (NAFMS), the P shears or secondary synthetic strike-slip fault, and the Riedel shears (R).

3.4. Paleostress Inversion

In order to able to understand the kinematic history of the region, 42 fault slip data were collected from near vicinity of the Aşağı Kuldan fault (Figures 36, 45 and Plate 1). During the collection of fault slip data (Table 2) two different events indicated by the overprinting slickenlines were observed. Then, the data were analyzed by using “TECTOR” software developed by Angelier (1989). 38 of these data yielded reliable results; however, 4 of them were found to be spurious and were deleted out.

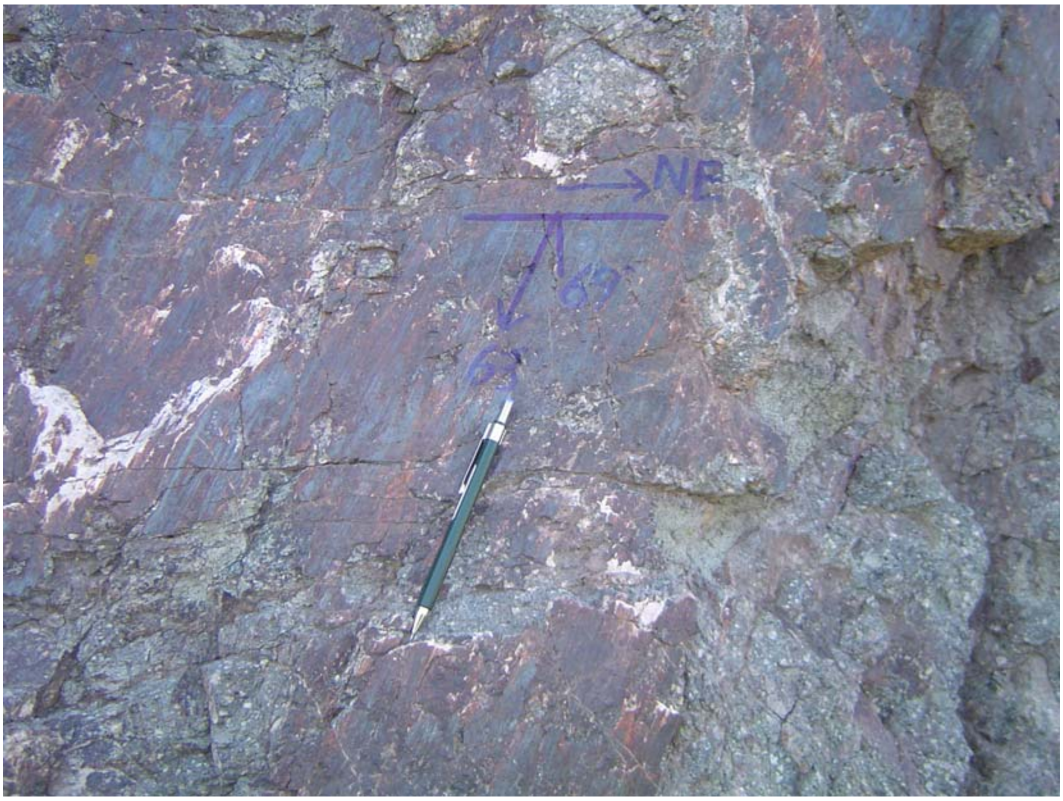

Figure 45. Close-up view of the slickenside near vicinity of the Aşağı Kuldan fault (Location: Station 1 in Figure 36)

After the analysis of the fault slip data, three different stress configurations were obtained, and coded accordingly (Figure 46). The specifications of each set are given on (Table 3).

Table 2. Fault slip plane data collected from near vicinity of Aşağı Kuldan Fault (see Plate 1 for location of station 1).

Station 1	**Slip Plane (Strike and Dip)**	**Rake**
1	N85° W,41° SE	36° E
2	N26° W,28° SW	0
3	N35° W,31° SW	11° S
4	N11° W,49° SW	0
5	N85° E,65° N	30° E
6	N86° E,70° N	33° E
7	N79° W,59° NE	51° E
8	N80° E,62° NW	48° E
9	N75° E,64° NW	45° E
10	N60° E,42° SE	30° E
11	N60° E,42° SE	60° E
12	N74° E,49° SE	18° E
13	N74° E,49° SE	46° E
14	N42° W,48° SW	25° S
15	N41° W,45° SW	25° N
16	N49° W,47° SW	32° S
17	N74° E,44° SE	14° E
18	N65° W,75° SW	59° S
19	N55° W,65° SW	64° S
20	N52° W,61° SW	52° S
21	N40° E,44° SE	42° E
22	N85° E,60° SE	12° E
23	N50° E,48° SE	37° E
24	N73° E,52° SE	34° E
25	N65° E,65° SE	29° E
26	N65° E,65° SE	48° E
27	N05° W,58° E	30° S
28	N-S,50° E	33° S
29	N03° W,56° E	25° S
30	N15° W,60° NE	16° S
31	N05° E,32° E	26 S
32	N05° E,35° E	36° S
33	N85° W,63° SW	39° E
34	N45° E,72° SE	62° S
35	N50° E,74° SE	72° S
36	N42° E,74° SE	63° S
37	N52° E,61° SE	53° S
38	N61° E,69° SE	63° S

STATION 1 : ESE of Aşağıkuzören Village

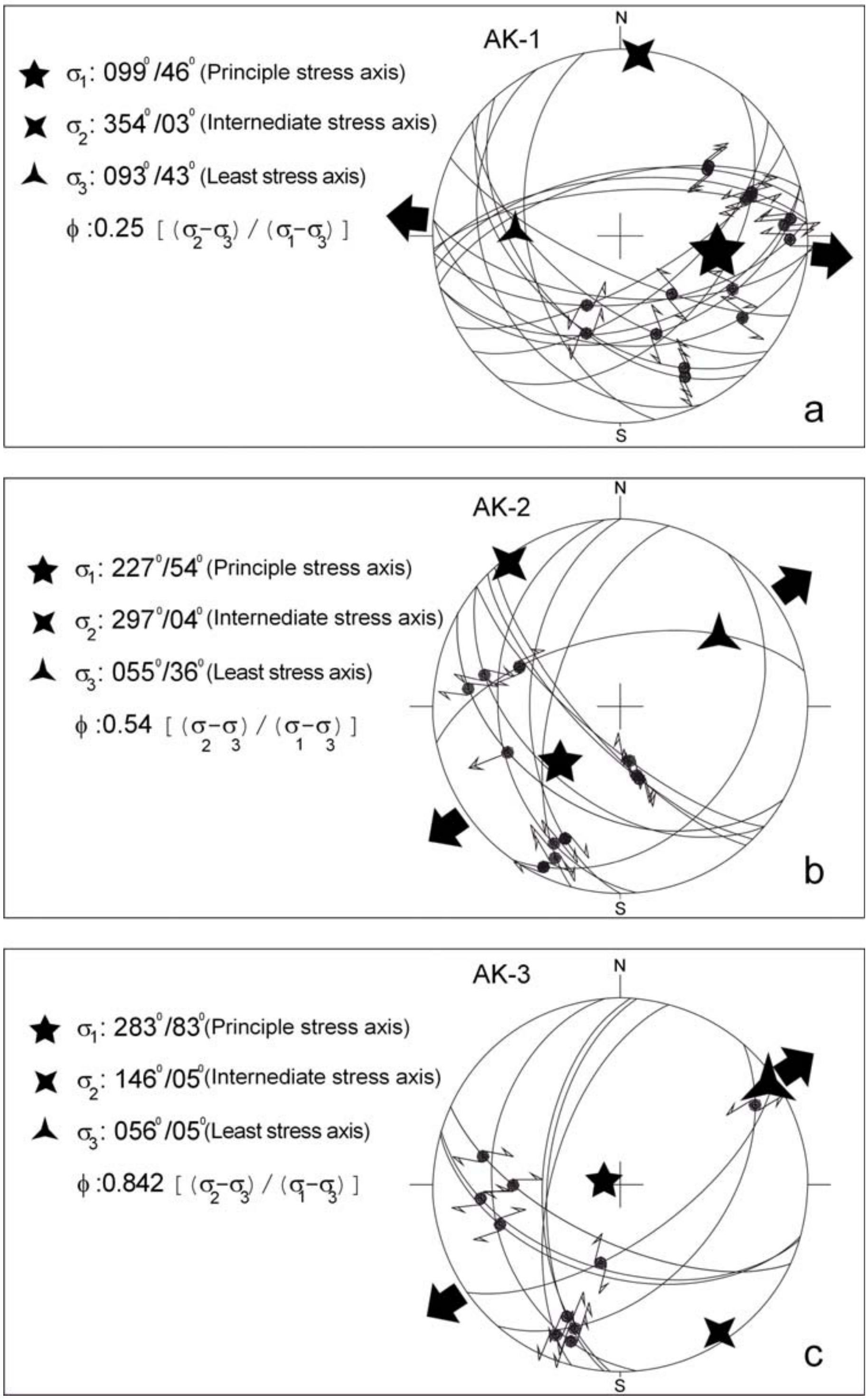

Figure 46. Kinematic analysis of the fault slip data taken from near vicinity of the Aşağı Kuldan fault (S1, see Figure 36 for location). The Diagram shows different stress configurations (Locality: ~ 500 m E of Aşağıkuzören village).

It is concluded that, kinematically there are two different deformation phases. The first deformation phase included in the AK-1 set and yielded the WNW-ESE direction of extension (**a** in Figure 46). Since the data was collected from the volcanics of the Galatean Arc Complex, it is thought that this phase of deformation is related to the extensional deformation affected the emplacement of the volcanics of the Galatean Arc Complex.

The second set includes the AK-2 and the AK-3 and are characterized by sub vertical σ_1 and the NE-SW extension which implies to that the region is being under the effect of NW-SE directed transtensional deformation (**b** and **c** in Figure 46). The stress ratio for the first set (AK_1) implies to that there is stress permutation between σ_2 and σ_3 while AK_3 implies stress permutation (Homberg *et al*. 1997) between σ_1 and σ_2. This is also illustrated by sub horizontal σ_2 which is the vertical stress in strike-slip settings. Due to stress permutation between σ_1 and σ_2 are swapped in order to result transtensional deformation. Otherwise, system should produce normal faults, since σ_1 is the vertical stress. The stress ratio for AK_2 implies to the normal lithostatic conditions for the region.

Table 3. Orientation, relative magnitudes, and the quality factors of the paleostress data constructed from fault plane slip data collected from near vicinity of Aşağı Kuldan Fault (see **Plate 1** for its location, Station 1)

SITE	σ_1		σ_2		σ_3		Stress ratio (Φ)	Number of Faults	MIN. RUP (%)	MAX. ANG. (°)
	Trend	Plunge	Trend	Plunge	Trend	Plunge				
AK-1	099°N	46°	354°N	03°	093°N	43°	0.25	16	74	16
AK-2	227°N	54°	297°N	04°	055°N	36°	0.54	11	71	26
AK-3	283°N	83°	146°N	05°	056°N	05°	0.842	10	87	24
MAX. ANG: Maximum Angular Divergence and about 100%, MIN RUP: Minimum Quality estimator on either direction and about 200%										

CHAPTER 4

DISCUSSION AND CONCLUSION

One of the main aims of this thesis is to explain the neotectonic evolution of the Yeniçağa Basin.

5.1. Evolution of the Yeniçağa Basin

New structural and stratigraphic data presented in the previous foregoing chapters have allowed us to refine the age chronology and reconstruct the neotectonic evolution of the Yeniçağa Basin. This basin displays two phases of evolution, indicated by the outcrop patterns of latest paleotectonic unit, namely the Eskipazar formation, the Plio-Quaternary deposits of the Betemürlü formation and the Upper Quaternary basin fill. The spatial distribution of these units within and surrounding the basin gives an idea about the evolutionary pattern of the basin.

The latest paleotectonic unit, the Eskipazar formation, 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 extensional tectonic regime was prevailing during the formation of these syn-depositional shear fractures and growth faults (Figure 31). During the Late Miocene – Early Pliocene time interval, the Eskipazar formation was actively being deposited in a paleotectonic basin that is formed by the NW-SE directed extension as indicated by the widespread presence of growth faults and shear fractures all through the Eskipazar formation (Figure 30).

The second phase of deformation took place after Early Pliocene and all the sequence of Eskipazar formation underwent a NE-SW directed compression and got folded with axes of folds trending NW-SE perpendicular to the maximum compression direction (σ_1) (Figures 34 and 35). 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 and with the onset of the neotectonic period this paleotectonic basin got abandoned. During the initial stages of the neotectonic period the Yeniçağa Basin started to develop in the northern parts with respect to the present position of the active basin, which is indicated by the widespread outcrops of the Plio-Quaternary Betemürlü formation. Nevertheless, in the following stages of the neotectonic period the on-going strike-slip deformation in the study area led to the development of the active Yeniçağa Basin relatively in the southern part and abandoned the basin formation in the south.

With the formation of the North Anatolian Fault System and onset of the neotectonic regime, several basins formed along the NAFS with their long axes parallel to the general trend of the NAFS and thus, nearly trending E-W. These basins are indeed, formed due to the strike-slip complexities along the NAFS and considered to be purely strike-slip basins. The Yeniçağa Basin is also a purely strike-slip basin with its long axis trending nearly E-W direction.

The present configuration of the Yeniçağa Basin suggests that this basin is a nearly E-W trending purely strike-slip fault wedge basin (Figures 47, 48).

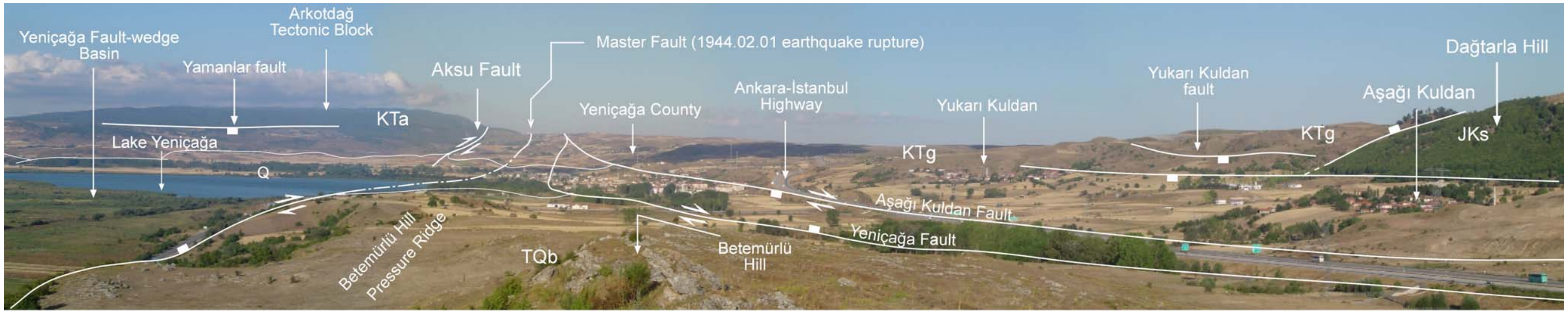

Figure 47. General view of the Yeniçağa section (Gerede Fault Zone) of the North Anatolian Fault System, Yeniçağa fault – wedge basin and its margin – bounding faults.JKs. Soğukçam Limestone, KTa: Upper Cretaceous ophiolitic mélange (the "Arkotdağ Formation"), KTg: Upper Cretaceous – Upper Miocene Galatean Arc Complex, TQb: Plio-Quaternary Betemürlü formation, and Q: Quaternary Alluvial sediments, PR. Pressure Ridge. (Location: Betemürlü Hill, view from W to E).

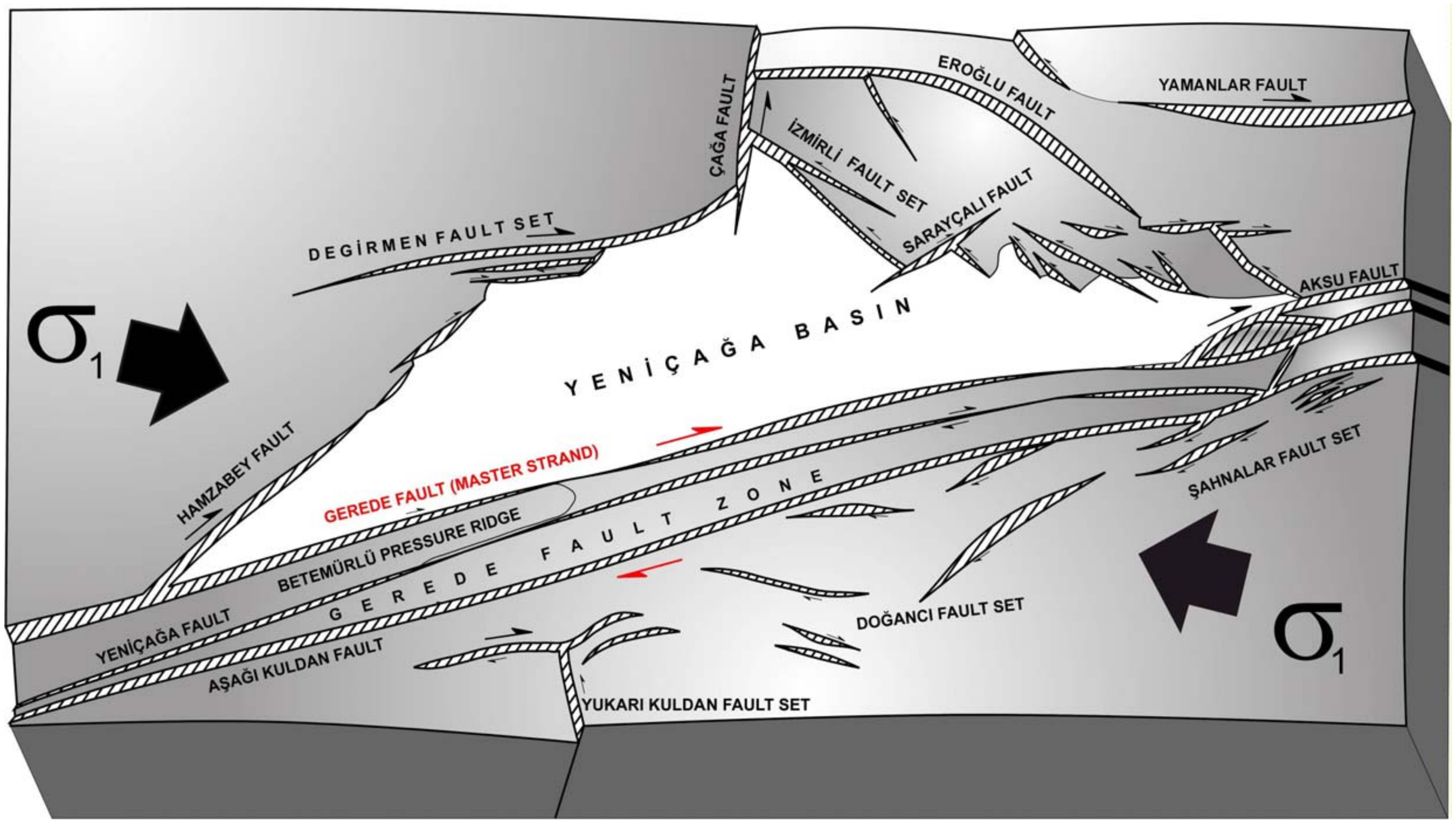

Figure 48. Sketch block diagram illustrating the present day configuration of the Yeniçağa Basin and the major strike-slip faults. σ_1: orientation of the local principle stress axis.

5.2. Conclusions

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

Based on the analysis of data gathered during the field studies and geological mapping of the study area at 1/25.000 scale the Yeniçağa Basin is interpreted to be a purely strike-slip fault wedge basin.

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

This study was focused on the neotectonic characteristics of the Yeniçağa 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.

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 master strand of the NAFS passing through the basin.

The 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 and oblique-slip normal faults.

Most of the settlements are located on water saturated, loose flood plain deposits forming the basin infill (Plate 1). Therefore, these settlements are open to earthquake hazard. Best solution of this problem is to construct structures at suitable places outside of loose, water saturated Quaternary basin fill and major active faults.

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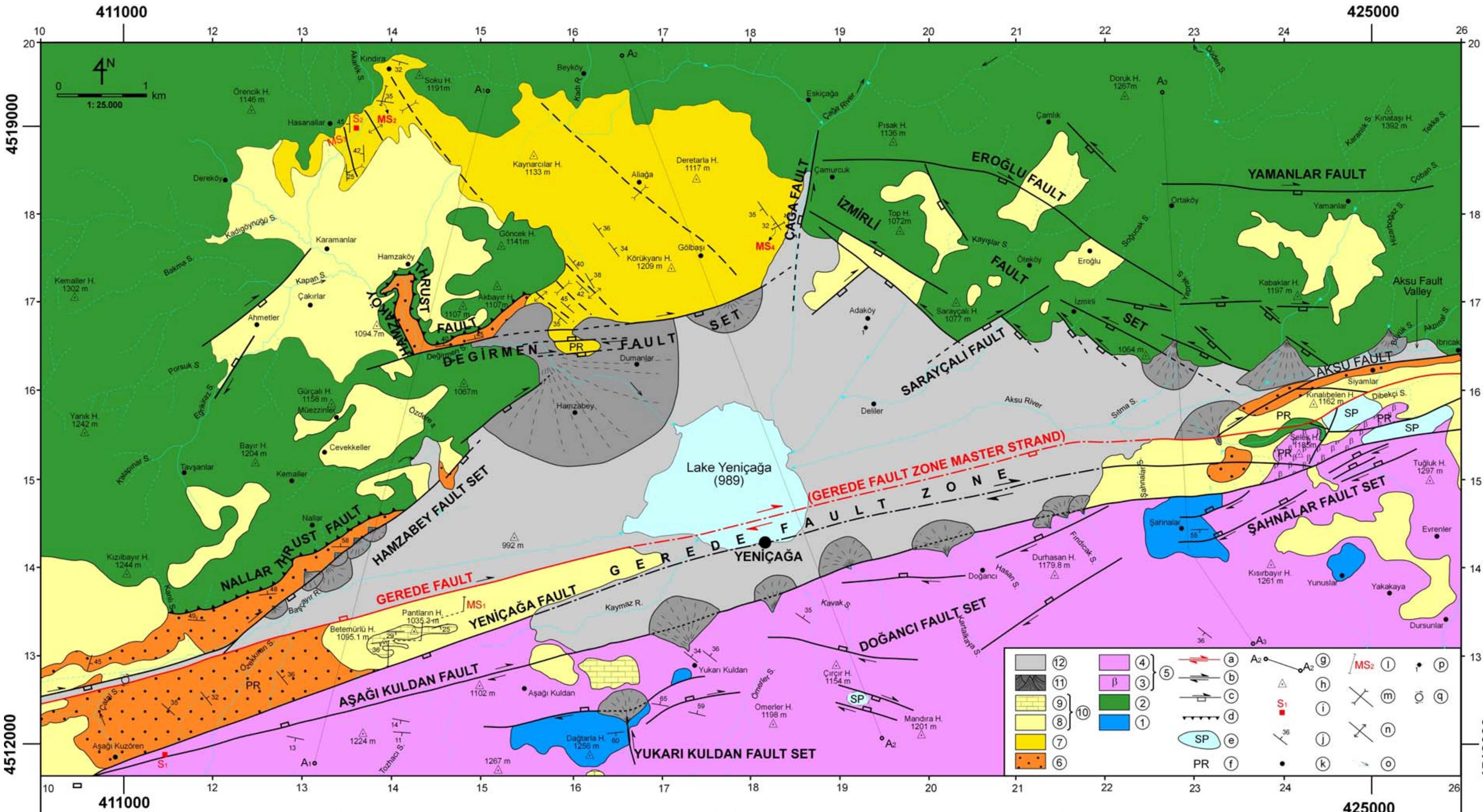
Plate 1. Geological map of the study area.

APPENDIX



Neotectonic Units
- (12) Quaternary Alluvion
- (11) Alluvial Fan
- (10) Betemürlü formation {TQ_b}
- (9) Quaternary travertine deposits
- (8) Plio-Quaternary terrace conglomerates

Paleotectonic Units
- (7) Eskipazar formation (Upper Miocene-Lower Pliocene fluvio-lacustrine clastics) {T_e}
- (6) Taşlık Formation (Lower-Middle Eocene red clastics and volcanic rocks) {T_t}
- (5) Andesite, basalt, tuff and aggomerates
- (4) Calc-Alkine Volcanics
- (3) β -Basalts (Alkali Basaltic Volcanics)

  Galatean Arc Complex {KT_g}
- (2) "Arkotdağ Formation" (Upper-Cretaceous ophiolitic mélange) {KT_a}
- (1) Soğukçam Limestone (Upper Jurassic-Early Cretaceous platform carbonates) {JK_s}

- (a) Master Strand of the Gerede Fault Zone
- (b) Strike-slip fault
- (c) Oblique-slip normal fault or strike-slip fault with minor amount of normal component
- (d) Thrust (triangles are on the upthrown side)
- (e) Sagpond
- (f) Pressure ridge
- (g) Lines of geological cross-sections
- (h) Elevation point
- (i) Fault plane measurement station
- (j) Strike-dip of bedding
- (k) Settlement
- (l) Measured section locations
- (m) Syncline Axis
- (n) Anticline Axis
- (o) Drainage
- (p) Borehole location
- (q) Feature displaced right-laterally during the Gerede-Çerkeş earthquake of 1944