POST MIOCENE TECTONIC OF ÇELTİKÇİ GRABEN, SOUTHERN MARGIN OF GALATIAN VOLCANIC PROVINCE, CENTRAL ANATOLIA

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submitted by **UMUR BERBEROĞLU** in partial fulfillment of the requirements for the degree of **Master of Science in Geological Engineering Department, Middle East Technical University** by,

Prof. Dr. Halil Kalıpçılar
Dean, Graduate School of **Natural and Applied Sciences** _______________

Prof. Dr. Erdin Bozkurt
Head of Department, **Geological Engineering** _______________

Prof. Dr. Bora Rojay
Supervisor, **Geological Engineering, METU** _______________

Examining Committee Members:

Prof. Dr. Erdin Bozkurt
Geological Engineering, METU _______________

Prof. Dr. Bora Rojay
Geological Engineering, METU _______________

Prof. Dr. Veysel Işık
Geologıcal Engineering, AU _______________

Prof. Dr. Lütfi Süzen
Geological Engineering; METU _______________

Assist. Prof. Dr. Fatma Toksoy Köksal
Geological Engineering, METU _______________

Date: 28.08.2019

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Surname: Umur Berberoğlu

Signature:

ABSTRACT

POST MIOCENE TECTONIC OF ÇELTİKÇİ GRABEN, SOUTHERN MARGIN OF GALATIAN VOLCANIC PROVINCE, CENTRAL ANATOLIA

Berberoğlu, Umur
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The Çeltikçi basin is located at the southern margin of a volcanic terrain known as “Galatian Volcanic Province” located on top of Cretaceous accretionary prism and to the south of North Anatolian Fault. The aim of this study is to investigate the difference in the style and intensity of deformation between Plio-Quaternary clastics and Miocene units. The units exposed in the area are classified as, from oldest to youngest, Miocene volcanics, Miocene Çeltikçi formation, Plio-Quaternary and Quaternary units. The fault-controlled talus to fan deposits and Quaternary alluvial deposits are the youngest units in the area. The dip-strike measurements of bedding planes and the analysis of fault slip data were used for the post-Miocene deformational studies. The intense faulting and folding are observed for the Miocene units. However, the Plio-Quaternary clastics are gently folded and poorly faulted. The field data and fault plane slip data analyses revealed that there is compression during post-Miocene to Late Pliocene period. However, during Quaternary and onwards the operating deformation is extension.

Keywords: Çeltikçi Basin, Galatian Volcanics, Paleo-stress Analysis, Neotectonics

ÖZ

ÇELTİKÇİ BASENİNİN MİYOSEN SONRASI TEKTONİZMASI, GALATYA VOLKANİK BÖLGESİ GÜNEY KENARI, İÇ ANADOLU

Berberoğlu, Umur
Yüksek Lisans, Jeoloji Mühendisliği
Tez Danışmanı: Prof. Dr. Bora Rojay

Ağustos 2019, 55 sayfa

Çeltikçi baseni, Kuzey Anadolu Fayı güneyinde Kretase yığışım prizması üzerinde gelişen Galatya Volkanik Alanında (GVP) yer almaktadır. Bu çalışmanın amacı, Miyosen ile Pliyo-Kuvaterner dizileri arasındaki deformasyon biçimi ve yoğunluk farklılığını araştırmaktır. Bölgede açığa çıkan birimler, en yaşlıdan gence doğru, Miyosen volkanikleri, Miyosen Çeltikçi formasyonu, Pliyo-Kuvaterner ve Kuvaterner birimler olarak sınıflandırılır. Fay kontrollü talus ve Kuvaterner alüvyal çökeller bölgedeki en genç birimlerdir. Tabaka düzlemlerinin eğim-doğrultu ölçümleri ve fay atım çizgilerinden yapılan analizler, Miyosen sonrası deformasyon çalışmalarında kullanılmıştır. Miyosen yaşlı birimlerde yoğun bir şekilde kıvrımlanma ve faylanma görülmektedir. Fakat, Pliyo-Kuvaterner kırıntılılar az miktarda kıvrımlanmış ve faylanmıştır. Saha verileri ve fay düzlemi üzerindeki atım çizgi analizleri, Miyosen sonrası ile geç Pliyosen dönemi arasında sıkışma rejimi olduğunu ortaya çıkartmıştır. Fakat, Kuvaterner ve sonrasında ise deformasyon gerilim şeklindedir.

Anahtar Kelimeler: Galatya Volkanikleri, Çeltikçi Baseni, Paleo-Stres Analizi, Neotektonik

To my wife,

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CHAPTER 1

INTRODUCTION

1.1. Purpose and Scope

The study area is located within the Galatian Volcanic Province, which is one of the major volcanic provinces of Turkey. It has been a part of many studies due to its tectonic activities were recorded in the history and its relationship with the economic deposits. The study area is also located at the south of North Anatolian Fault that limits the northern margin of Galatian Volcanic Province (GVP) (Figure 1.1).

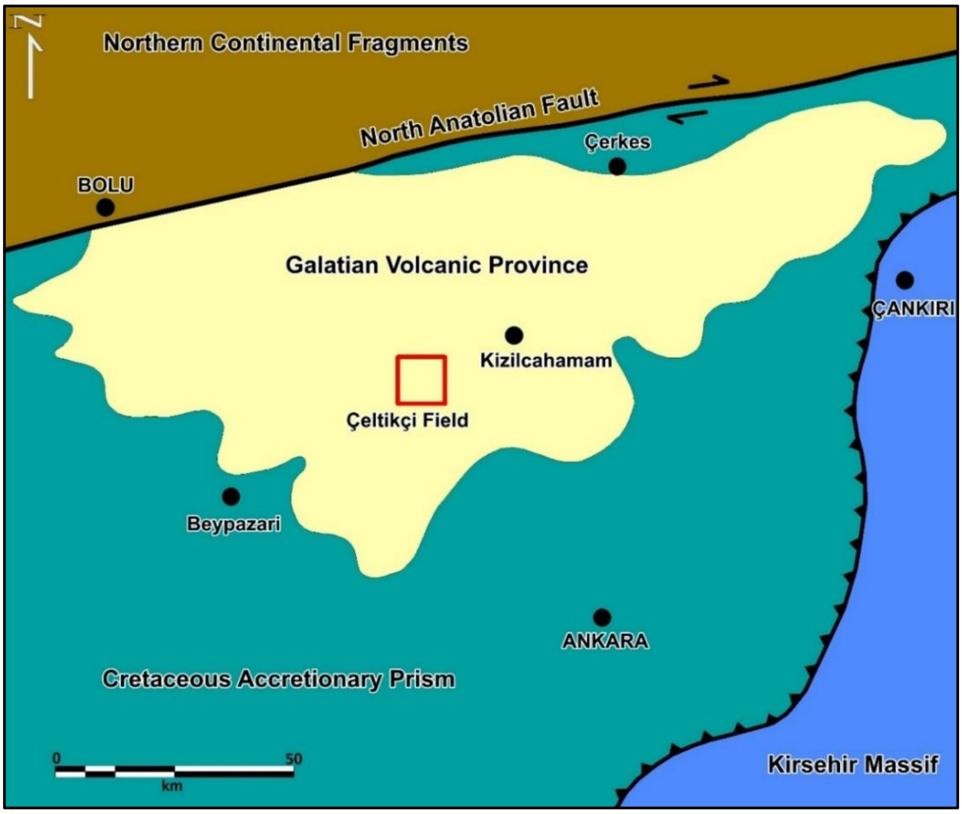

Figure 1.1. Tectonic setting of the GVP.

There are Neogene basins associated with the GVP in the region, and their stratigraphic characteristics and the spatial distribution are still poorly known. The Çeltikçi basin is one of these Neogene basins. Due to the relationship with GVP and the North Anatolian Fault, the Çeltikçi basin has an important position in order to better explain the geology of this region. The faults exposed in the basin might be related with the North Anatolian Fault.

The effects of tectonism are clearly observed at the Çeltikçi basin. The intense folding and faulting are the most distinguishing geological structures especially for the Miocene units. However, it is not same for the Plio-Quaternary units. The Plio-Quaternary clastics overlie all these structures and the intensity of deformation is low within this units.

This thesis aims to understand the post-Miocene deformational patterns and orders in Çeltikçi area. The stratigraphy of the region is simplified on the presence of an unconformity developed between the Miocene units and Plio-Quaternary clastics in order to define relative age dating of the deformation.

1.2. Geographic Location

The study area is situated in the Central Anatolia, 60 kilometers north of Ankara, the capital city of the country. The area is also situated between Kızılcahamam and Güdül which are the settlements of most popular townships of Ankara. The study area is 24 km southwest of Kızılcahamam from which access is the divided highway D 750 for south 2.3 km to the turnoff for the Güdül town.

1.3. Methods of Study

The preparation of this thesis consists of several stages from the beginning to the end.

Before starting the field studies, a literature survey was conducted to understand the geology of the study area and the region. At this stage, various articles, publications and geological maps about regional and local scale were examined. Afterwards, a detailed field study was started and geological units, faults, foldings and other structural elements were mapped. The faults were defined according to the observation during the field studies. The bedding plane measurements and the slip lineation data from the fault planes were collected to perform structural analysis. These measurements were collected separately from rock units of different age groups and detailed notes were taken.

Since the study area is located in intense tectonic area, the seismicity of the study area and its surroundings was investigated. In this context, regional and local scale fault zones have been determined by field and literature studies. In addition, information about all earthquakes occurred in the study area and its immediate vicinity was collected and presented within the scope of the thesis.

The rose diagrams were prepared to analyze the attitudes of bedding planes. Two different types of rose diagrams were prepared to show the difference between Miocene units and Plio-Quaternary clastics.

The software Win Tensor was used to analyze the slip-data. This software works according to the Angelier Inversion Method (Angelier 1979; 1984; 1991). By using this software, the different deformational phases were separated, and the principal paleo-stress directions were calculated.

1.4. Regional Geology

The study area is located on the southern part of Galatian Volcanic Province (GVP). This volcanic province is located on top of Cretaceous accretionary prism and to the south of North Anatolian Fault (Öngür 1976; 1977) (Figure 1.1). The name of "Kızılcahamam volcanics" or "Köroğlu volcanics" are also used for the volcanic products of this volcanism (Türkecan et al. 1991). However, "Galatian Volcanic Province" is the best representative for this area (Toprak et al. 1996).

The previous studies conducted around the study area are generally related with volcanics particularly on the petrography-geochemistry and age, the presence of organic rich matters, and on the geothermal resources.

The pre-Miocene age of rock units include pre-Triassic metamorphics, Triassic Complex, Jurassic-Cretaceous Atlantic type margin sequences, Upper Cretaceous-Paleogene ophiolitic mélange and Eocene basins (Koçyiğit 1991). The Miocene clastics and volcanics unconformably overlie the pre-Miocene units. Miocene lavas and volcanoclastics of GVP are inter-fingering with Miocene sequences. These sequences also overlie the volcanic products of GVP. The organic layers were located within Miocene and Pliocene sequences. Quaternary deposits unconformably overlie all the units (Figure 1.2).

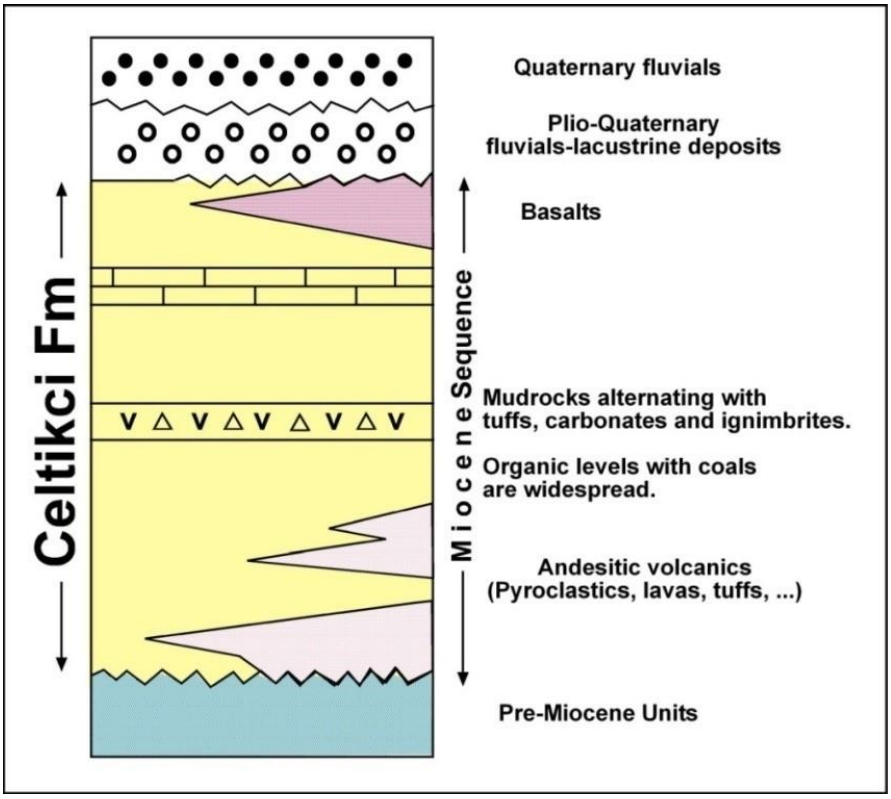

Figure 1.2. Simplified columnar section of the Çeltikçi area.

CHAPTER 2

STRATIGRAPHY

The stratigraphy of the region constructed on the Pre-Miocene basement volcanics. The Neogene sedimentary sequence called as Çeltikçi Formation is deposited above Miocene volcanics. The Çeltikçi Formation is divided into five informally named conformable members. The Çavuşlar member composed of marls and claystone is the lowest unit and has organic rich layers. A thick tuff and associated clastics, which is called as Abacı member, overlie Çavuşlar units. The Abacı tuff overlain by the Kocalar member composed of marl-claystone. The limestone of Aktepe member overlie the Kocalar units. The Bezci member is the youngest unit in the Çeltikçi Formation and it is represented by fluvial clastics. Fault-controlled talus to fan deposits and Quaternary alluvial deposits are the youngest units in the study area (Figures 2.1 and 2.2).

2.1. Miocene Volcanic Rocks

The dominant rock type exposed in the study area is andesitic-andesitic basaltic volcanic rocks. In this study, the term volcanic rocks cover all the lavas, pyroclastics or eruption centers. The base of volcanics is not observed within the study area. However, the upper boundary is observed, and the overlying rock unit is not the same everywhere. The volcanics overlain by mudrocks and clastics unconformably in some parts, but in some other areas the mudrocks and clastics are totally silicified with the effects of intrusive contacts.

The volcanic rocks mainly include lava flows and pyroclastics of andesitic to andesitic basaltic composition. In the north of Çeltikçi, it is indicated that the total thickness is more than 500 m. In some parts of this area, alternating pyroclastics and lava flows are well orderly exposed. The Neogene mudrocks are covered by the lavas and pyroclastics to the northeast of Binkoz village and the Miocene age coal bearing mudrocks overlie all these rocks (Figure 2.3).

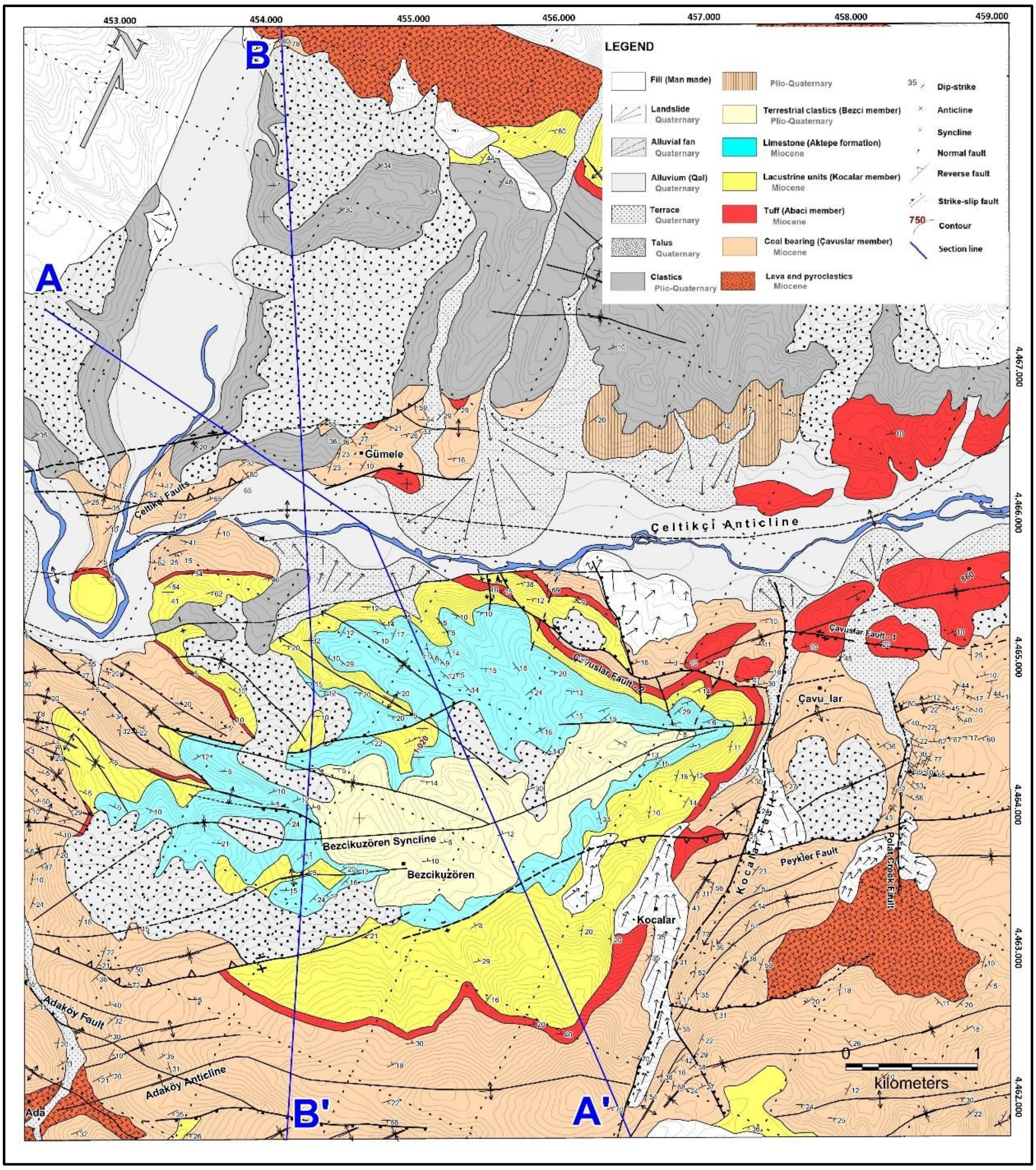

Figure 2.1. Geological map of the study area.

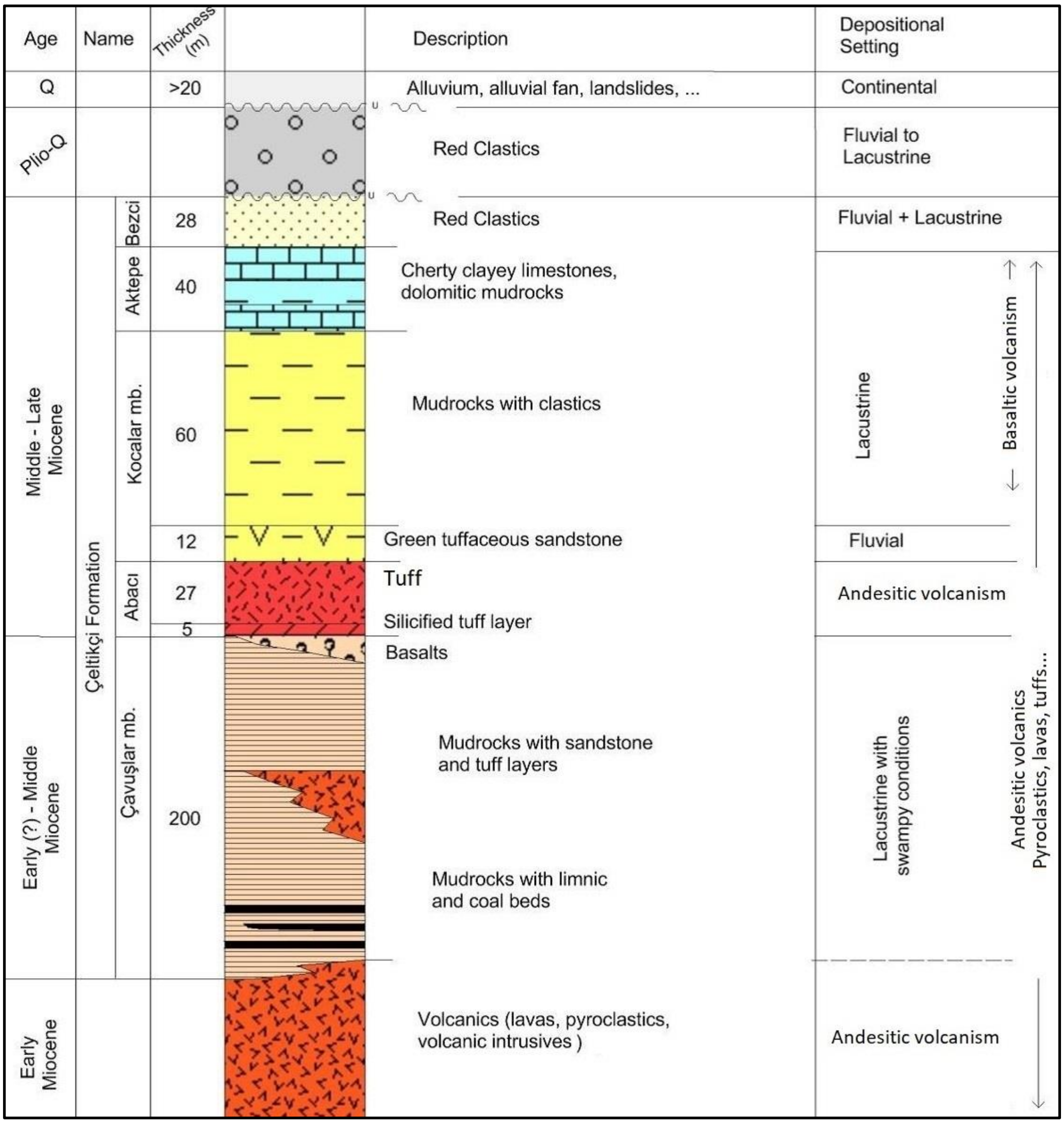

Figure 2.2. Columnar section of the Çeltikçi area.

In Galatian Volcanic Province, the volcanism is divided into two different stages with different tectonic settings (Türkecan et al. 1991; Tankut et al. 1995; Wilson et al. 1997; Adıyaman et al. 2001; Koçyiğit et al. 2003a). The continuous rifting process and subducting slab generate this volcanism. The calc-alkaline character volcanic cycle is the oldest and major phase. The composition of these volcanic units is ranging from K-rich basaltic trachyandesite to rhyolite with minor occurrences of alkali-basalts

(Türkecan et al. 1991). The cycle coincides with 25 Ma to 10 Ma (Early-Late Miocene) (Türkecan et al. 1991; Wilson et al. 1997) or even much older (since Paleocene, 65 Ma) (Koçyiğit et al. 2003b). The source of the older phase is lithospheric mantle. During the first volcanic cycle, this one modified by earlier subduction. In Galatian Volcanic, the parental magmas of the Early Miocene volcanism were originated in a post-collisional tectonic setting (Tankut et al. 1990; Gökten et al. 1996; Tankut et al. 1998). The age of latest cycle is indicated as 8.5 Ma to 11 Ma. These volcanics consist of alkali basaltic flows capping the older volcanic sequences (Türkecan et al. 1991).

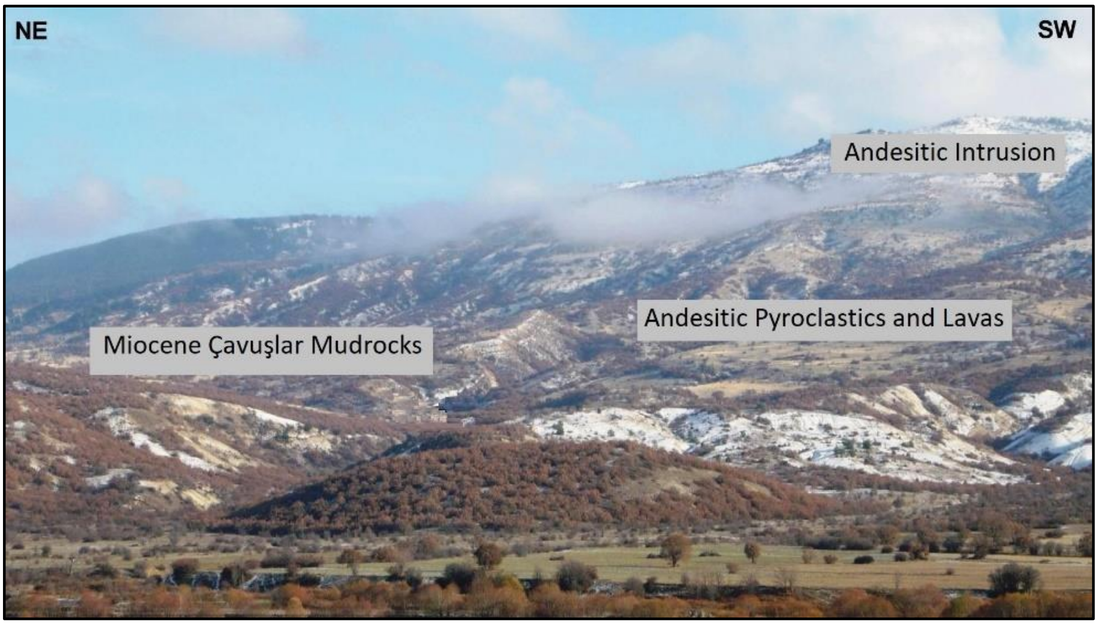

Figure 2.3. Miocene Çavuşlar sequence overlies the Miocene volcanics.

2.2. Miocene Çeltikçi Formation

Neogene Çeltikçi formation is informally divided into five conformable members. They are called as, from oldest to youngest, Çavuşlar member, Abacı member, Kocalar member, Aktepe member and Bezci member (Figure 2.2).

The unconformable relationship is observed between Çeltikçi Formation and volcanic rocks in some parts of the GVP. This relationship is also observed in the Gümele area. The Abacı tuff is important zone for the mapping studies because it is used as a marker zone to separate mudrocks of Çavuşlar and Kocalar members.

The existence of mammalian fossil, and the paleontological and lithological observations indicated that the Miocene units coincide with Middle- Late Miocene (Ozansoy, 1961; Gürbüz, 1981). There are also radiometric and palynological datings conducted in the study area. The palynological analyses performed on coal beds alternating with mudrocks indicate the Middle Miocene to Late Miocene age (Akyol, 1968; Turgut, 1978). There are some dating analyses conducted from the tuff samples alternating with lacustrine units. The results reveal different age intervals as 25 Ma to 21 Ma (Türkecan et al. 1991), 16.2 Ma (Ercan et al. 1990), 20.9 to 9.6 Ma (Keller et al. 1992), 19.7 to 16.9 Ma and 9.51 Ma (Tankut et al. 1995). All these studies indicate an age interval as Early (?) to Late Miocene for the Miocene sequences.

The interbedded sequences of terrestrial sediments and volcanics/volcaniclastics show that the paleogeographic location consists of a continental depositional setting with lakes around the terrestrial volcanic vents in an inter-arc depositional system on İzmir-Ankara Suture Belt during Neogene period (Gökten et al. 1988; 1996; Koçyiğit et al. 1988; Erol, 1993). The alkaline lakes with calc-alkaline volcanism covered quite large areas at the northwest of Ankara. The effects of this volcanism is observed entire central Anatolia.

2.2.1. Çavuşlar Member

Çavuşlar member is located on top of the andesitic volcanics and it is the lowest part of the Çeltikçi Formation (Figure 2.2). It unconformably covers the volcanic rocks and conformably overlain by tuff units of Abacı member (Figure 2.4). The thickness of this member is around 200 m at the south of Çavuşlar village.

The composition of this member is sandstones, cream to white mudrocks, tuffs and organic levels.

The interlayered tuff layers with mudrocks and gray to white color, crossbedded, pumice bearing sandstone is very common within Çavuşlar member. It can be clearly observed at northeast of Kocalar village (Figure 2.4). The lateral continuity of these layers can be easily followed from Kocalar to north of the Gümele village.

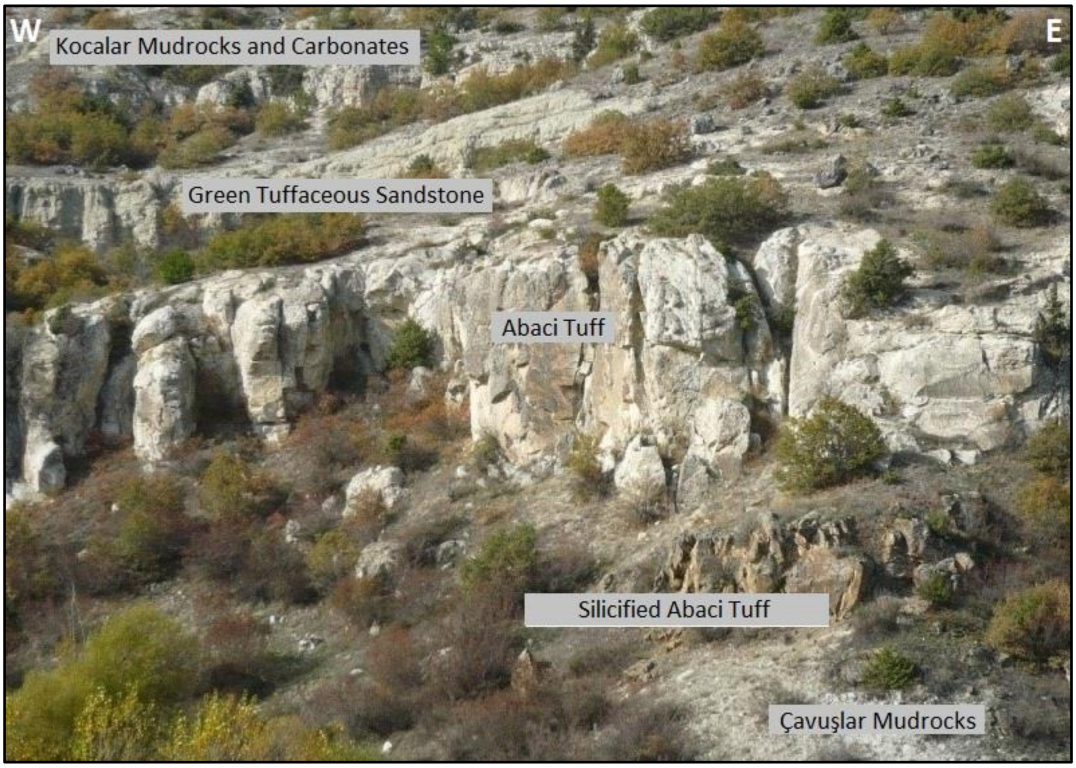

Figure 2.4. General view of Miocene Çeltikçi sequence.

The Çavuşlar member shows the effects of silicification in the study area. The layers of silica and some silicified lenses are recognized in mudrocks. In addition, the silicified sequences, because of intense volcanic activity, is observed within this member. These evidences give information about the presence of silica. It can be said that the silica is present in the system as primary and secondary because of effects of volcanism. There are places where the silicification is relatively dense within the study area as Demirciören village, north of Alibeyköy, northeast of Peyikler, and Bağlıca-Çeltikçi-Adaköy areas.

The rock units of Çavuşlar member deposited in a lacustrine environment. The effects of swampy conditions and volcanic activity is also observed in the depositional environment. The Middle Miocene age was indicated for the region (Akyol, 1968; Turgut, 1978).

2.2.2. Abacı Tuff

Abacı member is stratigraphically located in the middle of Çeltikçi Formation. It is important because the stratigraphy of Çeltikçi Formation constructed on the position of Abacı tuff. The Çavuşlar member overlain by Abacı tuff and Kocalar member is located at the top of this marker zone conformable. There is a sharp contact with Çavuşlar member and gradational with mudrocks of Kocalar member.

The thickness of the Abacı member reaches 27 m in some parts of the area. The thickness decreases and diminished towards western part and eastern part of the study area (Figure 2.1). However, the member is very important to differentiate the Miocene units and to make interpretation about structure of the area.

The member is divided into two main group according to lithology. The lower part is generally silicified and impervious massive tuff layer with a maximum thickness of 5 m. The upper part is clearly separated with highly porous character and light-colored pumice fragments. The thickness of this layer reaches up to 22 m around Çavuşlar area (Figure 2.4). It is also observed that tuff is hydrothermally altered by the basaltic dykes and along the joints.

Green colored tuffaceous sandstone with cross bedding structures overlies the Abacı member and the lateral continuity of this unit can be followed in the study area. The thickness of the sandstone is approximately 12 m in the study area.

It is estimated that the Abacı tuff is erupted and deposited onto mudrocks of the Çavuşlar member within a lacustrine environment. In this process, sedimentation continues unceasingly during Middle Miocene.

2.2.3. Kocalar Member

The mudrocks of Kocalar member overlie the Abacı tuff and overlain by the limestone of Aktepe member. There is a conformable relationship between the Kocalar mudrocks, the Aktepe limestones overlying the Kocalar mudrocks, and the Abacı tuff underlying the Kocalar member. The thickness of this unit is about 60 m. It is very clear with the bottom and top boundaries at SW of the Çavuşlar village (Figure 2.4).

The unit is lithologically described as cream colored mudrocks with sandstone beds and alternating tuff layers. It is interpreted that these rock units are deposited in a silica rich lacustrine environment within clastic influx.

2.2.4. Aktepe Member

The typical section of the Aktepe carbonates is exposed in an area between Gümele, Kocalar and Aşağıada villages (Figure 2.1). The contact relation with the upper and lower units is observed very well in this area (Figure 2.4). The thickness of the unit is approximately 40 m. In some parts, the silicification related with the hydrothermal activities of faulting and volcanism causes some problems to separate this unit especially to the west of study area.

The beige-cream colored carbonates are observed at the bottom and the mudrocks bearing sandstone and tuff layers continues to the upper parts. The upper part of the unit is dominated by the light colored, highly porous, thick bedded, limestones/dolomitic mudrocks with silica nodules-lenses.

Aktepe member is lithostratigraphically correlated with the Upper Miocene limestones in Central Anatolia.

2.2.5. Bezci Member

The pinkish red color clastics with soft morphologies and gentle dip amounts are the units of Bezci member, which is observed clearly around Bezcikuzören village (Figure 2.1).

The unit displays a gradual relationship with Miocene Aktepe carbonates at the bottom contact and unconformably overlain by the Plio-Quaternary clastics (Figures 2.2 and 2.5). However, it is very hard to separate from Kocalar member to the west of Mahkemeağıcın and west of Abacı villages. The total thickness of the unit is more than 30 m in some places.

The common lithologies of Bezci member are polygenetic sandstones-siltstones with some clayey carbonate “soil horizons” and conglomerate.

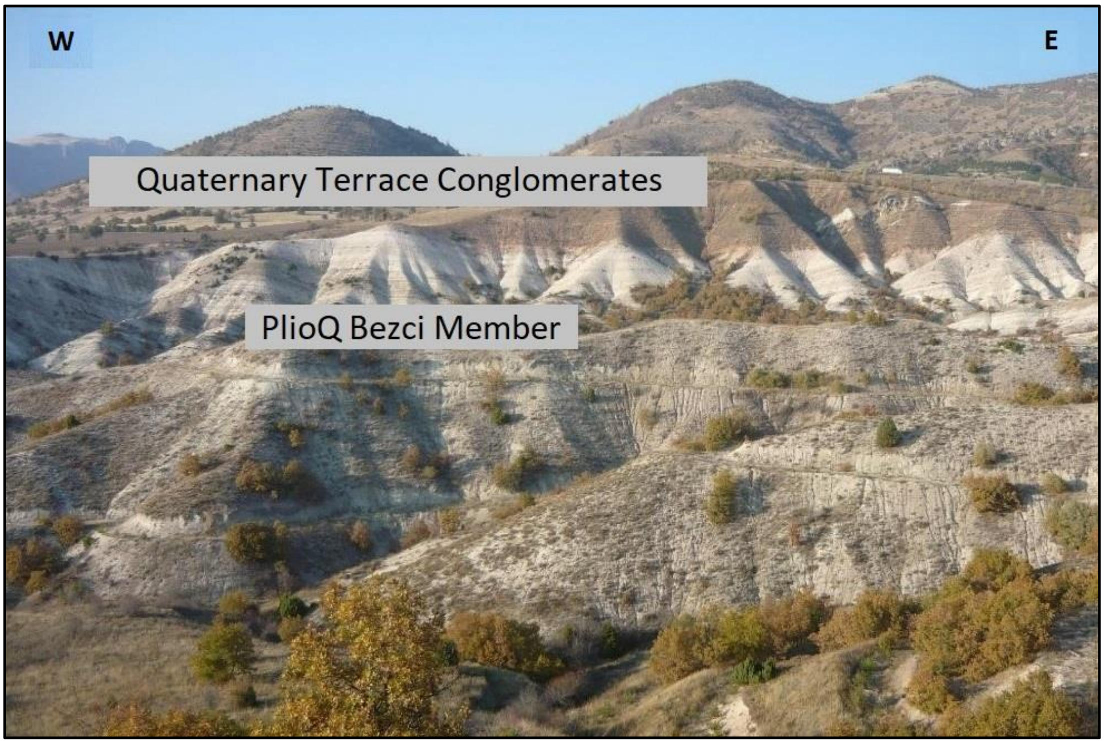

Figure 2.5. General view of Bezci member.

The depositional environment can be described as terrestrial setting with carbonate soil horizons and short-lived lacustrine periods. It is expected that age of the units is to be post-Miocene, as Plio-Quaternary. The mammalian fossils located in the area indicated the date as Early Pliocene (Ozansoy, 1961; Tekkaya, 1973; 1974a, b; Şen and Rage, 1979; Tatlı, 1975).

2.3. Plio-Quaternary Units

The Plio-Quaternary clastics can easily be confused with Bezci member because of lithological similarities. The common lithologies are polygenetic conglomerate-sandstone-siltstone with some limnic-organic horizons (Figure 2.6).

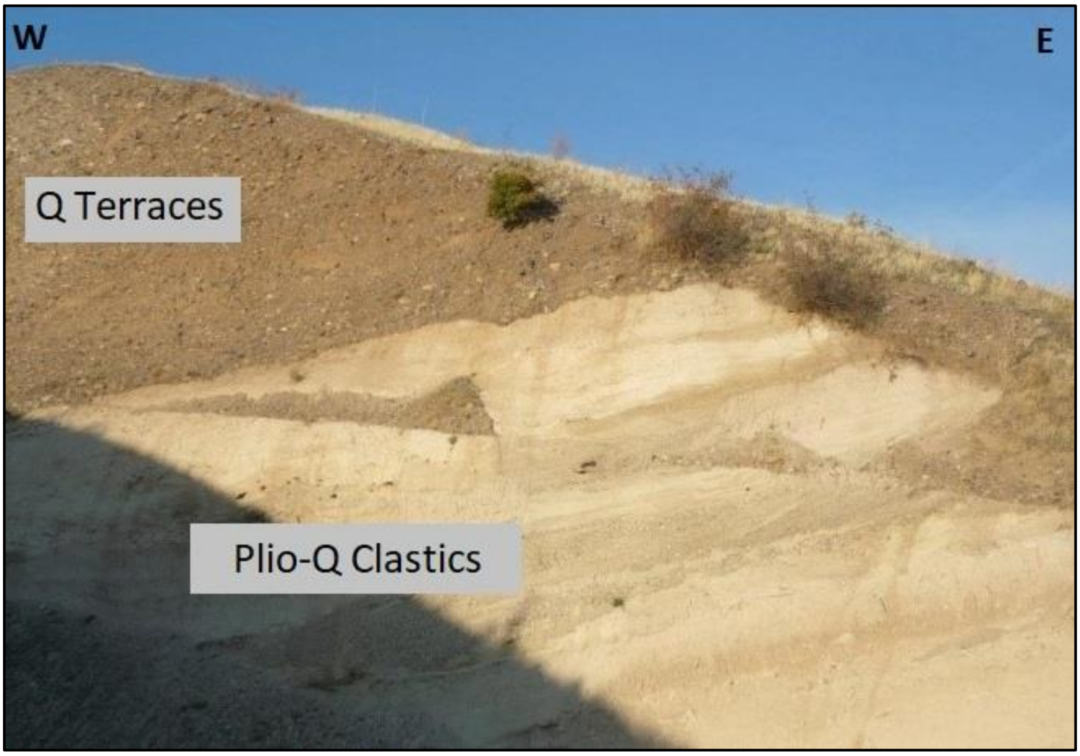

Figure 2.6. The Plio-Q units unconformably overlain by the Quaternary terrace conglomerates (W of Gümele town).

The bottom contact of Plio-Quaternary clastics with the Miocene Çeltikçi Formation is unconformable. This contact is very important to investigate the post-Miocene tectonic evolution. There is also another unconformity with the Quaternary clastics at the top.

The Plio-Quaternary clastics are generally associated with the faults in the area. The composition is massive talus like accumulation with almost angular pebbles or blocks. Fine to medium grained clasts and bedded strata can observed away from the fault.

The Plio-Quaternary clastics can give information about the activity of the faults. In the study area, there are several isolated polygons determined as Plio-Quaternary units and these are close to the faults determined during mapping studies (Figure 2.1)

2.4. Quaternary Units

The Quaternary clastics are deposited in the channels of drainage system and they are accepted as present-day units (Figure 2.5 and 2.6). The river terraces composed of poorly sorted and well rounded conglomerates (volcanic coble bearing) and they unconformably overlie the Plio-Quaternary clastics. These are accepted as present-day units and they are generally observed around Kirmir Stream (Figure 2.1).

CHAPTER 3

STRUCTURE OF THE AREA

3.1. Regional Tectonism

Turkey located on Eastern Mediterranean-Himalayan seismic belt is under the threat of earthquakes. In Turkey, the main driving neotectonic structures are respectively North Anatolian Fault (NAF), the East Anatolian Fault (EAF), Aegean and Eastern Mediterranean Subduction Zone and Dead Sea Fault (Figure 3.1).The North and East Anatolian Faults have right and left lateral characteristics respectively, and along these two fault systems, the Anatolian Plate moves at a speed of 25 mm/year and 15 mm/year in the west-southwest direction on the oceanic crust of the African Plate (McClusky et al. 2000). Both fault systems are active, as evidenced by both historical and current earthquakes. The biggest seismic event that derives from these two tectonic structures is the Erzincan earthquake of 1939 with a magnitude of 7.8 (Ambraseys, 2001). Similarly, the Dead Sea Fault is a left lateral intra-continental transitional fault that connects the EAF to the Red Sea rift and separates the African and Arabian Plates. The Aegean-Eastern Mediterranean Belt is an active subduction zone, and the African Plate subducts towards the north with 35 mm/year under the Anatolian Plate along this subduction zone. It is the source of shallow-medium-deep focused earthquakes (Kahle et al. 2000).

The study area, located approximately 70 km south of the NAF, is located above the subduction zone of the Izmir-Ankara-Erzincan Suture Belt (Cretaceous Accretionary Prism). Therefore, both the study area and the Ankara region are geologically complex and are located in a transition zone where compressional strike-slip faulting and expansionary normal faulting affect each other.

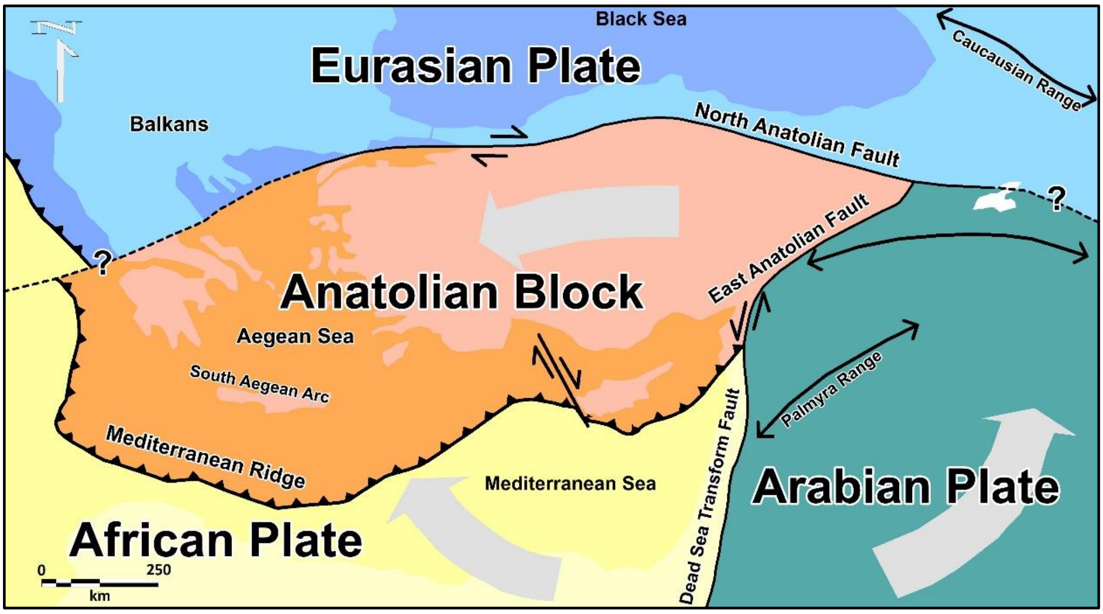

Figure 3.1. The neotectonic map of the Turkey and its surroundings (Bozkurt and Rojay, 2005).

3.2. Regional Fault Belts

As a result of this study carried out in order to determine the earthquake sources of Çeltikçi and its vicinity, the faults were determined, and measurements were taken for the kinematic analysis where the fault planes were observed clearly. The paleo-stress analysis of the major faults was made and their geometry, quality and whether they were active were determined. Furthermore, the current earthquake epicenter distribution was compared with the detected and mapped faults to determine which faults are active. The project area is located within the major fault zones and these are; 1. North Anatolian Fault (Aktaş Fault, Çerkeş Fault), 2. Korgun-Kalecik-Kesikköprü Fault, 3. İnönü-Eskişehir-Cihanbeyli Fault and 4. Tuzgölü Fault (Figure 3.2).

North Anatolian Fault (NAF): North Anatolian Fault is described as a right lateral strike slip fault. It is 1700 km in length and 110 km in width and extending between the Iranian border to the east and the northern Aegean Sea to the west. NAF separates the Eurasian Plate and the Anatolian Plate (Figure 3.1). It consists of a number of active and potentially active faults in different sizes and is the most important source of the earthquake in Turkey and the environment, has led to many historical and current destructive earthquakes. According to GPS measurements, the motion of the NAF is about 2-2.5 cm / year (Reilinger et al. 1997; Kahle et al. 2000; McClusky et al. 2000).

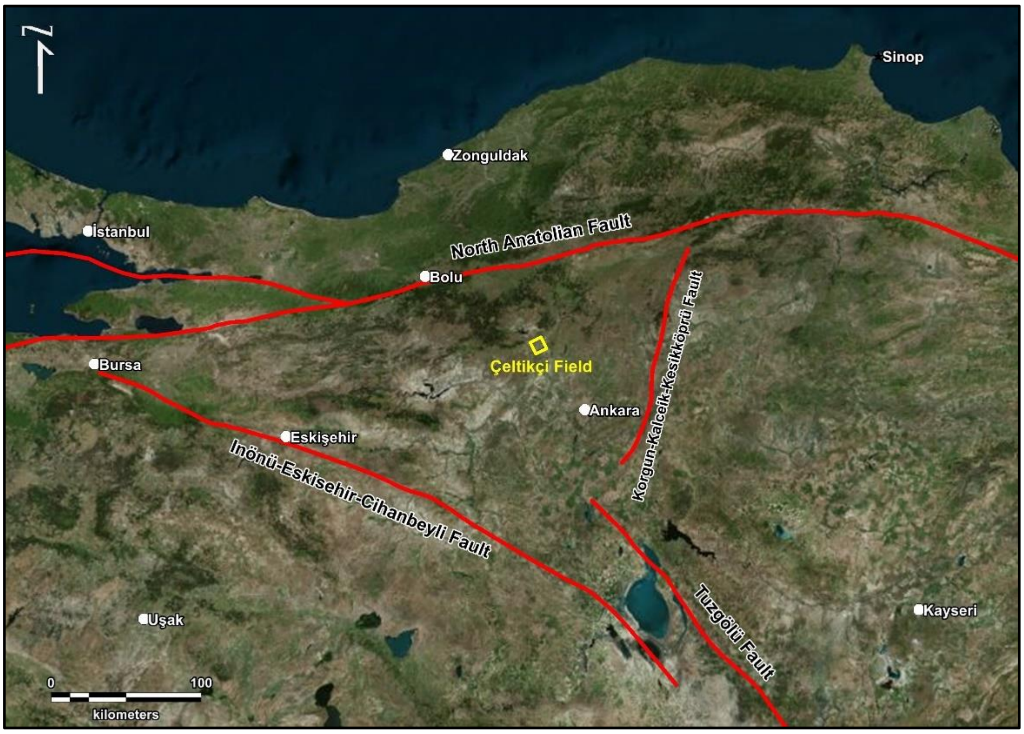

Figure 3.2. The map of regional faults.

The closest part of the fault to the study area (Ilgaz-Bolu segment) is approximately 40 km wide, 200 km long and consists of many faults of different sizes. The WSW-trending fault, which is located at the northernmost of this region, extends between the north of the Ilgaz district in the east and the Yeniçağa district in the west and includes the main seismogenic fault of the NAF. This segment has been the source of many devastating earthquakes affecting the province of Ankara and its surroundings. The earthquakes of 1668, 1943, 1944 and 1953 were caused by the faults formed during this generation and affected the province of Ankara.

The faults which are the continuation of the branches of NAF are the Aktaş Fault and the Çerkeş Faults. The Aktaş Fault is a 6 km wide, 30 km in length and N30E trending right lateral strike slip fault. It crosscuts the Jura-Cretaceous carbonates and Late Cretaceous-Miocene Galatian volcanic rocks along its extension. Late Pliocene-Early Quaternary aged terraces, the offset on streams by faults and epicenter distribution of the earthquake indicate that Aktaş Fault is probably active. For Çerkeş Fault, the geological data such as linear hot springs, current travertine formations and seismic activities reveal the presence of this fault. During the earthquake of 01 February 1944 with a magnitude of 7.3 (Ms) on the main seismogenic fault of the NAF, the Çerkeş Fault Zone became active, triggered and in some cases surface cracks developed. The earthquake of 07 September 1953 with a magnitude of 6.0 (Ms), originates directly from the Çerkeş Fault Zone and the epicenter is in the north Atkaracalar.

İnönü-Eskişehir-Cihanbeyli Fault Belt: İnönü-Eskişehir-Cihanbeyli Fault Belt is 430 km in length and 25 km wide fault zone. It extends between the west of İnegöl District in the northwest and Sultanhan (Tuz Gölü) in the southeast. The western half is generally WNW-trending and the eastern half is NW-trending normal fault with a right lateral strike-slip component (Özsayın and Dirik 2007, Özsayın et al. 2013). This fault zone was first described and interpreted by Şaroğlu et al. (1987).

Along the fault zone, pre-Miocene rock assemblages, Miocene-Early Pliocene lacustrine-stream sequences and Miocene volcanic units are observed. Generally, Plio-Quaternary terraces, hot spring and travertine formations are developed along this fault zone.

Grabens of various sizes (e.g. from west to southeast, İnegöl, Bozüyük, Eskişehir, Çifteler-Akgöl grabens; Yeniceoba, Yeşilöz, Hacımusa, Plio-Quaternary Cihanbeyli grabens) and horsts (e.g. Sivrihisar horst) are important structural elements along this belt.

Fault plane shear data show that the faults within this fault zone are oblique slip normal faults with right lateral strike slip component (Özsayın and Dirik 2007, Özsayın et al.

2013). The presence of approximately 100 m alluvial fans along this fault zone and the relative elevation of the Late Pliocene-Early Quaternary stream fault terraces by 400 m indicate that the velocity on the main fault is approximately 0.13 mm/year. However, some faults did not affect the current 30-50 cm thick soil cover at the top indicates that some segments are not active in the last period.

As a result, most of the faults within the İnönü-Eskişehir-Cihanbeyli fault zone are active, and these faults have the potential to produce small and medium earthquakes. These are the 1956 Eskişehir earthquake and the 1975 Yenimehmetli earthquake (Ergin et al. 1967). However, the earthquake of 4.6 (Md) in Yenimehmetli in 1975 is the closest to the study area, but it is 160 km away from the study area. Both the geological data summarized above, and the low intensity seismic activity indicate that many fault segments forming the İnönü-Eskişehir-Cihanbeyli Fault Zone are active.

Tuzgölü Fault Belt: The Tuzgölü Fault Belt, which is defined by Ilkin Beekman (1966) and is one of the important structures leading to intra-continental deformation within the Anatolian plate, is a normal fault with a right lateral strike-slip component. It is approximately 220 km in length and extends between Hasandağ in the southeast and Paşadağ in the northwest.

The section of the Tuzgölü Fault Zone between Hasandağ (Aksaray) and Paşadağ is quite linear and consists of lots of fault segments. Plio-Quaternary aged, undeformed Plio-Quaternary units, pre-Pliocene aged, highly deformed (folded, folded and thrusted) pre-Miocene units, Miocene-Quaternary aged Cappodocian volcanics, travertine outcrops, high angle alluvial cones and conglomerate of terrace indicate that this fault is active.

Lack of seismic data and the earthquakes that are assumed to occur on this zone (Kırşehir; 1983 Sofular-Köşker earthquake; Ms = 4.8) and (Paşadağ; 2007 Bala earthquakes; ML = 5.6) shows the activation of fault at the northern end of the fault zone. It also shows a seismic gap throughout the fault zone.

As a result of the fault plane slip data analysis, it was observed that Tuzgölü fault is normal fault and 0.12mm/year vertical slip was proposed (Özsayın et al. 2013).

Korgun-Kalecik-Kesikköprü Fault Belt:

Korgun-Kalecik-Kesikköprü fault belt extends in 200 km length between the Ilgaz district in the north and the Paşadağ elevation (northwest end of Tuzgölü) in the south. In general, this fault zone is the western boundary of the Paleocene intrusive rocks forming the Kırşehir Massif in the east.

The fault zone, which consists of many small-sized faults, cuts and controls Kızılırmak and many streams, controls undeformed Plio-Quaternary aged terrace sediments, cuts Paleozoic metamorphics, Late Cretaceous and Eocene basin sequences, various rock types of the Late Cretaceous ophiolite mélange, Oligocene-Miocene rivers and lacustrine sequences, and causes to form folds and thrusts within these rocks.

The possible total deformation rate along this fault zone is about 0.2 mm/year. It is very low and can only produce small earthquakes. The earthquake of Korgun (Çankırı) which occurred on 09 March 1902 (Ambraseys and Finkel, 1987) was caused by this fault. In Çankırı province, 3000 houses were almost completely destroyed, and 4 people were died and nearly one hundred people were injured (Eyidoğan and others 1991). This fault zone, which has been silent for 112 years, has not produced a destructive earthquake to date, except for a small number of small earthquakes. This fault zone creates a seismic gap, but its potential to produce a high magnitude earthquake is very low.

3.3. The Seismicity of Ankara Region

The map of Turkey Earthquake Belts published by ministry of public works indicates that the study area is located in the 2nd and 3rd degree earthquake zones (Figure 3.3). In this study, seismicity and seismic events occurring in the study area until 1900 are classified as Historical Earthquakes and Recent Earthquakes occurring since the beginning of 1900. These earthquakes are summarized below.

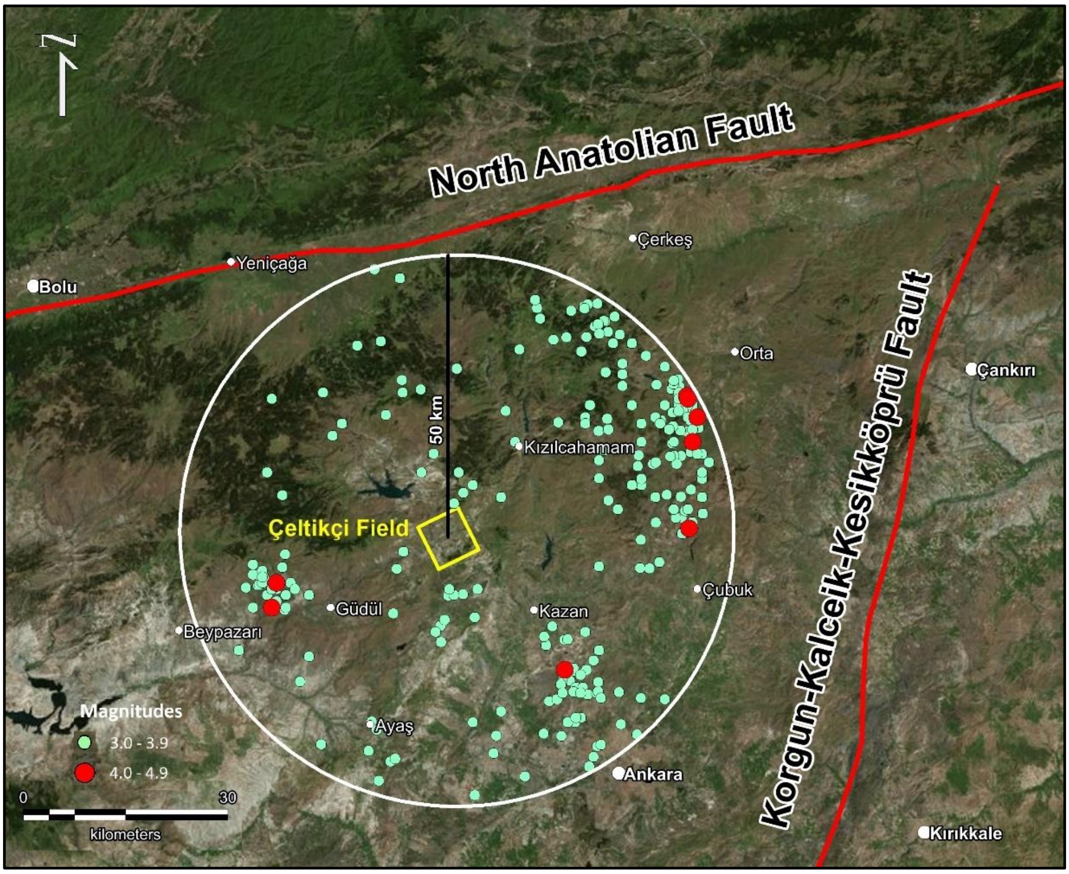

Figure 3.3. The seismic map of study area and its vicinity (Data is from ERD, 2014b).

3.3.1. Historical Earthquakes

Although the historical earthquakes occurring within the study area have not been reliably documented, they have affected Ankara and nearby settlements except for earthquakes caused by the North Anatolian Fault. These are;

1668 Earthquakes:

In the catalogs published by various researchers, seven separate earthquakes occurred in July 1668 are mentioned. These are 3 and 10 July 1668 Bolu-Kastamonu earthquakes (Soysal et al., 1981), 12-15 August Ankara earthquakes (Ambraseys and Finkel, 1995), 17 August 1668 North Anatolian earthquake (Soysal et al., 1981), and 1668 Bolu-Kastamonu-Amasya earthquake (Ergin et al., 1967). These earthquakes affected Central Anatolia and caused destruction and damage in and around Kale and Beypazarı (Ambraseys and Finkel, 1995).

The earthquake of 12 August 1668 began with shock in the last days of June 1668 and caused severe damage to Beypazarı and death of seven people on 12 August 1668 (Ambraseys and Finkel, 1995). The second earthquake of similar magnitude was repeated in Ankara three days after the first and during this earthquake, the houses around Ulus and the walls of Ankara castle were severely damaged and two people lost their lives (Ambraseys and Finkel, 1995).

1875 Mamak (Ankara) Earthquake:

This earthquake was indicated with a magnitude of VI in the study prepared by Ergin et al. (1967). It is not certain whether this earthquake has occurred.

In summary, no historical earthquakes occurred within the borders of Ankara except for 1668 and 1875 earthquakes. However, although five separate earthquakes occurred in the near regions of Ankara are included in different catalogs, except for one of them, they did not cause any damage or loss of life in Ankara province.

3.3.2. Recent Earthquakes (1975-2013)

There are total of 20 earthquakes that occurred in or in the vicinity of the Ankara, affecting the city center of Ankara or the smaller settlements connected to it. The magnitudes of these earthquakes are ranged from 4.0 to 7.4. Some of these are;

30 July 1975 Yenimehmetli (Polatlı) Earthquake: The epicenter of earthquake with a magnitude of 4.6 (Ms) and 2 km in depth is in the north of Yenimehmetli town (Kalafat 1998) and 130 km away from the Çeltikçi area. The earthquake felt strong in Ankara did not cause any loss of life and serious damage, but wall cracks were observed in buildings located close to the epicenter. Although there is no focal mechanism solution, it is considered that the earthquake originated from faults trending WNW-ESE.

21 April 1983 Sofular-Köşker (Kulu) Earthquake: The epicenter of earthquake with a magnitude of 4.8 (Ms) and 10 km in depth is in the west of Sofular village (Kalafat 1998) and 140 km away from the Çeltikçi area (Eyidoğan et al. 1991; Kalafat 1998). This earthquake, which is felt as a V intensity in the city center of Ankara, caused the destruction of two houses in Sofular village and the destruction of about 60 houses in Köçker village. There was no loss of life during the earthquake. The focal mechanism solution of the earthquake revealed that the source of the earthquake is an approximately NNW-trending fault with a normal component.

01 June 1987 and 25 September 1992 Kazan (Ankara) Earthquakes: The epicenter of earthquake with a magnitude reported as of 3.0 and 2.7 (Md) is in the southwest of Kazan and 40 km away from the Çeltikçi project area. Although there is no information about the environmental impact of the earthquake, the focal mechanism solution of the earthquake gives normal fault which is the oblique component (Baran 1996). The field observations show that this earthquake was caused by a normal NE-SW trending fault between the southwest of Kınık village and Yenikayı village.

04 April 1995 Başbereket (Ayaş) Earthquake: The epicenter of earthquake with a magnitude of 4.0 (Md) and 11 km in depth is Başbereket village and 30 km away from the Çeltikçi area. There is no information about the effects of the earthquake. The focal mechanism solution of the earthquake was made by Baran (1996) and it is indicated that the earthquake was caused by normal faulting which is a significant right lateral strike slip component. The field studies show that this earthquake was caused by a fault segment which is trending the NNE forming the Ayaş Fault belt.

22 August 2000 Uruş (Beypazarı-Ankara) Earthquake: The epicenter of earthquake with a magnitude of 4.8 (Md) and 6.2 km in depth is north of Uruş and 30 km away from the Çeltikçi area (Demirtaş et al. 2000). The earthquake caused significant damage to 12 concrete villas in Uruş and some houses in the villages of Kırkkavak, Tahtacıörencik, Kavaközü, Kayıköy and Karacaviran. Although the focal mechanism of the earthquake has not been solved, it is highly probable that the earthquake originated from NE-trending fault. Since the internal deformation continues at a low speed, the faults here can be the source of small and rarely medium sized earthquakes.

20 December 2007 Bala (Ankara) Earthquake: The epicenter of earthquake reported with a magnitude of 5.5 (Mw) and 10 km in depth is south of Bala and 80 km away from the Çeltikçi area (Zünbül et al. 2008). It caused damage in the villages of Sırapınar, Yeniyapan and Afşar in the south of Bala, and there was no loss of life. Earthquakes are medium magnitude and strongly felt in the central districts of Ankara but are also felt in surrounding cities such as Kırşehir, Kırıkkale, Niğde and Yozgat. Although the focal mechanism solutions of the earthquake are varied, all give lateral strike-slip faulting. The earthquake occurred along the NE-trending fault (probably the southwest continuation of the Ezinepazarı-Kırıkkale fault) and was triggered and continued along the NW-trending fault (northern end of Tuzgölü fault).

3.4. The Active Tectonics of the Çeltikçi Graben

The Çeltikçi Graben is defined as a closed basin developed by the effects of Miocene aged volcanism. Graben, which is controlled by faults on the northern side, has a sedimentary contact on the southern side, which requires different definitions. In defining the graben, the area is primarily divided into i) Miocene and post-Miocene-pre-Pliocene, and ii) post-Pliocene. The structures belonging to these periods can be divided into two groups. The first of these is the structures that developed between Miocene and Pliocene periods. The paleotectonic structures that caused the deformation of all rock units before the Pliocene, i.e. fold, lateral strike-slip faulting and thrust faults, were developed during the compression period. For example, the reverse component lateral strike slip faulting at the northern edge of the graben is the structure of this period. These structures are not active today and have no significant impact on the seismicity of the region. The second group of structures is the extension or transtension structures developed within the extensional regime that began in the Pliocene and is still active today. These are neotectonic structures.

Current Çeltikçi Graben is the remnant of a huge basin. Unlike its first dimension, the graben is very narrow and elongated in the N50E direction. It is 30 km in length and 5 km in width. It is a depression area with an average height difference of 270 m between the center (730-800m) and the edges (950-1000m).

Peçenek Faults: Peçenek Faults are composed of a number of faults. It is approximately 3 km in width, and 30 km in length. The trend of the fault is nearly N50E and the fault type is right lateral strike-slip with normal component. Although the dominant component is a right lateral strike-slip, there is a significant amount of oblique-slip normal component. Peçenek Faults develop completely within the Miocene volcanics. There is not enough data for the current activity of Peçenek fault. However, although the epicenters of the earthquakes in the close area - for example Çamlıdere earthquakes that occurred in 27 February 2003 and varying in size from 2.7 to 4.0 (Md) indicate the presence of seismic activity, the faults here may be the source of small and rarely medium sized earthquakes.

Ayaş Fault: Ayaş fault is a normal fault with right lateral strike slip component. It is 2 km in width and 20 km in length. The trend of the fault is N24E. It extends along Oltan, Ayaş and Bayramköy.

Ayaş Fault cuts various rocks (Paleozoic schists and marbles, Jurassic-Cretaceous limestones, Paleogene volcanics-clastics and carbonates, Miocene volcanics and sedimentary sequences), thrust faults formed within and between Miocene and older units, the fold axes, volcanic domes and cones. Plio-Quaternary terraces are important structures that show vertical movement.

The kinematic data of the Ayaş Fault indicates a total of three phase. The first one is thrust, the second is strike-slip faulting, and the last and the youngest is normal faulting (Demirci 2000). The kinematic analysis of the measurements representing the youngest movement shows that the movement that is still active today is a normal faulting and there is an extension in Ayaş region in the NNW-SSE direction. Although there is not enough seismic data, Ayaş fault is an active structure that can produce small and medium earthquakes (magnitude 5 and smaller).

Bayındır Faults: These faults are located in a zone with 20 km in length and 10 km in width. There are parallel E-W trending faults in this zone. The fault in the north is located between the village of Kızık in the east and the south of Peçenek district in the west and the others are one km north and south. Bayındır faults crosscuts Miocene volcanics and highly folded Miocene lacustrine sequences. Bayındır faults form a step-like structure with a northern look. The northern blocks of the faults have downthrown and small grabens have been formed.

Thick talus deposits and cones formed along the fault zone. As a result of kinematic analyzes made from well-preserved fault planes show that normal fault with minor lateral components.

The linear water resources, presence of fault breccias and talus indicate that it is a potential active fault. In addition, the epicenters of the 8 small earthquakes that occurred between 27 February 2003 and 11 March 2003, and whose magnitudes (Md) ranged between 2.7-3.8 show that the faults are seismically active. Since the proposed annual motion rate in this area is very low (0.25 mm/year), due to the low speed development of intra-continental deformation, faults in this area may be the source of small and rarely medium sized earthquakes.

Kızılcahamam Fault The total length of this fault is nearly 20 km and it starts northwest of Kızılcahamam and extends in NW-SE direction to Kızılcahamam district. Plio-Quaternary terraces have been suspended at different heights to faults that offer step type geometry. This is a fault group that does not have serious earthquake potential.

3.5. Fault Pattern of the Study Area

Since the study area is a region where the effects of tectonism are seen intensively, there are many major and minor faults. The slickenlines, juxtaposition of rocks, drag folds, and cross cutting relation help to determine the types of the faults located in the area. The differentiation of the deformational phases is very important to reveal the structure of the area. The most useful data to differentiate the order of phases is overprinting in the slickenlines. The cross-cutting relationship of the structures is also important to separate the deformational phases to each other.

The faults observed within the Miocene units are generally results of compression. The type of the faults is strike slip and reverse with dextral components. The general trend of these structures is ENE-WSW orientation. The same trend is also observed for the younger faults. Most of them are nearly parallel to the Miocene confined faults. It can be explained by the reactivation of post-Miocene faults during extension period. These faults are probably the relics of the post-Miocene - pre-Plio-Quaternary deformational phase. The effect of this period can be observed on structures of Plio-Quaternary unites.

The faults within the study area are divided into some groups according to their attitudes and they are N-S trending faults, E-W trending faults, Kirmir valley and Northern margin faults (Figure 2.1).

N-S trending ones are classified as Kocalar and Polatcreek Faults; E-W trending ones are classified as Çavuşlar Fault-1, Çavuşlar Fault-2, Peyikler, Adaköy, and Kirmircayi valley faults (Çeltikçi Faults) and Northern margin Fault.

3.5.1. N-S Trending Faults

The strikes of the high angle normal faults, folds and stratigraphic units are generally perpendicular to the N-S to NW-SE trending faults that are dextral strike-slip or oblique-slip faults. The latest activation age of these faults is probably post-Miocene - pre-Holocene.

Kocalar Fault (KF); Kocalar Fault is a N-S to N30W trending high angle oblique normal fault (Figure 2.1 and 3.4). It extends for 5.5 km from south of Kocalar village to west of Çavuşlar village and to Kirmircayi Stream. There is no slip data because of the soft nature of the sediments. However, the normal offsets and dragfolds of the faults help to define the type of fault as oblique normal faults. The interpretation about the offset amount is more than 50 m. The eastern block of the fault is downthrown during the latest fault activity. There are lots of indication of the faults such as linear narrow valleys, landslides, truncation of Abaci tuff, downthrown and truncation of syncline and drag folds. It is interpreted that age of the faulting is probably post-Miocene and it corresponds to post-Plio-Quaternary- pre-Holocene. The Kocalar fault shows different fault mechanism in time. The western block is downthrown for post-Miocene period. Later the mechanism changes during post-Pliocene-pre-Holocene and the eastern block is downthrown.

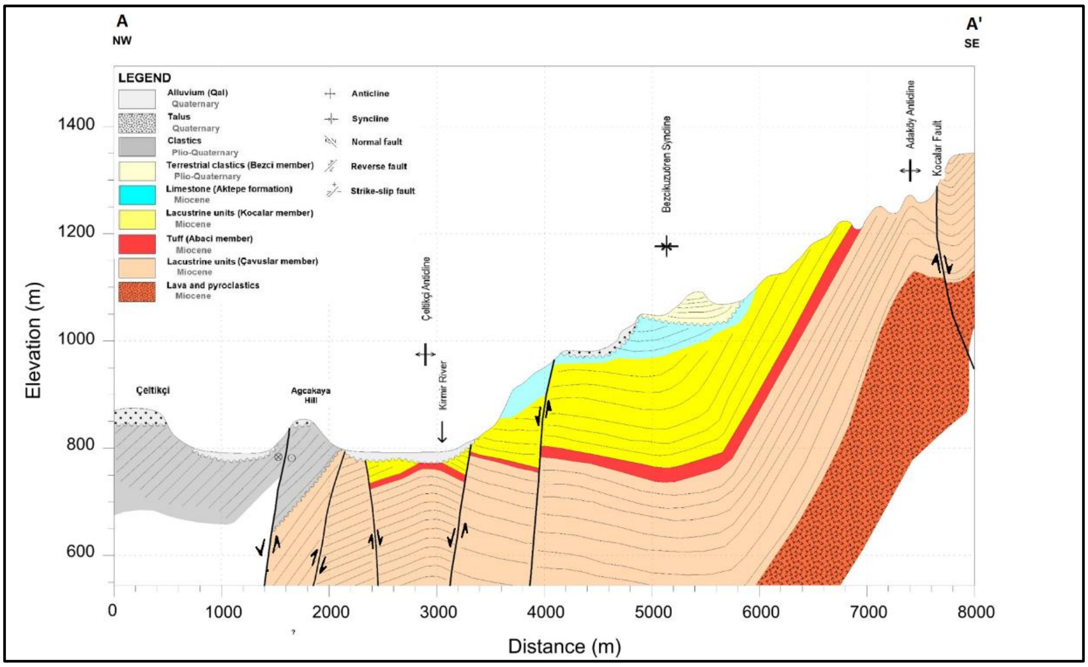

Figure 3.4. The cross-section A-A'.

Polatcreek Fault (PcF); The Polatcreek Fault extends along Polat creek for 2 km (Figure 2.1). The sudden changes in strikes of beds, truncation of coal beds and landslides are the indicator of this fault. The trend is nearly N20W and the possible offset is 500 m right lateral. It is observed that the western block is uplifted. There is no slip data about this fault.

3.5.2. E-W Trending Faults

Çavuşlar Fault-1 (CF-1); Çavuşlar Fault-1 is a strike-slip fault with normal component. It extends in N65E direction for 2km to the north of Çavuşlar. The southern block of this fault is downthrown. This fault can be easily observed generally within the Abacı tuff in the field (Figure 2.1). The analysis of the slip data reveals a left lateral strike slip fault with normal components developed by the effects of NE-SW compression. Later, the direction of the stress fields changes, and the WNW-ESE compressional regime causes right lateral strike slip faulting.

Çavuşlar Fault-2 (CF-2); Çavuşlar Fault-2 is a right lateral strike-slip fault with normal component. The trend is N72E and it extends for 3 km to the east of Gümele. The northern block of this fault is downthrown. The cross-cutting relation with the Abaci tuff is clearly observed with a fresh morphology (Figures 2.1). The slip data reveals that the type of fault is right lateral strike slip with normal component. This fault is the result of WNW-ESE compression. In addition to the slip data; rock falls, landslides, and hanging Quaternary are the indication of faulting. It is estimated that possible throw is more than 40 m. The motion of the fault is observed as right lateral and also left lateral. This causes difficulties to calculate the exact throw of the fault.

Peyikler Fault (PF); The Peyikler fault is a normal fault with a trend of N60E. There are lots of indicator of this fault such as silicification, landslides, sudden slope changes, normal drags, linear vegetation, talus deposits and rock falls. There is no slip data.

Adaköy Fault (AF); The Adaköy Fault is a normal fault with a trend of EW direction. It is observed that the fault extends for 2 km to the north of Aşağı Adaköy village

(Figure 2.1). The mylonites, slickenlines, brecciation and travertine development are the most important indicators of the fault and they are well-preserved. The slip data collected from fault plane (E-W/77N/75NE/Normal faulting, E-W/77N/79NE/Normal faulting and E-W/77N/82NE/Normal Faulting) indicates that the type of the fault is normal fault and it developed by the results of NNE-SSW extension. The northern block of this fault is downthrown. Post-Plio-Quaternary- Pre-Holocene age is estimated for Adaköy Fault.

3.5.3. Kirmir Valley Faults

Çeltikçi Faults (CeF); The general trend of Çeltikçi faults is in N69E direction and they extend from Çeltikçi to north of Gümele for more than 3 km (Figure 2.1 and 3.5) The indicators of the faults are Fe-staining, silica travertines, brecciation, silica veins-dykes and silicification. In addition to these, the slip data is observed on the fault plane. It indicates that the type of fault is reverse to right lateral strike slip faults with reverse components. These mechanisms are the result of NNW-SSE to WSW-ENE compression. The northern blocks are thrusted.

3.5.4. Northern Margin Faults

It is clearly observed that the northern margin of Çeltikçi graben is highly elevated. The northern margin faults extend for more than 6 km from far north of Çeltikçi to far north of Abaci village. There are lots of indicators of faults such as Quaternary talus deposits, sudden slope changes, landslides and spatial distribution of Holocene terraces. In addition to these indicators, it is possible to find slip data on the fault planes and they reveal that the type of fault is right lateral strike slip and reverse faulting developed by the results of NW-SE compression. The N14W trending normal fault developed under NNE-SSW extension lately crosscut these faults.

It is estimated that there is a buried fault along the Kirmir Stream, and the southern margin of the Kirmir stream is controlled by this fault (Figure 2.1). The possible length of this fault is approximately 11 km and it is located between south of Mahkemeağacın town and south of Çeltikçi village (Figure 2.1). The Miocene units can be observed elevated where northern block is downthrown.

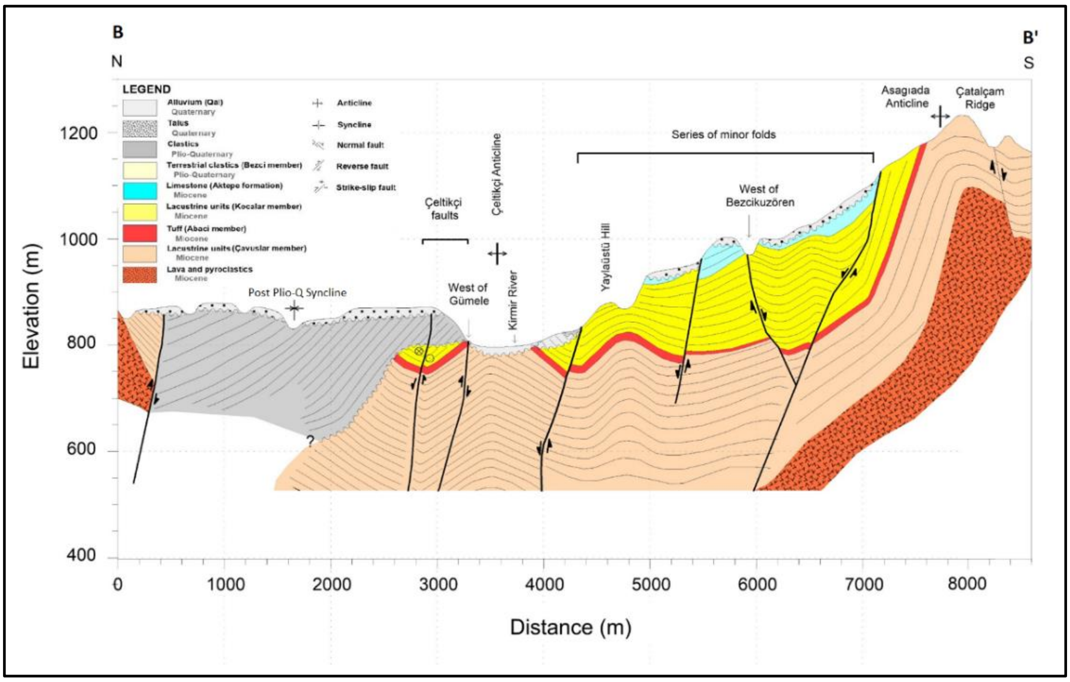

Figure 3.5. The cross-section B-B'.

3.6. Analyses on Structures

During field studies, two different types of structural data which are dip-strike of bedding planes and slickenlines from fault planes were collected. However, poorly documented joints and related analysis are the missing elements of the survey.

Rose diagrams are prepared from the strike data to analysis the trends of bedding planes and to identify the regional folding during post-Miocene and post-Plio-Quaternary – pre-Holocene periods. The software Win Tensor v.5.8.8 (Angelier Inversion Method) was used to analyze of the fault slip data. This software can help to clarify different deformational phases affected the study area.

3.6.1. Attitude of Bedding Planes and Folding

The most distinguishing geological structure of post-Miocene deformation in the study area is folding (Figures 2.1, 3.6, 3.7, 3.8 and 3.9). Various size of structures is observed, and they are ranging from outcrop-scale to 1:25 000 map-scale. There are syn-sedimentary folds in outcrop scale as well.

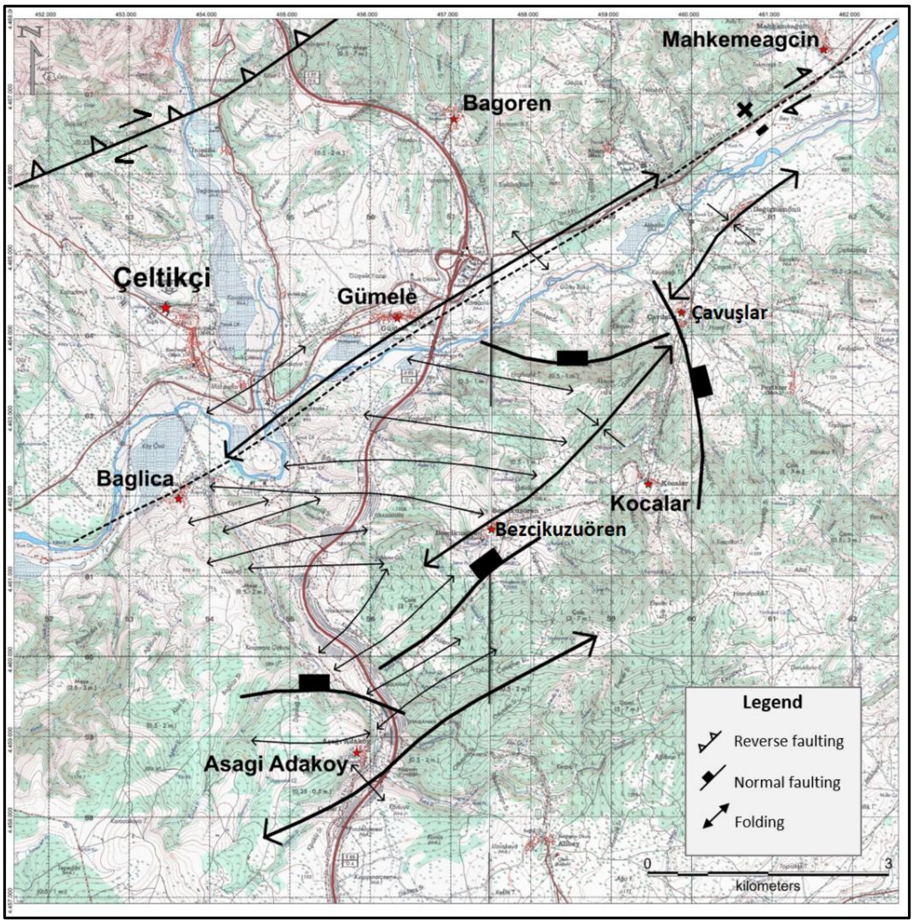

Figure 3.6. Major folds and fanning out minor ones.

On the other hand, the huge fanning out syncline cause a wide range in fold analysis (Figure 3.6). A major syncline of almost NE-SW trending is well-developed between Çavuşlar and Asagiada villages and minor ones towards west (Figure 3.6). There are series of anticlines and synclines with asymmetrical attitudes associated with the faults in the study area. Therefore, there might be blind thrusts beneath the folds where there are asymmetrical folds.

The most important data to understand the post-Miocene tectonic evolution in study area is the unconformity between Miocene units and Plio-Quaternary clastics. In some places, the angular difference between the attitudes of bedding planes of the Miocene units and Plio-Quaternary clastics is so small (Figure 2.1). It is very clear that there is a difference in the intensity of the deformations of these two rock packages.

Rose diagrams of bedding planes are prepared for measurements collected from the rocks of the same age to analyze folding and attitude of bedding planes. In order to have a better understanding, dip-strike data is separated for each rock packages except Quaternary units due to the lack of data to conduct reliable bedding plane analysis. A total of 466 dip and strike measurements are collected from Miocene and Plio-Quaternary units. The software GeoSoft is used to prepare the rose diagrams indicating the attitude of the strike of the bedding plane with and dip amounts of them.

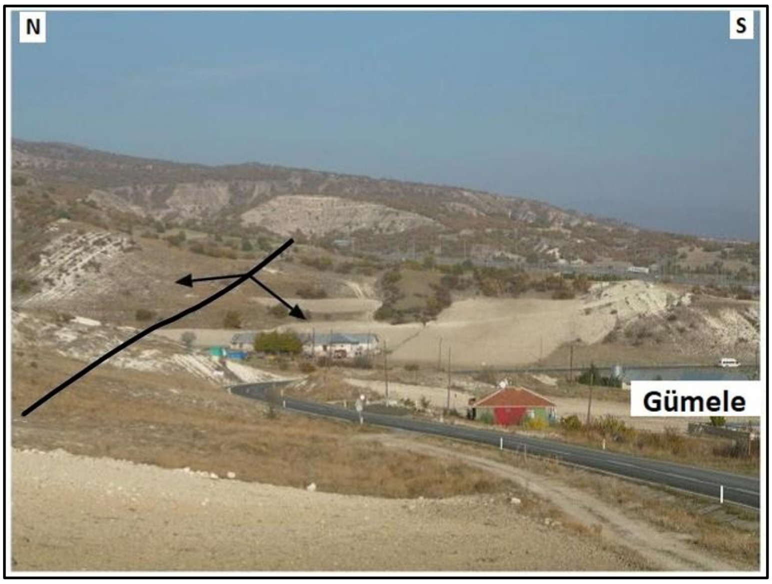

Figure 3.7. Series of post-Miocene close anticlines (W of Gümele town).

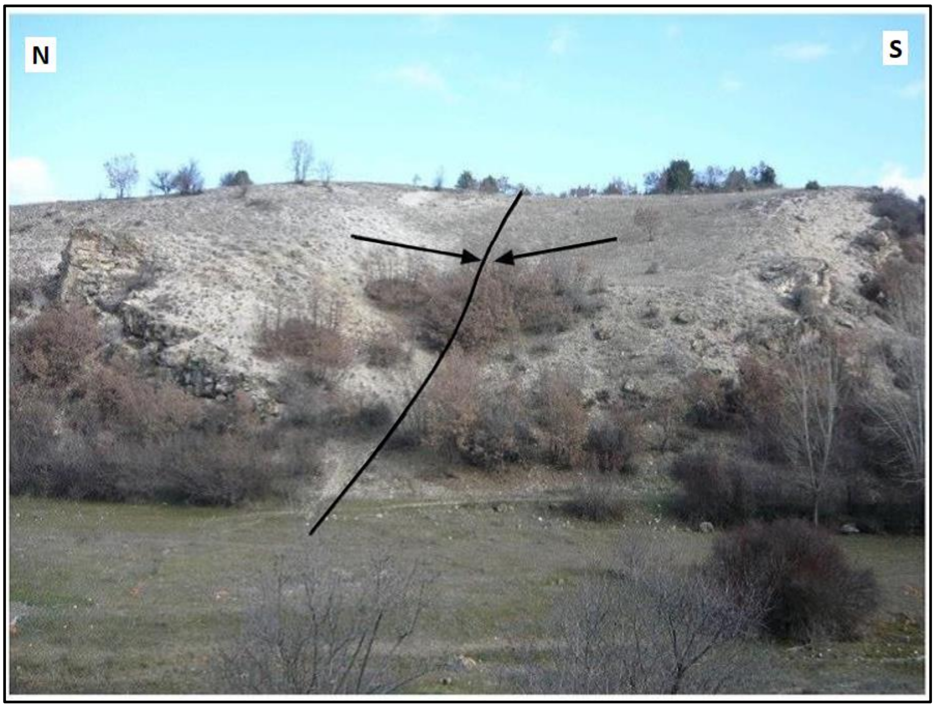

Figure 3.8. Series of post-Miocene open synclines (SW of Gümele town).

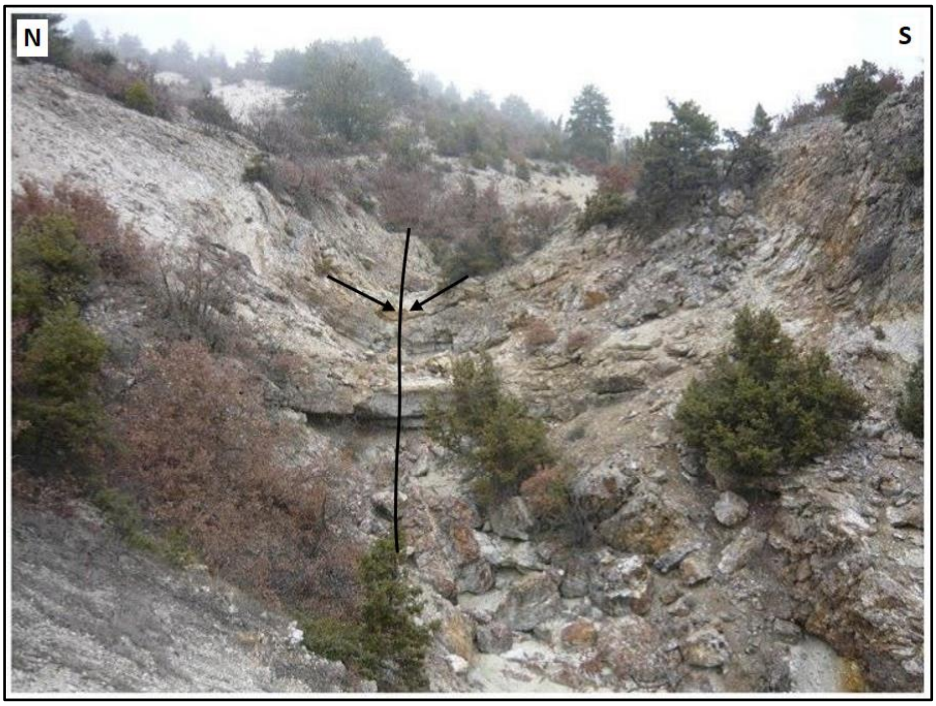

Figure 3.9. Series of post-Miocene close synclines (SW of Gümele town).

Bedding plane measurements were recorded from Miocene units in order to reveal the attitudes of bedding clearly. A total of 448 dip and strike measurements were collected from the Miocene units. The diagram prepared by the strike measurements from the Miocene units with 10 class intervals reveals that the dominant trends are at N75E and N85W directions (Figure 3.10). The diagram prepared by the dip amounts of bedding planes collected from the Miocene units has a broad range of values from 02° to 87°. Since the deformation rate is high in the Miocene units, the dip amount changes accordingly. For this reason, the dip amount is close to vertical in some places. The dip directions are generally in NNW and SE direction. (Figure 3.11). The research area is composed of folded structures within the Miocene units. The general fold axes trends indicated by the rose diagram are ENE-WSW (N75E) and almost E-W (N85W) for the Miocene units.

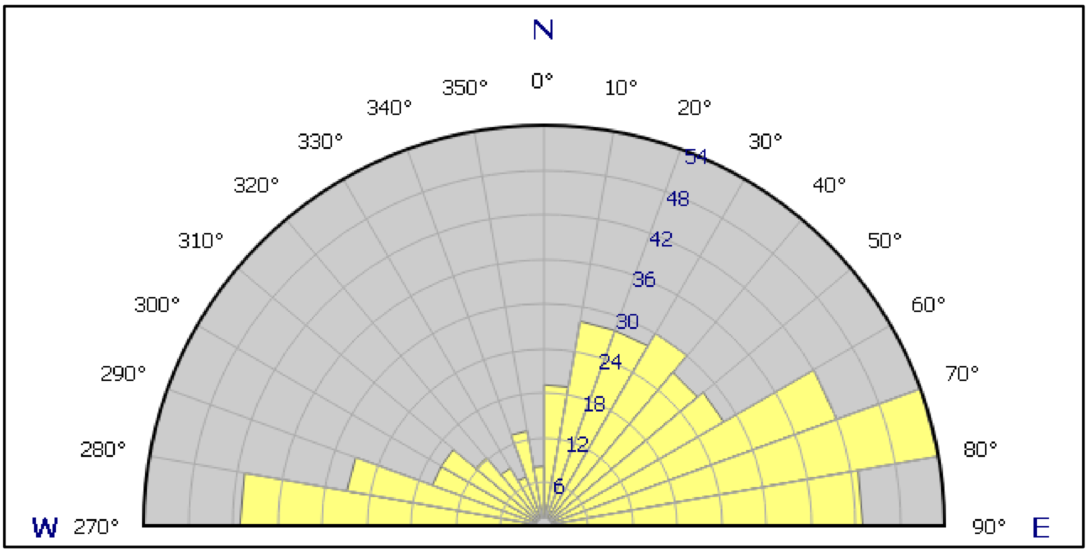

Figure 3.10. Rose diagram of the strikes of Miocene beds with 10 class intervals.

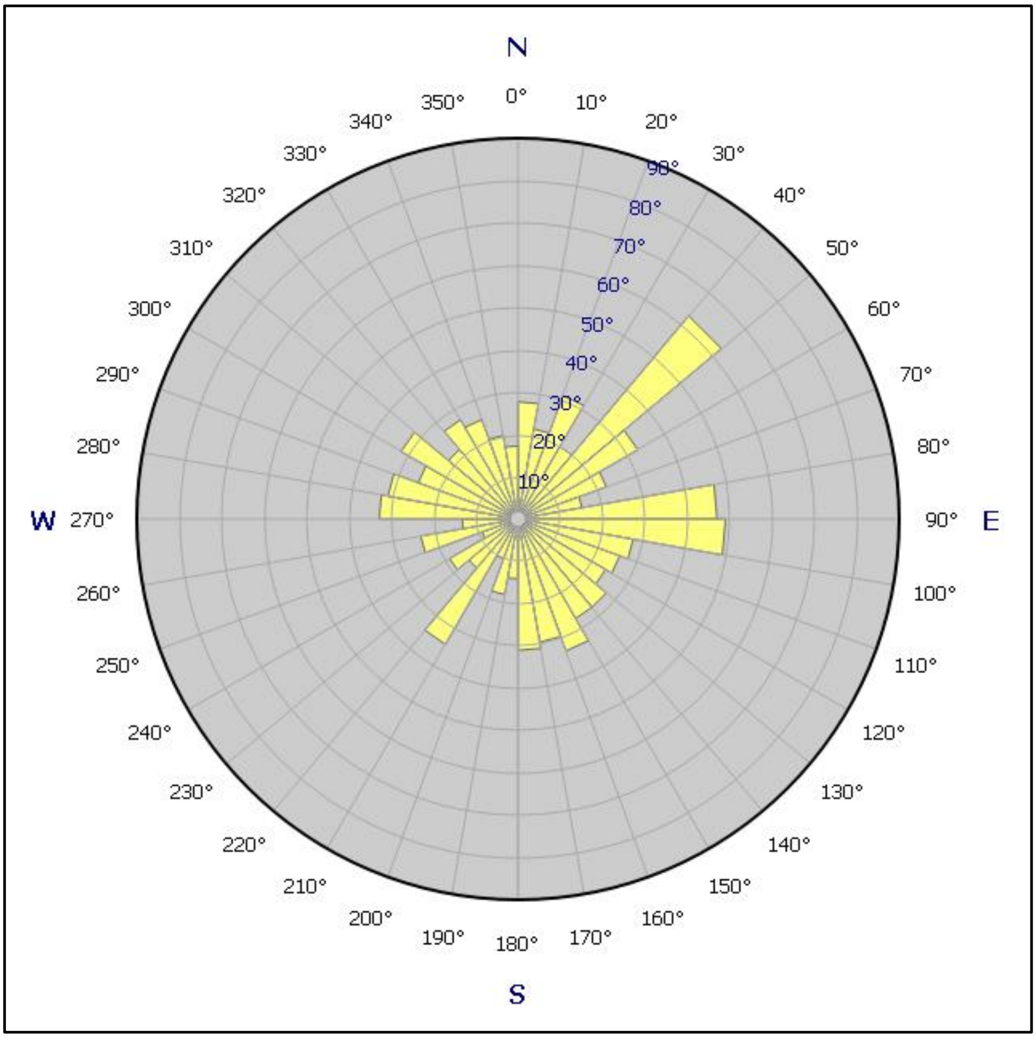

Figure 3.11. Rose diagram of the dip amounts of Miocene beds with 10 class intervals.

Although the dip and strike measurements taken from Plio-Quaternary units as not many as in Miocene units, they indicate a general trend of strike. A total of 18 measurements were collected from the bedding planes. The rose diagram prepared according to these measurements poorly pronounced a strike and folding trend of N80E due to a smaller number of measurements where Miocene units well pronounced a trend of ENE-WSW (N75E) and almost E-W (N85W) (Figure 3.12). The diagram prepared by the dip amounts has a range of values from 05° to 60°.The dip direction is generally in NNW direction. (Figure 3.13).

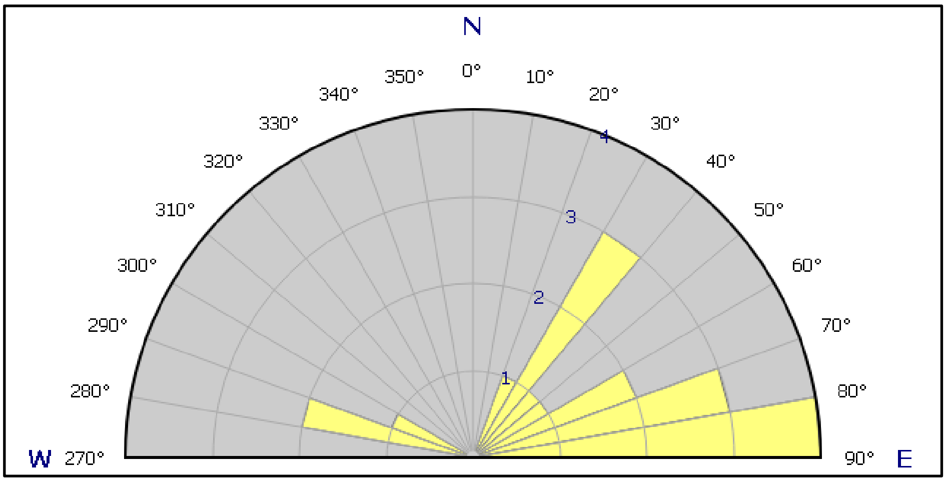

Figure 3.12. Rose diagram of the strikes of Plio-Quaternary beds with 10 class intervals.

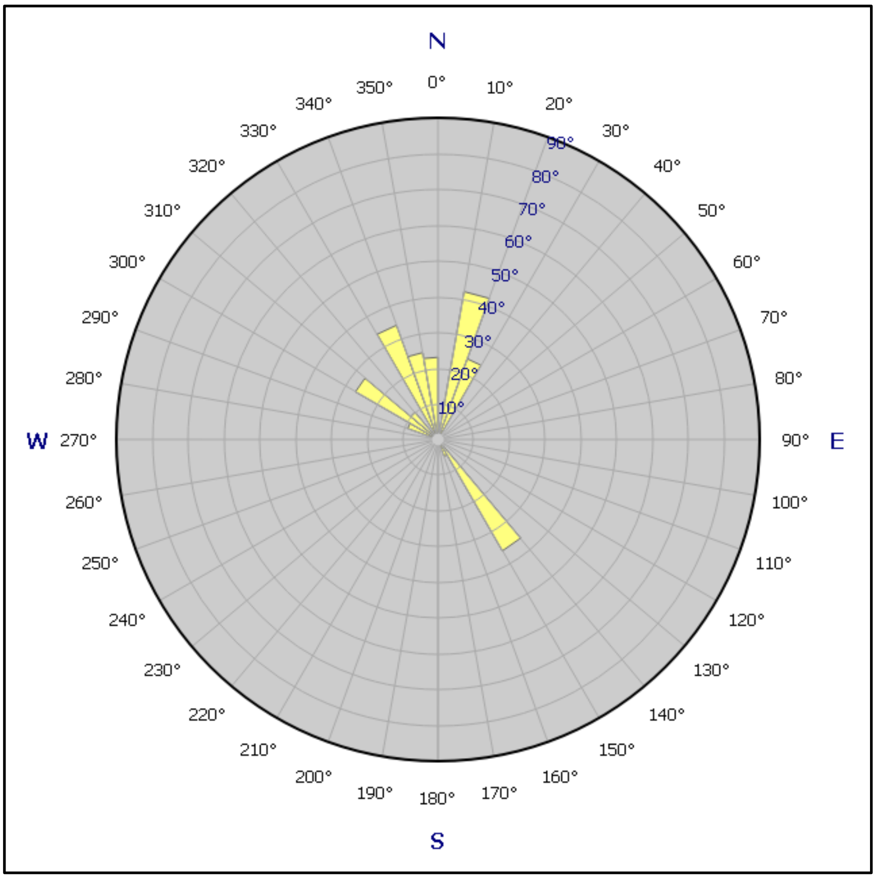

Figure 3.13. Rose diagram of the dip amounts of Plio-Quaternary beds with 10 class intervals.

Two different fold patterns with different frequencies and amplitudes manifest two compressional phases. The intensity of deformation within Miocene units are more than Plio-Quaternary clastics, so the folded structures are very common. Miocene units were underwent more contractional deformation phases. However, bedding plane values from Plio-Quaternary units indicate no compressive effects.

Another rose diagram was prepared for the silica veins. The dominant trend of these veins is approximately N25E/75SE (Figure 3.14).

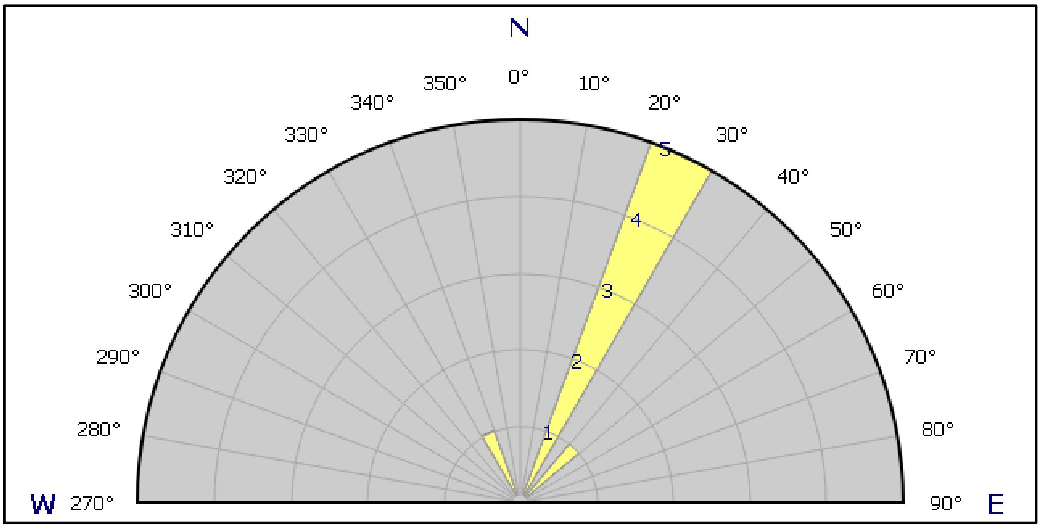

Figure 3.14. Rose diagram of the strikes of silica veins with 10 class intervals.

3.6.2. Slip Data Analysis

In tectonic researches, a kind of inversion method (Win Tensor Software) are used to analyses the orientation of maximum shear stress from the fault plane slip data. There are some parameters as strike and dip amount of fault plane, shear sense and rake to conduct this analysis. A total of four outputs are obtained by this technique as R (stress ratio), $\sigma 1$ (the maximum stress direction), $\sigma 2$ (the intermediate stress direction) and $\sigma 3$ (the minimum stress direction). The stress ellipsoid can be used to visualize them.

In addition, the orientation of the fault plane and the stress ratio R, which is calculated by the formula (σ2- σ3)/(σ1-σ3) states the slip direction (Angelier 1989, 1994).

It is the friction coefficient (ϕ) that controls the activation of fault. The weakness plane acts as a fault when the friction coefficient exceeds the initial friction. There are some factors controlling the behavior of the weakness plane. The stress regime is determined according to the principal stress axes (σ1, σ2, σ3), the amount of stress ratio (R), and the weakness plane is affected by the system of stress. When σ1 is vertical, the stress regimes are determined as radial extension (0.0<R<0.25), pure extension (0.25<R<0.75), and transtension or radial compression (0.75<R<1.0) according to the value of stress ratio (R). When σ2 is vertical, the stress regimes are determined as transpression (0.25>R>0.0), pure strike slip (0.75>R>0.25) and transtension (1.0>R>0.75). When σ3 is vertical, the stress regimes are classified as transpression (0.0<R<0.25) and pure compression (0.25 <R<0.75) (Figure 3.15).

The orientation of σ1 and σ3 principal axes, and their ratio(Φ) are important for the reliability of the results. Quality of the result can be accepted as good when the ratio is less than 0.4, but over 0.2. In this case, the σ1 axis is clear, however, σ3 axis was clear when the ratio exceeded 0.7 (Rojay and Karaca, 2008).

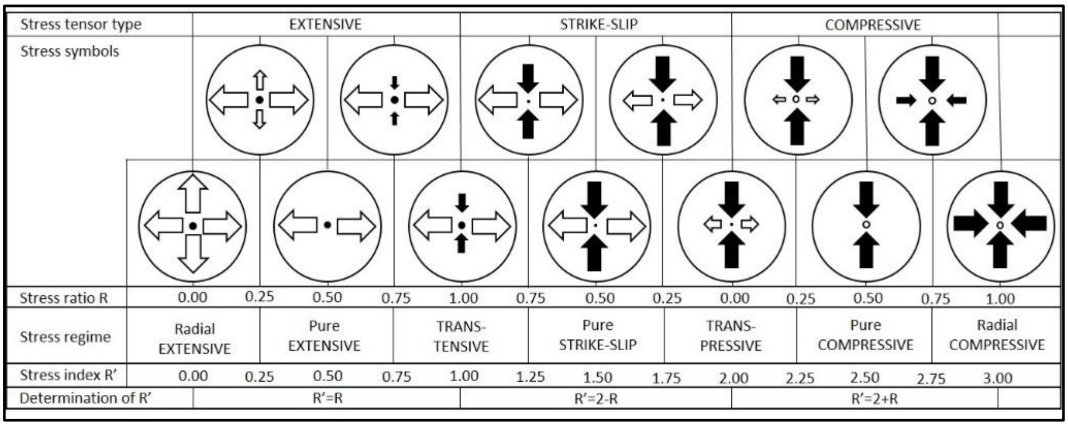

Figure 3.15. Illustration of the meaning of stress regime index R' versus stress ratio R and orientation of the principal axes of the stress ellipsoid (Delvaux et al. 1997).

The data collected during the field studies reveal some relation between the phase of the deformation (Figures 3.16, 3.17, 3.18, 3.19, 3.20 and 3.21).

The overprint and cross-cut relation are observed with the two sets of slickenside measurements. The older one, which is crossed and overprinted by the younger phase, is right lateral strike slip fault with normal component. The results of principal stress axes are 04/280 (σ1), 80/166 (σ2), 09/010 (σ3), and the principal stress difference (R) is 0.5. Therefore, it can be said that there is a WNW-ESE compression and it is observed that σ1 is horizontal. The younger set is occured under the E-W extension regime and it is a normal faulting. The results of principal stress are 71/171(σ1), 00/004 (σ2), 04/273(σ3), and the principal stress difference (R) is 0.5 (Figure 3.16). In brief, the normal faults overlap the right lateral strike slip faults.

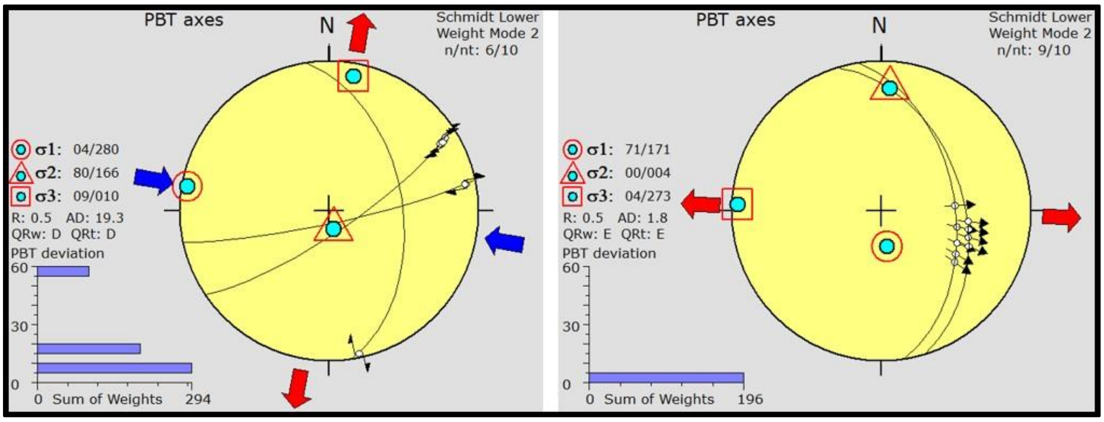

Figure 3.16. The results of principal stress axes of right lateral strike slip fault overprinting and cross-cutting normal fault (457740E-4468473N).

The other overprint relation is observed between the strike slip and normal faulting. The left lateral strike slip faulting with normal component is the older one occurred under NNE-SSW compression and WNW-ESE extension regime. The results of principal stress axes are 01/191 (σ1), 80/093 (σ2), 10/281 (σ3), and the principal stress difference (R) is 0.5. The younger one, which is normal faulting with right lateral component, was occurred under NNE-SSW extension regime and it overlaps the older left lateral strike slip faulting. The results of principal stress axes are 39/294 (σ1), 38/062 (σ2), 29/177 (σ3), and the principal stress difference (R) is 0.49. (Figure 3.17).

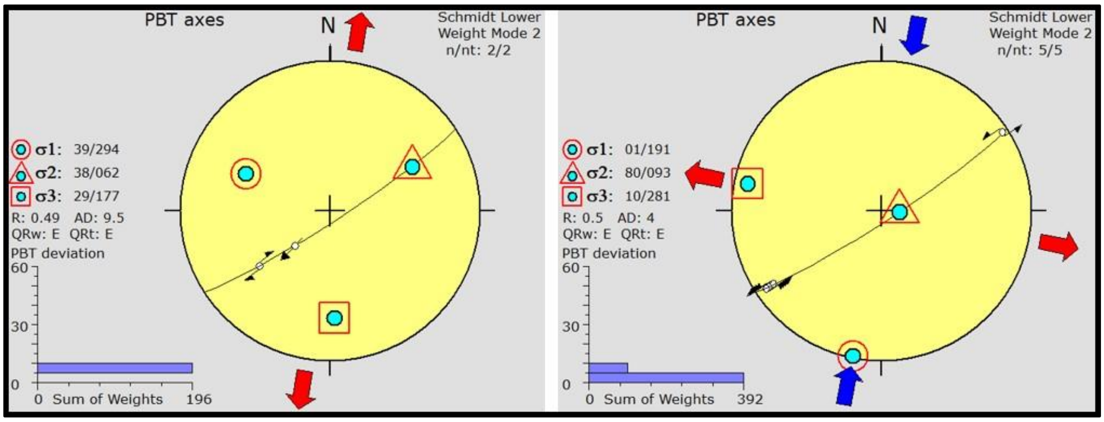

Figure 3.17. The results of principal stress axes of left lateral strike slip fault overprinting oblique normal faulting (457881E-4468080N).

The effects of reverse faulting are also recognized in the study area. The left lateral strike slip faulting with reverse component is occurred under N-S compression regime. The results of principal stress axes for N-S compression regime are 26/174 (σ1), 35/065 (σ2), 44/292 (σ3), and the principal stress difference (R) is 0.5. The effects of NW-SE compression are also observed on the reverse faulting. By the effects of this regime, the results of principal stress axes are 24/316 (σ1), 01/225 (σ2), 66/132 (σ3), and the principal stress difference (R) is 0.5 (Figure 3.18).

There is not much data showing the realationship between the reverse faults and the strike slip faults. However, normal faulting is the final stage of deformation in the study area and postdates the reverse and strike slip. Therefore, the reverse faulting is a part of strike slip compressional regime.

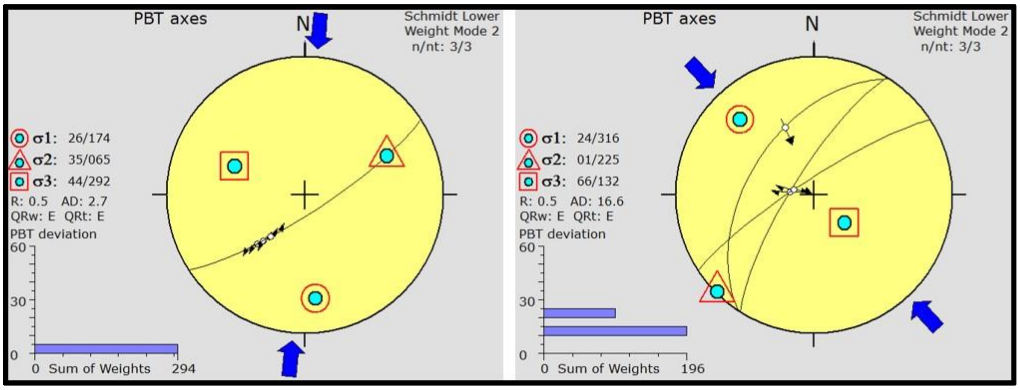

Figure 3.18. The results of principal stress axes of reverse faulting (454715E-4463399N).

The relation between left lateral and right lateral strike slip motion is observed on the same fault plane. The older one is left lateral strike slip faulting with normal component developed in NNE-SSW compression regime. The results of principal stress axes are 00/015 (σ1), 71/108 (σ2), 19/285 (σ3), and the principal stress difference (R) is 0.49. The younger one, which is right lateral strike slip faulting with normal component developed under WNW-ESE compression regime. The results of principal stress axes are 31/280 (σ1), 58/117 (σ2), 08/015 (σ3), and the principal stress difference (R) is 0.53. It can be observed on the fault plane that the right lateral strike slip fault overprints the left lateral strike slip fault (Figure 3.19).

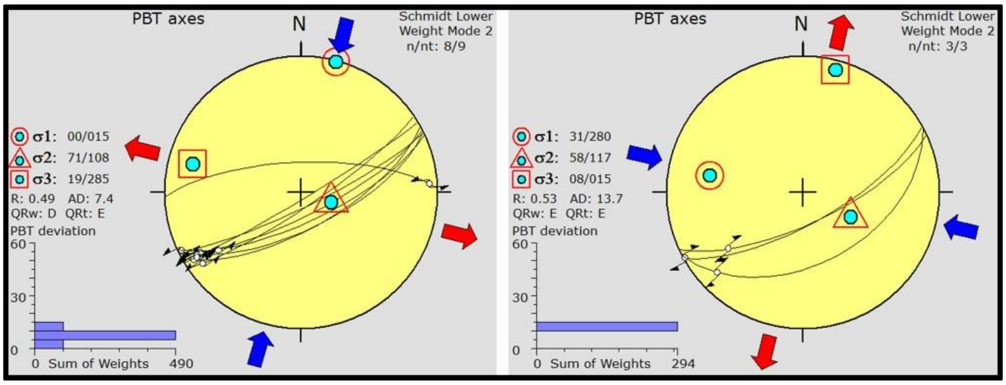

Figure 3.19. The results of principal stress axes of left lateral strike slip fault overprinting right lateral strike slip fault (459956E-4464514N).

The changes of stress orientation within time can observed with some analyses. The NNW-SSE compression is the older phase of deformation and the left lateral strike slip faulting with normal component is developed under this regime. The results of principal stress axes are 10/356 (σ1), 70/236 (σ2), 17/089 (σ3), and the principal stress difference (R) is 0.50. Later the regime changes, and the WSW-ENE to WNW-ESE compression controls the strike slip faulting. For the WSW-ENE compression, the results of principal stress axes are 16/087 (σ1), 70/230 (σ2), 12/354 (σ3), and the principal stress difference (R) is 0.50. The results of principal stress axes for the WNW-ESE compression are 30/291 (σ1), 60/106 (σ2), 02/200 (σ3), and the principal stress difference (R) is 0.47. (Figure 3.20).

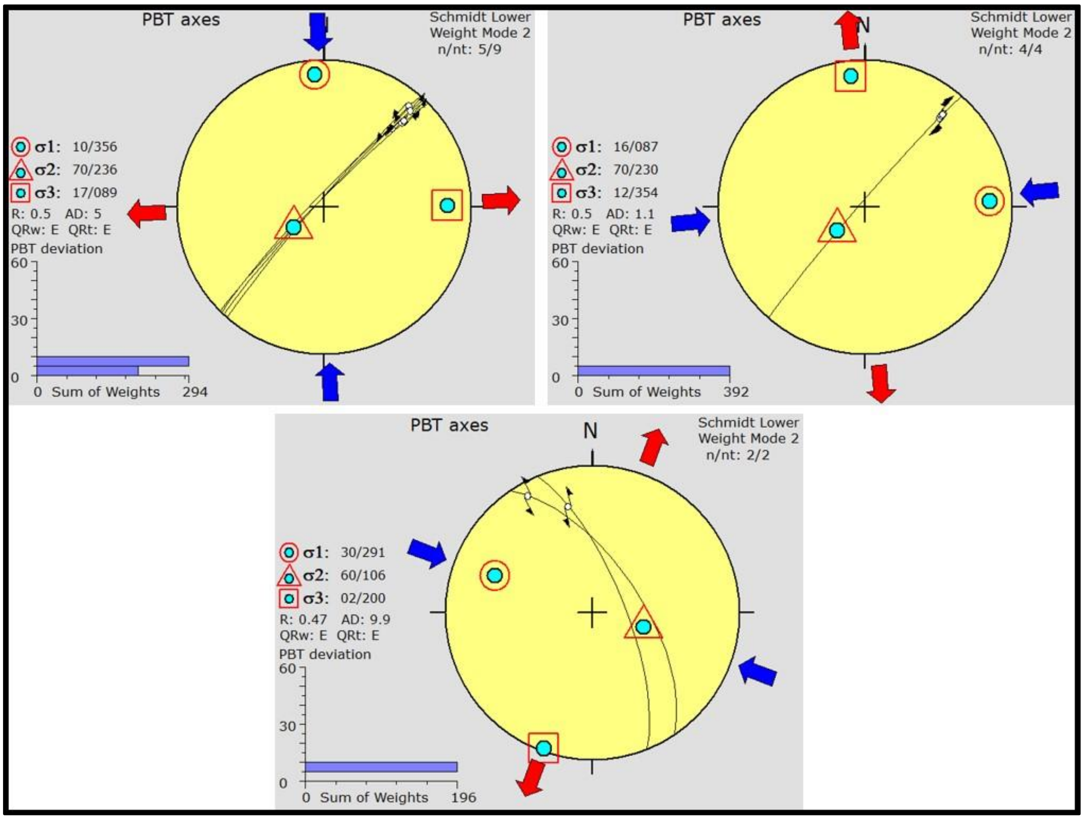

Figure 3.20. The results of principal stress axes showing the changes of stress orientation within time intervals (459781E-4464463N / 454925E-4463876N / 456051E-4464348N).

The final deformation phase is controlled under ESE-WNW to NE-SW extensional regime. For the ESE-WNW extension, the results of principal stress axes are 69/222 (σ1), 18/006 (σ2), 12/100 (σ3), and the principal stress difference (R) is 0.50. The principal stress axes are changing in NE-SW extension regime. (Figure 3.21).

The normal faults are developed within the last deformation phase in the study area and overprint all the right lateral strike slip and the left lateral strike slip faults.

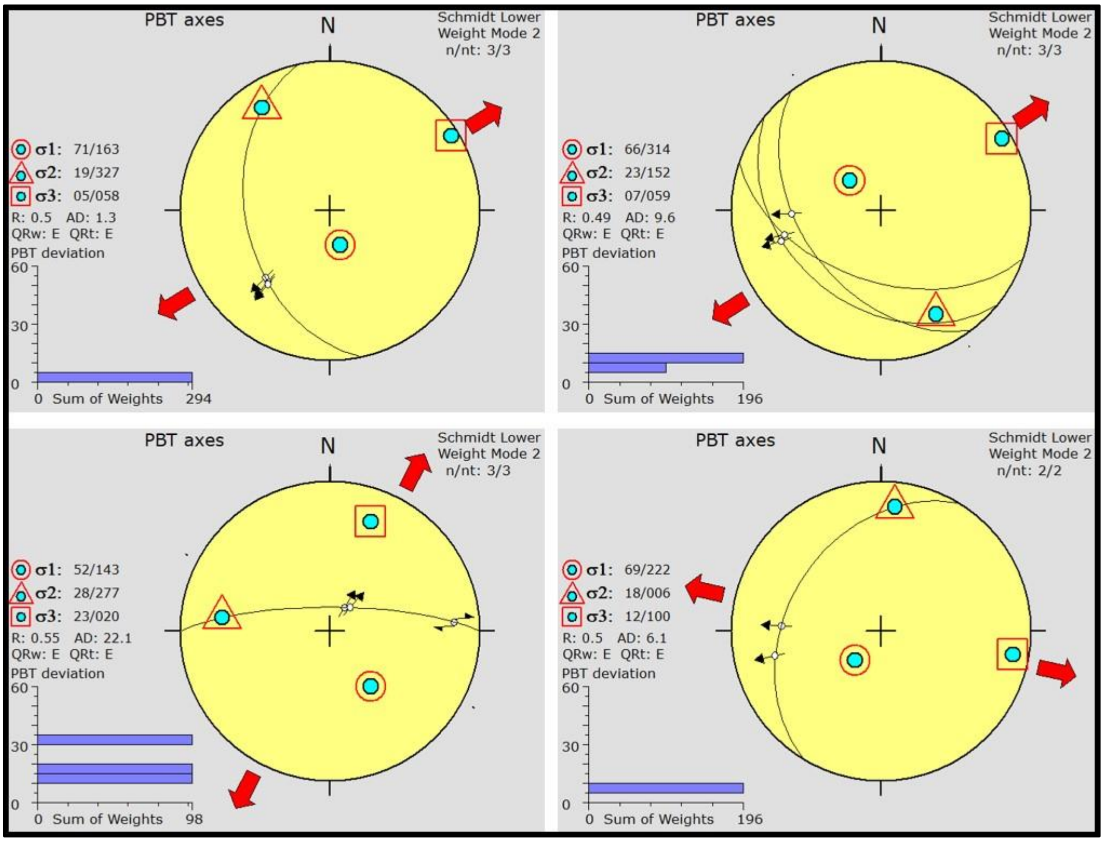

Figure 3.21. The results of principal stress axes of normal faulting developed under ESE-WNW to NE-SW extension regime (458072E-4459172N / 459926E-4464437N / 459239E-4459669N / 469924E-4463384 N).

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CHAPTER 4

DISCUSSION AND CONCLUSION

4.1. Discussion

The discussion on the post-Miocene tectonism of the Çeltikçi graben is focused on three main points: i) the results of slip data analysis b) timing of deformations c) origin of deformation. The results of this thesis show similar characteristics and some differences with previous studies on these subjects.

Rojay and Karaca (2008) studied on the post-Miocene deformation at the southeastern margin of GVP. The study area is located at the south of Çeltikçi area. Their studies were based on the fault plane slip data and bedding plane attitude of the Miocene and Plio-Quaternary units. The results of the fold analyses of Miocene units revealed an asymmetrical fold axis trending NE direction. The fold analyses of Plio-Quaternary clastics indicated asymmetrical fold axis trending NE. These results show that an almost identical trend for all post Miocene folds although there is an angular unconformity between Miocene and Plio-Quaternary sequences. This study also indicates information about the deformational phases obtained by the analyses of fault plane slip lineation data. The deformational phases of the area are explained as:

i) The NW-SE trending post-Miocene compressional regime.
ii) The NW-SE to NNE-SSW extensional regime, operating since the Pliocene.

Yürür et al. (2002) indicated several faults at the southern margin of the Galatian Volcanic Province. According to this study, the extension directions are in NNE-SSW, NW-SE and NNW-SSE. A volcano-sedimentary sequence is deposited by the result of this extension between the Early Miocene and Pliocene. They indicated that the sedimentation, volcanism and extension may begin in Early-Middle Miocene. Their comments about the stress fields related with the North Anatolian Fault movements and Galatian Volcanic Province extensions are different. It should be noted that the North Anatolian Fault represents the northern margin of GVP. It means that the extensional regime of GVP ended before the initiation of NAF at the Early Pliocene.

Kaplan (2004) studied the seismotectonic events at regional scale and also the neotectonics structures of the area around Uruş, which is located approximately at 35 km southwest of Çeltikçi. The study shows that the Ankara region is characterized by intermediate to small earthquakes. In Ankara region, the sources of the earthquakes are;

i) NE-trending sinistral strike slip faulting with normal slip component,
ii) NE and NW trending oblique slip normal faulting with strike slip component,
iii) ENE trending reverse faulting with strike slip component.

In this study, it is claimed that there are active faults in the Ankara region. These faults are in NE-, NNE-, ENE-, NE, and WNW- trending and generally oblique-slip faults characterizing an extensional neotectonics regime in the south.

Demirci (2000) revealed some results about the tectonic phases of the area between Beypazarı and Çeltikçi, NW of Ankara. In this study, slip data analysis are carried out by the use of Angelier's direct inversion method. This study indicates three main phases of deformation as;

i) E-W compressional regime, the oldest deformation phase.
ii) N-S compressional regime, the second deformation phase.
iii) Extensional regime, the last phase of the deformation.

Öngür (1976,1977) prepared the geological map an area close to Çeltikçi field. The faults exposed in the area were examined in detail. It was claimed for the first time that the faults form a graben and it is called as Çeltikçi graben. All the faults are indicated as a normal fault in this study with a general trend of NE-SW direction.

This thesis shows the deformational difference between the Miocene and Plio-Quaternary units. The intense folding and faulting are observed in the Miocene rock units. However, it is not same for the Plio-Quaternary units. They are gently folded and less faulted. So, it is clear that the attitude of folding is different in post-Miocene and post-Plio-Quaternary periods. There are some similar observations with the study of Rojay and Karaca (2008) about this subject.

The fault plane slip analyses conducted in this thesis indicate the compression during post-Miocene to Late Pliocene period. Later the regime changes, and the extensional deformational phases controls the Quaternary periods and onwards. It can be said that some results of the fault slip data analyses are conformable with some previous studies. The differences can be observed about the timing and origin of the deformation with some of the previous studies.

4.2. Conclusion

- The results of seismicity studies show that magnitude of the earthquakes occurring in and around the study area does not exceed 5. The closest source of earthquake that may affect the project area is the North Anatolian Fault located 60 km north. Huge offsets were not observed in the faults measured at the study area. The highest observable one is 50 m. To summarize, the seismicity of the area is low.

- The dominant strike trends of the Miocene units are N75E and N85W directions. General trend of axes of the folds measured is ENE-WSW (N75E) and almost E-W (N85W) trends in the Miocene units.

- The dip directions of the Miocene units are generally in NNW and SE directions. The dip amounts have a broad range of values from 02° to 87°. In some places, the dip amounts are close to vertical because of intense deformation in Miocene units.

- The rose analysis done on Plio-Quaternary units poorly pronounced a folding trend of N80E due to a smaller number of measurements where Miocene units well pronounced a trend of ENE-WSW (N75E) and almost E-W (N85W).

- The dip amounts of Plio-Quaternary units vary from 05° to 60° and the dip direction is generally in NNW direction. As the deformation intensity is less than that of Miocene units, the dip amounts are also relatively less.

- The studies reveal the deformational difference between the Miocene and Plio-Quaternary sequences. The Miocene units are strongly deformed. The intense folding and faulting are observed during the field studies. However, the intensity of deformation is low within the Plio-Quaternary units.

- The slip data analyses and field studies show different deformation phases between post-Miocene to Quaternary period. The left lateral strike slip faults are developed under the control of compressional phase. Later, the right lateral ones are developed by the effects of compression. The normal faults are the products of final stage deformation in the region. In brief, there is compressional regime during post-Miocene to Late Pliocene period. Later the regime changes and, the extension is observed during Quaternary and onwards.

- The slip data analysis shows Plio-Quaternary normal faulting overprints the pre-Pliocene strike-slip faulting.
- The relationship between the reverse faulting and strike slip faulting cannot observed or identified in the field. However, normal faulting postdates the reverse and strike slip faulting. Therefore, the reverse faulting can be considered as a part of strike slip compressional regime.

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