EVOLUTION OF THE ÇİÇEKDAĞI BASIN, CENTRAL ANATOLIA, TURKEY

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ERHAN GÜLYÜZ

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

Prof. Dr. Canan Özgen ______________________
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. Zeki Çamur ______________________
Head of Department, **Geological Engineering**

Assoc. Prof. Dr. Nuretdin Kaymakçı
Supervisor, **Geological Engineering Dept., METU** ______________________

Prof. Dr. Erdin Bozkurt
Co-Supervisor, **Geological Dept., METU** ______________________

Examining Committee Members:

Prof. Dr. Vedat Toprak ______________________
Geological Engineering Dept., METU

Assoc.Prof. Dr. Nuretdin Kaymakçı ______________________
Geological Engineering Dept., METU

Prof. Dr. Erdin Bozkurt ______________________
Geological Engineering Dept., METU

Prof. Dr. Kadir Dirik ______________________
Geological Engineering Dept., Haccettepe University

Assist. Prof. Dr. Arda Özacar ______________________
Geological Engineering Dept., METU

Date: 31.12.2009

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, Last Name: Erhan GÜLYÜZ

Signature:

ABSTRACT

EVOLUTION OF THE ÇİÇEKDAĞI BASIN, CENTRAL ANATOLIA, TURKEY

GÜLYÜZ, Erhan

M. Sc., Department of Geological Engineering
Supervisor: Assoc. Prof. Dr. Nuretdin Kaymakçı

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Çiçekdağı basin developed on the Central Anatolian Crystalline Complex (CACC) is a foreland basin developed as the southern integral part of the Çankırı Basin during the Late Paleocene to middle Oligocene. The basin has two compartments separated by the Çiçekdağı High comprises two sedimentary cycles. The oldest cycle comprises Baraklı, Kocaçay and Boğazköy formationsa and is exposed both in the northern and the southern sectors. They were deposited in marine conditions. The second cycle comprises İncik and Güvendik formations and was deposited in continental settings. The first cycle comprises uniformly south-directed paleocurrent directions in both the northern and southern sectors whereas the second cycle deposits are represented by south-directed directions in the southern sector, and bimodal directions in the northern sector. In addition, the second cycle formations contain progressive unconformities and coarsening upwards sequences indicative of thrusting. Internal structures of the units and paleostress data indicate that the basin experienced over-all compression and local extension due to flexural bending. This gave way to inversion of some of the normal faults and uplift of the Çiçekdağı High during the deposition of second cycle in the Late Eocene to middle Oligocene time which subsequently resulted in compartmentalization of the basin.

Key words: Çiçekdağı basin, Central Anatolian Crystalline Complex (CACC), foreland basin, paleocurrent, paleostress

ÖZ

ÇİÇEKDAĞI HAVZASININ EVRİMİ, ORTA ANADOLU, TÜRKİYE

GÜLYÜZ,Erhan

Yüksek Lisans, Jeoloji Mühendisliği Bölümü

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Çicekdağı havzası Geç Paleosen–orta Oligosen döneminde Orta Anadolu Kristalen Kompleksi üzerinde Çankırı Havzasının güney uzantısının bir parçası olarak önülke havzası biçiminde gelişmiştir. Havza Çiçekdağı yükseliminden dolayı birbirinden ayrı iki farklı sedimanter dönem geçirmiştir. Baraklı, Kocaçay ve Boğazköy formasyonları ilk dönemde çökelmiştir ve havzanın hem kuzey hemde güney sektöründe gözlenebilmektedir. Bu birimler denizsel ortamda çökelmişlerdir. İkinci dönem ise kıtasal çökellerle temsil edilen İncik ve Güvendik formasyonları ile tanımlanmaktadır. İlk dönem birimlerinde paleo-akış yönleri düzenli olarak havzanın kuzey ve güney sektöründe güneyi göstermektedir fakat ikinci dönem birimlerinde paleo-akış yönleri havzanın güney sektöründe sadece güneyi göstermesine rağmen kuzey sektörde hem güneyi hem kuzeyi göstermektedir. Bunlara ek olarak ikinci dönem birimlerinde sıkıştırma rejiminin sonuçları olarak progresif uyumsuzluklar ve genç birimlere doğru tane boyunda artış gözlenmektedir. Havza ortasındaki bükülmeden dolayı, birimlerin içsel yapıları ve paleostres verileri havzanın genel olarak sıkıstırma, bölgesel olarak ise genişleme rejimine maruz kaldığını göstermektedir. Bu durum Geç Eosen – orta Oligocene döneminde bazı normal fayların ters çalışmasına ve Çiçekdağı yükseliminin oluşumuna neden olmuştur.

Anahtar kelimeler: Çiçekdağı havzası, Orta Anadolu Kristalen Kompleksi(OAKK), önülke havzası, paleo-akış, paleostres

to my father

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CHAPTER 1

INTRODUCTION

1.1 Scope and Problem Definition

Kırşehir block located in central Anatolia (Figure 1) has a triangular geometry and is one of the largest metamorphic complexes in the Eastern Mediterranean region (Şengör & Yılmaz 1981, Görür et al. 1984). Northern boundary of this block is delimited by the İzmir–Ankara–Erzican Suture Zone (IAESZ) while its south-western and south-eastern boundaries are defined by the Tuzgölü and Ecemiş fault zones respectively. It is thought to be the northern metamorphic equivalent of the Tauride-Anatolid Block (TAB) of Gondwana affinity and was metamorphosed due to processes related to the northwards subduction of the northern Neotethys Ocean and collision of the intervening continental blocks (Şengör and Yılmaz 1981). Namely, these blocks include the Tauride-Anatolide Block in the south and the Sakarya Continent of Eurasian affinity in the north. Although, it's metamorphic history is relatively well established (Whitney & Dilek 1998, Whitney et al. 2001, Gautier et al. 2002, Whitney & Hamilton 2004, Gautier et al. 2008), however, its timing and mechanism of exhumation is still under debate. In addition to metamorphics, the Kırşehir Block also comprises widespread magmatic rocks and overlaying mainly Cenozoic sedimentary rocks. The metamorphic and intrusive rocks of the Kırşehir Block are named as Central Anatolian Crystalline Complex (CACC) (Göncüoğlu et al. 1991).

On top of the CACC a number of isolated Cenozoic basins have been developed (Figure 2). The largest of these basins include Çankırı, Sivas, Çiçekdağı, Hacıbektaş, Ulukışla and Tuzgölü basins. These basins have similarities in type of infill, tectono-stratigraphy, and evolutionary history combined with similar kinematic and structural development (Görür et al. 1998, Gürer & Aldanmaz 2002, Kaymakci et al. 2009).

All of these basins include a very thick Paleocene to Recent infill that are resting on major end of Cretaceous unconformity. The Upper Paleocene to Oligocene is represented by flysch to molasses sequences intercalated with volcanic rocks. It is proposed that the oldest deposits which shed detritus from the CACC are the Late Paleocene to Middle Eocene deposits at the southern tip of the Çankırı Basin that marks the onset of the exhumation of the CACC (Kaymakci et al. 2009). Except for the Sivas Basin where Burdagalian to Serravalian marine incursions occurred, in all of these basins, Lower to Upper Miocene is represented by fluvio-lacustrine clastics with thick evaporate sequences (Figure 3). The Sivas basin is located in the eastern margin of the Kırşehir Block and straddles the Izmir-Ankara-Erzincan Suture, the Kırşehir Block and the other Anatolide-Tauride Block units (Yılmaz and Yılmaz 2006). This basin has almost same stratigraphic sequence as Çankırı Basin as having CACC as basement and is represented by Upper Paleocene to Oligocene flysch and the molasse sequences, Lower to Upper Miocene shallow marine fluvio-lacustrine clastics and Plio-Quaternary fluvial deposits (Figure 3) (Temiz et al. 1993, Temiz 1996).

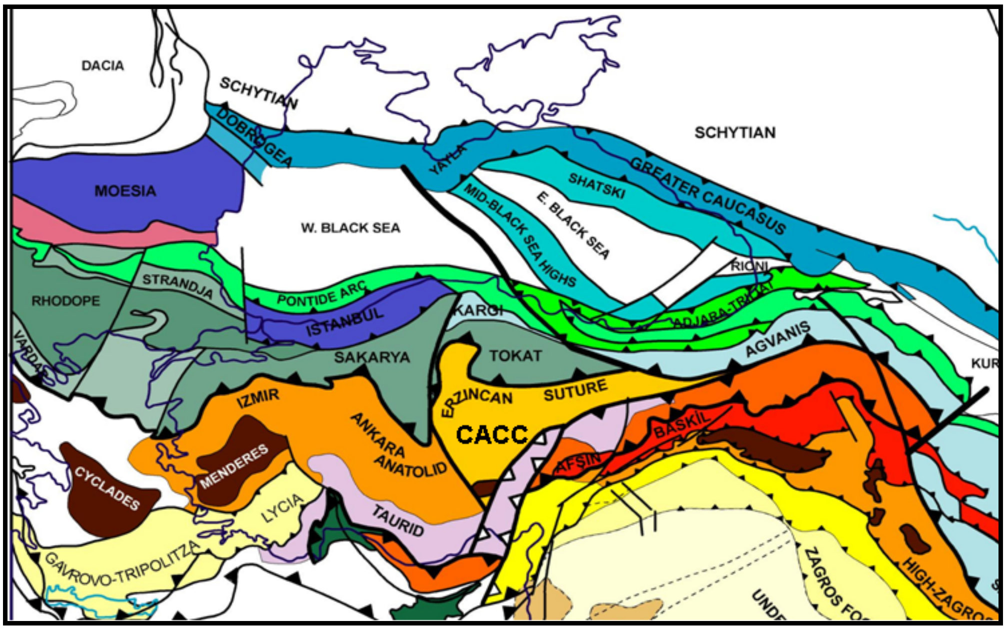

Figure 1. Plate tectonic configuration of the Eastern Mediterranean (Kaymakci et al. 2010). Note the position of the Central Anatolian Crystalline Complex (CACC).

Although, the geology and evolution of the basins surrounding the Kırşehir Block are relatively well known, however, there is no published study which addressed the tectonostratigraphical evolution of the Çiçekdağı basin located within the Kırşehir Block. Therefore, the main aim of this thesis work is to study the tectonostratigraphy of the Çiçekdağı Basin using, structural and sedimentological tools in order to shed some light on the exhumation history of the CACC and Cenozoic evolution of the region.

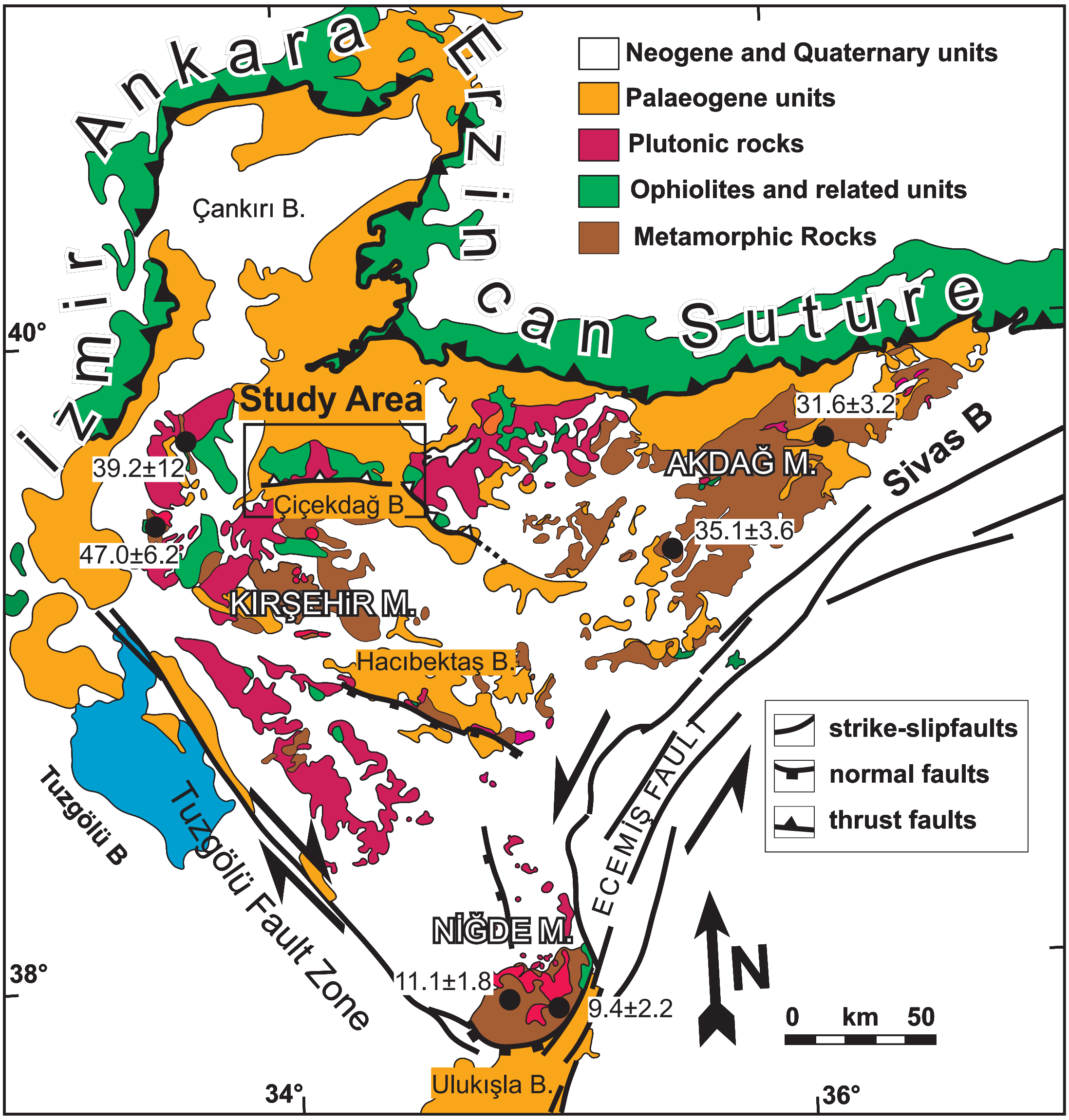

Figure 2. a) Simplified tectonostratigraphical map of Central Anatolia indicating the position of Kırşehir Block and related Cenozoic Basins. The numbers refer to apatite fission track ages of Kırşehir, Akdağ and Niğde massifs in Ma (Whitney et al. 2001).

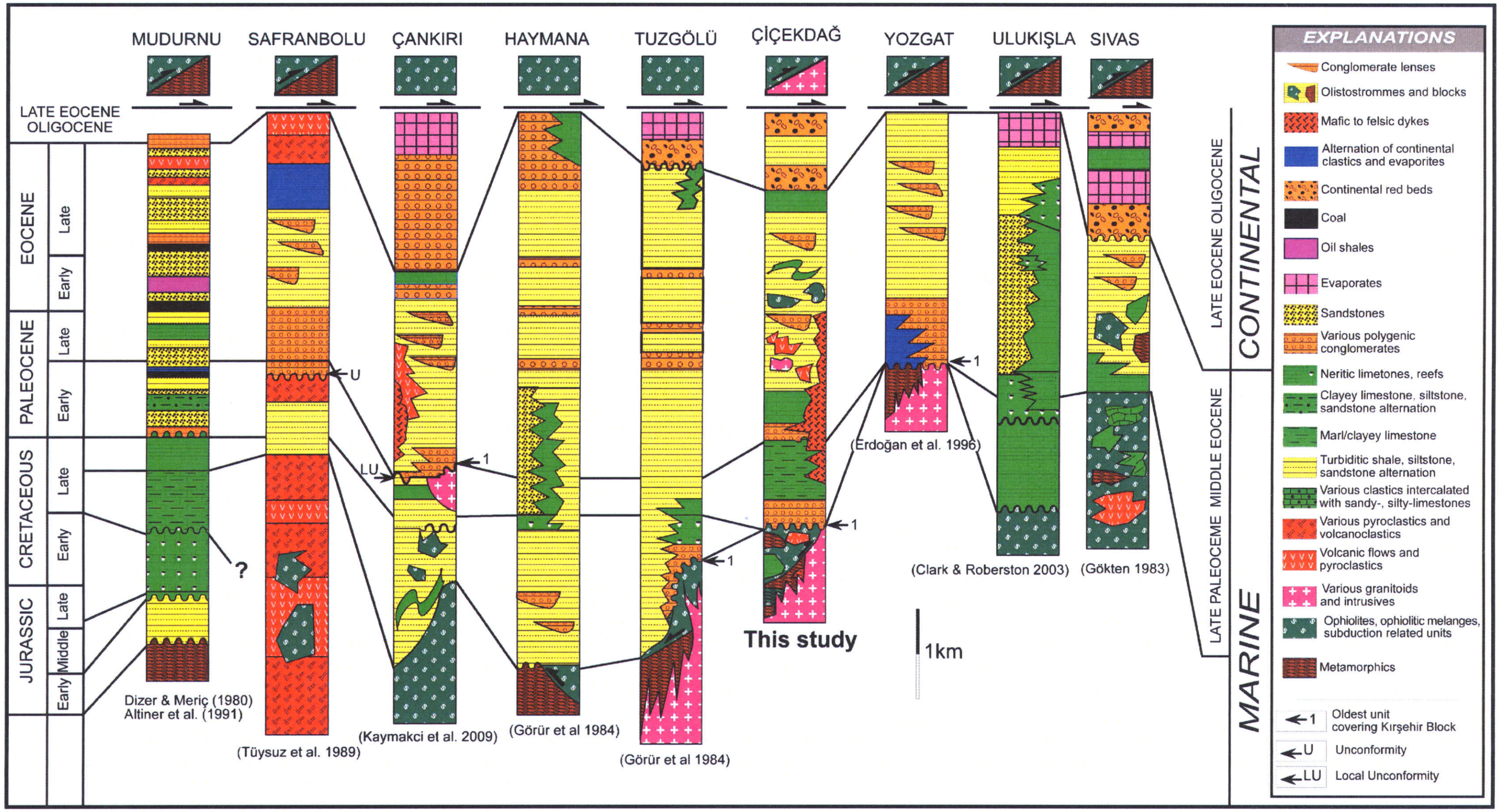

Figure 3. Correlation of central Anatolian Basins (modified from Kaymakcı 2000).

1.2 Method of Study

This research is carried out in three different working stages. These include; preliminary works, field works and post-field office work.

The preliminary works include literature survey about the Central Anatolia and reconnaissance survey about the study area. It is realized that there is no published literature information addressing directly the evolution of the Çiçekdağı basin.

The second stage includes field studies. During the field studies three different data sets were obtained.

Establishing the stratigraphy of the basin and determination of contact relationships between different lithostratigraphical units and facies associations. During this stage published 1/100000 scale geological map prepared by MTA (General Directorate of Mineral Research and Exploration) and 1/25000 scale topographic maps were used as base maps. During this study, already delineated lithological boundaries and structures were checked and in case where our observations differ from that of MTA maps they were updated and mapped out precisely with hand held GPS.

In order to establish the detailed stratigraphy of the basin infill, two sections were measured along two traverses, in the northern and southern side of the basin. From these sections in every 3 meters interval magnetostratigraphic samples were collected. Unfortunately, due to time constrains these samples have not been measured yet. Therefore, their results could not be included in this thesis. In addition, in order to understand the sediment supply and dispersal system and its change in time, from the coarse clastics, paleocurrent data have been collected in different parts of the basin using compass and GPS for sample location positioning.

3) This third data set includes collection of fault-slip data sets from the mezoscopic structures in the basin fill for paleostress analysis. For this purpose, all the spotted faults in remote sensing stage and during the

field studies were analyzed in detail for their kinematic characteristics and relevant data are noted. Then, using the Angelier (1994) criteria, the possible formation sequence of these faults were determined and dated. The collected data include location, orientation of the fault plane, rake of slip lineations, sense of movement, and sequence of formation in case where overprinting kinematic indicators were observed.

The last part of the research includes processing and analysis of the collected data and preparation of figures and thesis writing.

1.3 Previous Works

The studies related to the central Anatolia can be categorized into three groups: first group is related to the metamorphic rocks, the second group is the magmatic rocks that include ophiolitic rocks and the third group includes the Cenozoic cover sequences. These studies are summarized below starting from metamorphic rocks, then magmatic rocks and finally the cover rocks.

One of the oldest study related to the metamorphic rocks of the CACC is carried out by Göncüoglu (1977) in the Niğde Massif which identified and classified the metamorphic rocks of the Niğde Massif as lithodemic units.

The other studies about metamorphic rocks of CACC are as follows;

Seymen (1981) studied the metamorphic rocks around NW margin of the Kırşehir Block near Kaman. He classified the crystalline rocks as the Kaman Metamorphic Supersuite and Kırsehir Intrusive Suite.

Lünel (1985) studied the magmatic and metamorphic rocks of Central Anatolia and named these crystalline associations as Kırsehir Complex.

Fayon et al. (2001) studied the crystalline rocks in Central Anatolia especially in Niğde, Kırsehir and Akdağ massifs in order to explain characteristics of exhumation of mid–crustal rocks. This study proposed a geodynamic scenario for the mechanism of exhumation of the metamorphic rocks and intrusion of the magmatic rocks based on plate convergence obliquity on timing and exhumation. They indicated two different tectonic zone in the Kırşehir Block. The northern zone was exposed regional metamorphism, folding and thrusting during the collision of Sakarya continent and the southern zone was exposed to wrench–dominated regime related to the Ecemiş Fault Zone. They speculated that the collision-related shortening in the Kırşehir Block was occurred due to folding and thrusts at the northern edge of the Tauride platform. They also indicated that the Kırsehir and Akdağ massifs in the northern CACC were exposed generally by erosion. In this study they proposed that the exhumation rate of Kırsehir massif was <0.05 km/m.y between 80 and 35 Ma during the convergence system of the northern branch of the Neotethyan Ocean.

Whitney et al. (2003) studied the Niğde Massif for its tectonic controls on metamorphism, partial melting, and intrusion to constrain the timing of these events. They proposed that and extensional regime in the Late Cretaceous gave rise to tectonic unroofing and rapid cooling of metamorphic rocks in the Niğde Massif.

Fayon and Whitney (2007) claimed that the final exhumation and cooling that took place in the Miocene had no significant thermal effects in the Niğde Massif.

There are a number of studies about the magmatic rocks of the Kırşehir Block; however, the most comprehensive studies related to the Kırşehir Block were carried out by Göncüoğlu et al. (1991, 1992, 1993 and 1994).

Göncüoğlu et al. (1991) studied all the rocks exposed on the Kırşehir Block and they classified for the first time the crystalline rocks of the Kırşehir Block as Central Anatolian Crystalline Complex (CACC). They combined three metamorphic massifs that include Kırşehir, Niğde and Akdağ massifs under a unified named; however, this classification excludes the sedimentary cover units.

The other studies about the magmatic and ophiolitic rocks of CACC in chronological order are as follows.

Akıman et al. (1993) categorized the granitoids of the CACC into three groups and studied only the first group in detail. These groups are include 1) western zone that is located mainly at the western margin of the Kırşehr Block along an arc-shaped belt extending from Niğde Massif in the south to Kırıkkale at the north-western corner. 2) The second group includes relatively smaller and disconnected outcrops along the eastern margin of the Kırşehir Block that extends from Sivas in the north-east to Niğde Massif in the south-west. 3) The third group includes a big batholith exposed along to the northern margin of the Kırşehir Block around Yozgat. Based on geochemical analysis they argued that the first group of granitoids are of collisional to late/post collisional types that were originated from partial melting of continental crust.

Göncüoğlu and Türeli (1993) studied the plagioranitoids from Central Anatolian Ophiolites near Aksaray and they claimed that the studied ophiolites were related to an intraoceanic subduction zone within the İzmir-Ankara-Erzincan ocean and have close relationship to an ensimatic island-arc.

Yalınız et al. (1996) also studied the Central Anatolian Ophiolites and they proposed that most of the ophiolitic rocks in the CACC are derived from a supra-subduction zone. Based on geochemical evidences they suggested that Central Anatolian Ophiolitic crust was probably generated during the Turonian-Santonian interval within the İzmir-Ankara-Erzincan Ocean. Ophiolites were obducted onto the Kırşehir Block in the pre–Upper Maastrichtian, immediately after its formation.

Boztuğ and Arehart (2007) revealed a crustal signature in the genesis of the post-collisional granitoids of Central Anatolia by using geochemistrical data. They indicated that Central Anatolian granitoids have been derived from different hybrid magmas containing crustal contribution in important percentage. Based on geochemical data they also suggested that genesis of the hybrid I-type and A-type granitoid magmas in central Anatolia can be related to the post-collisional extensional-related geodynamic setting that was maintained by slab break-off or lithospheric delimitation mechanisms.

Boztuğ (1998) dealt with Central Anatolian alkaline plutonism and he suggested that the source of this plutonism can be related to the adiabatic decompression mechanism in the passive margin of the Anatolides in a post-collisional lithospheric thinning within a tensional regime after crustal thickening due to Anatolide - Pontide collision along the northward subduction zone of the northern branch of Neo-Tethys.

Boztuğ (2000) reported a crustal signature in the genesis of the post-collisional granitoids of Central Anatolia by using geochemistrical data. They indicated that Central Anatolian granitoids were derived from different hybrid magmas sources that contain large volumes of crustal contribution. Based on geochemical data they also suggested that genesis of the hybrid I-type and A-type granitoid magmas in central Anatolia can be related to the post-collisional extension related geodynamic setting that was maintained by slab break-off or lithospheric delamination mechanisms.

Düzgören-Aydın et al. (2001) studied in order to explain the nature of the magnetism in Central Anatolia during the Mesozoic post–collisional period and they indicated that Central Anatolia has different magma types reflecting different stages of post–collisional magnetism. They also said that the early stage of post–collisional magnetism was related to lithospheric delamination, the mature and advance stages of post –collisional magnetism was related to the episodic extentional tectonic regime.

İlbeyli (2004) worked on the collision-related plutonics in north-west Central Anatolia and they suggested a model for the origin of coexisting calc-alkaline and alkaline magmas in the CACC.

Boztuğ et al. (2009) provided age data from the intrusions located Kaman- Kırsehir region in order to geothermochronology quantifying cooling and exhumation history of the region. Briefly, they concluded that these intrusions were exhumed rapidly during the Early to Middle Paleocene because of the uplift triggered by collision between TAP and EP.

Boztuğ et al. (2009) presented new age data from The Karacayır syenite (N Sivas) in order to explain the relationship between the emplacement, cooling and exhumation history of the The Karacayır syenite and the regional tectonic regime. They concluded that the rapid exhumation and the compressional regime related with collision along IAES are directly connected.

Boztuğ et al. (2008) provided new age data from the plutonic rocks of the CACC and compiled the existing literature data. Based on this compilation they suggested a geodynamic model including cooling to exhumation history of Central Anatolian Granitoids. Briefly, in this model they indicated that fast cooling and fast exhumation of Central Anatolian granitoids had occurred during the Early–Middle Palaeocene and this situation was accompanied with the Central Anatolian foreland basins.

As mentioned previously the number of studies related to the sedimentary cover of the Kırşehir block is very limited. Therefore, we summarized below, only the most complete studies related to evolution of the basins along the rim of the Kırşehir block.

One of the oldest studies that addressed the evolution of the Tuzgölü Basin is carried out by Görür et al. (1984). They provided surface and subsurface data about the basins and proposed an evolutionary scenario based on plate tectonic concepts.

The evolution of the Çankırı Basin is studied by Tüysüz and Dellaloğlu (1992) and they proposed that the evolution of the basin is related to the subduction of Ankara-Erzincan ocean.

Tüysüz et al. (1995) proposed that the evolution of the Çankırı Basin during the Late Cretaceous is also related to collision of a sea mount which is embedded within the margin of the basin.

Kaymakcı et al. (2000, 2003) proposed a model for the kinematic evolution of the Çankırı Basin. They proposed that the basin was evolved through four different deformation phases. The first phase is related to the subduction of the northern Neotethys Ocean, the second phase is related to Palaeocene-Early Miocene collision. Third phase is related to Middle Miocene extension and the last phase is related to strike-slip tectonics during the Neotectonic period since the Late Miocene.

Kaymakcı et al. (2009) studied the Late Cretaceous to Recent tectonostratigraphical evolution of the Çankırı Basin and proposed that the basin was evolved from a fore-arc basin in the Late Cretaceous to a foreland basin during the Cenozoic.

Gökten (1993) provided a complete study of the infill of the Sivas Basin. Later a number of studies were conducted in the basin which addressed only some parts of the Sivas basin or only certain aspects of it. Such as tectonostratigraphy of its eastern tip (Poisson et al. 1996, Temiz et al. 1993), its paleomagnetic evolution (Gürsoy et al. 1997).

Dirik et al. (1999) studied on tectonic and stratigraphic evolution of the Sivas Basin and they concluded that the basin was opened as an intra-continental extensional basin on the Tauride-Anatolide Platform in Late Maastrichtian extensional tectonism in Central Anatolia.

Yılmaz and Yılmaz (2005) provided a model for the tectonostratigraphic evolution of the Sivas Basin. They also provided data about basin formation mechanism and kinematic data about deformation phases in the region. They concluded that the Sivas Basin is a post-collisional intra-continental basin.

Clark and Robertson (2003) studied on tectonic and sedimantological evolution of Ulukısla Basin and provided a model. They concluded that this basin formed under tensional (or transtensional) regime as a syncollisional basin.

1.4 Regional Tectonic Setting

The Central Anatolian Crystalline Complex refers to the metamorphic and magmatic rocks of the Kırşehir Block and is the largest metamorphic terrains in the Eastern Mediterranean region. The controlling factors on Central Anatolia in Cretaceous-Eocene time is related to evolution of the northern branch of the Neo-Tethyan convergence system which is also responsible for the formation of İzmir-Ankara-Erzincan (IAE) Suture Zone resulted from closure of the Northern Neotethys Ocean and collision of the Pontides in the north and Tauride–Anatolide platform (TAP) in the south (Şengör and Yılmaz, 1981).

The subduction of the Neo-Tethyan ocean northwards beneath the Pontides (Eurasian affinity) along the İzmir-Ankara-Erzincan suture zone and an intra-oceanic subduction beneath an oceanic island arc (Yalınız et al. 2000) started during the Cenomanian–Turonian. The obduction of the ophiolitic rocks and the island arc material onto the Tauride-Anatolide Platform occurred during the late Cretaceous. The obduction gave rise to metamorphism of the northern tip of the TAP which is now recognized as the Kırşehir Block. Continent-Continent collision and post-collisional convergence between the TAP and the Pontides took place during the Late Palaeocene to Early Miocene (Kaymakci et al. 2009). The continuation of collision is accompanied with granitoid intrusions (Boztuğ & Harlavan 2008, Boztuğ et al. 2004). Formation of Central Anatolian foreland basins (CAFB) (between Late Paleocene to Oligocene?) are directly related to this collision (Boztuğ et al. 2008, Kaymakci et al. 2009). These basins contain Paleocene to recent infill that records the collision to post-collisional evolution of the region (Erdogan et al. 1996, Kara 1991, Kaymakci et al. 2003, Poisson et al. 1996). The infill of these basins is derived from both the Pontides and the CACC which indicates that the CACC is exhumed during the early Cenozoic. Çiçekdağı basin is located directly on top of the CACC and forms the south-easternmost extension of the Çankırı Basin. It overlies the CACC with a nonconformity and has more than 2 km infill derived mainly from the north in its lower part and derived both from the north and the south in its upper parts which indicates that the basin has two distinct evolutionary periods. The lower part of the basin is characterized by Paleoecene-Lower Eocene fine clastics and Middle Eocene shallow marine nummulitic limestones overlaid by Late Eocene to Oligocene thick continental red clastics composed of thick-bedded conglomerates, sandstones and mudstones of dominantly fluvial origin. The uppermost part of the basin is characterized by greenish to buff shales and marls intercalated with gypsum horizons of middle to late Oligocene age. The Neogene and Quaternary deposits are exposed only in limited outcrops and are unconformable to all the true basin fill deposits of the basin which are of Paleogene in age.

CHAPTER 2

STRATIGRAPHY

The rock units exposed in the study area can be divided into two groups (Figure 4 and 5). The first group includes the basement rocks that comprise the magmatic rocks associated with ophiolitic and metamorphic rocks belonging to Central Anatolian Crystalline Complex (CACC). The second group comprise the cover units that include the Upper Paleocene to Oligocene basin infill and post-Early Miocene sediments. The Paleogene basin infill is the main concern of this study. Therefore, only the basin infill units were studied in detail. In order to have unity and consistency, the basement and post-Oligocene units will be described very briefly based on published literature and unpublished reports.

2.1 Basement Units

The basement unit in the study area collectively named as Central Anatolian Crystalline Complex (CACC) by Göncüoğlu et al. (1991). They comprise three groups; 1) Central Anatolian metamorphics (CAM), 2) Central Anatolian ophiolites (CAO), 3) Central Anatolian granitoids (CAG). Detailed description of these units is beyond the scope of this study, therefore, only brief description will be given in the next section.

2.1.1 Central Anatolian Methamorphics (CAM)

CAM forms the oldest unit in the study and can be observed in its southestern parts. CAM crops out in three different exposures and named separately as; 1) Kırşehir Massif (Seymen 1981 and 1982), 2) Niğde Massif (Göncüoğlu. 1977), and 3) Akdağ Massif (Göncüoğlu et al. 1991) (Figure 2). Each of these complexes have similar lithologies and comprises from bottom to top; the core (Gümüşler metamorphics), schistose cover (Kaleboynu metamorphics), marble cover (Aşıgediği metamorphics, (Göncüoğlu et al. 1991, 1993). The metamorphic core is the oldest rocks of CAM and represented by volcano-sedimantary, intrusive rocks and limestone protoliths subjected to HT-LP (7–8 kbar, 650^0–750^0 C) metamorphic conditions (Göncüoğlu et al. 1991, Whitney et al. 2001). The schistose cover is composed of siltstone, marl and quartzite protolith. The marble cover contains marble, cherty marble, and dolomitic marble, which are possibly belong to the Paleozoic to Mesozoic Tauride platform carbonates. According to Göncüoğlu (1993), deposition of these carbonates is related to the southern passive margin of the Northern Branch of the Neotethys and their metamorphism is related to its closure during the Early Cretaceous to Palaeogene.

According to Whitney et al. (2001), CAM can be divided into two groups based on their different pressure-temperature-time (P-T-t paths) and tectonic histories; 1) northern zone, includes the Kırşehir and Akdağ massifs, and comprises folded, thrust-faulted metasedimantary rocks intruded by gabbro and granitoids and is related to the final closure of Northern Branch of Neotethys during Late Cretaceous time along IAE sture. 2) southern zone includes the Niğde Massif being a structural dome and formed due to oblique convergence related to closure of the southern Neotethys in the Late Cretaceous along the Inner Tauride Suture.

In the southest part of the study area the core (Gümüşler Formation) and the marble cover (Bozçaldağ Formation) of CAM are exposed.

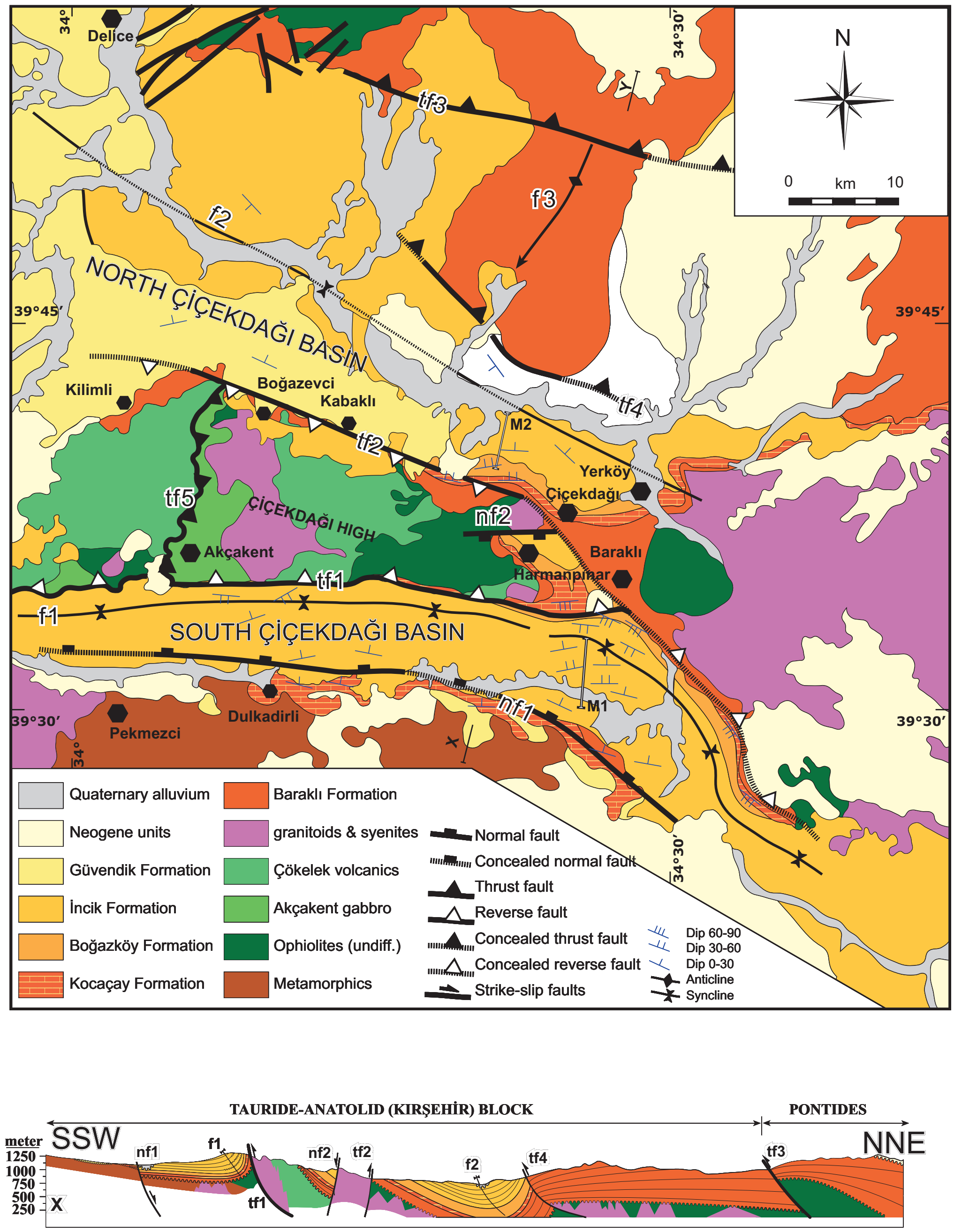

Figure 4. Geological map of the study area and cross-section along line XY. M1 and M2 donates lines of measured sections (modified from 1991 MTA map). Numbers 1-50 are paleocurrent measurement sites. The dip data is representative from about 100 measurements.

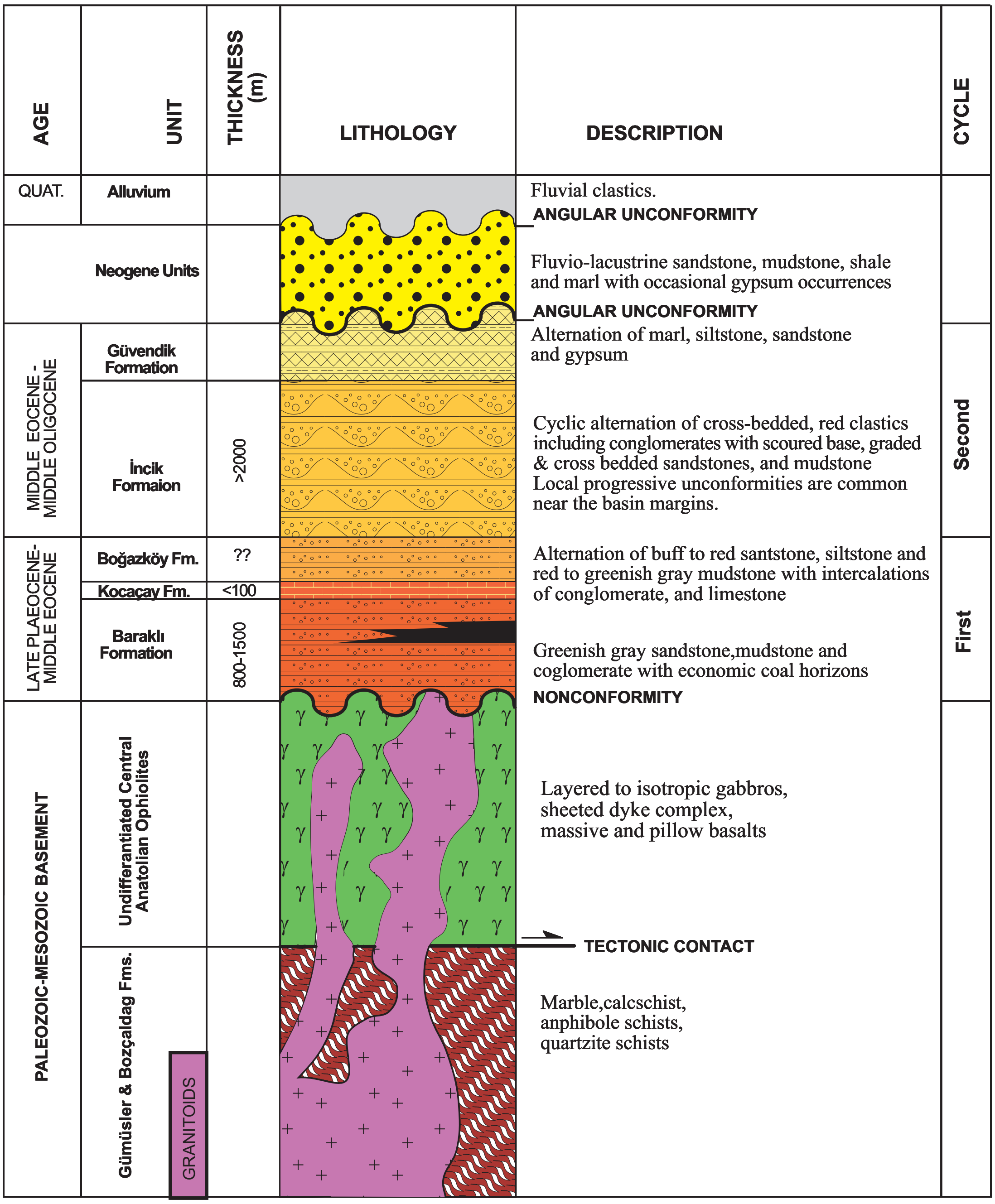

Figure 5. Generalized columnar section of the study area.

2.1.1.1 Gümüşler Formation

This unit was firstly named by Göncüoğlu (1977). It is exposed in the southern margin of the study area around between Dulkadirli, Pekmezci and İnlimurat villages. Gneisses form the lower parts of this unit whereas schists forms upper parts. Generally, granitic gneisses, biotite-muscovite gneisses with amphibolite, amphibole schists, pyroxene schist, quartzite,

quartzite schists and rarely marble bands form this unit. The base of the unit could not been observed in the study area.

It is nonconformably overlaid by the cover units. The cross units onlaps to these unit from north to south.

It is equivalent to Kalkalıdağ formation of Seymen (1982) and Köklüdere Formation of Dökmeci (1980).

2.1.1.2 Bozçaldağ Formation

This unit was firstly named by Seymen (1982) and is exposed between Çamlıktepe hills and Dulkadirli village.

Light gray, white, pinkish white color holocrystalline marbles forms this unit. Generally, carbonates (platform carbonates according to Göncüoğlu, 1993) constitute the protolith of this unit.

It is intruded by granitoids of CAG. Contact metamorphism due to intrusions is very prominent along the intrusive contacts in the field. Like other CACC units it is nonconformably overlain by the Paleogene basin infill.

It is equivalent to the Aşağıgediği Formation of Göncüoğlu (1977) and Bozçaldağ Marbles of Kara (1991) (Figure 5).

2.1.2 The Central Anatolian Ophiolites (CAO)

The CAO generally lacks the mantle ultramafics (tectonites) and are characterized by cumulates, sheeted dykes, pillow basalts and associated sedimentary rocks (Yalınız et al. 2000). The epi-ophiolitic cover comprise Lower Turonian-Campanian pelagic sediments and intruded by Upper Cretaceous-Lower Palecone Granitoids intrude it (Göncüoğlu et al. 1991; Yalınız et al 1996).

The CAO are developed generally in supra-subduction zone environments during Cenomanian to Campanian. The N-MORB type of ophiolites are generally exposed in the north of the CACC within the Izmir-Ankara-Erzincan Suture Zone (Göncüoğlu & Türeli 1993, Tüysüz et al. 1995, Yalınız 2008).

In the central part of the study area ophiolitic rocks belonging to CAO are observed as Çicekdağ Ophiolites (CO). The CO is observed in the field as two different units; 1) Çökelik volcanics, 2) Akçakent gabbro. Both of these units reflect island arc origin (Göncüoğlu and Türeli 1993, Erdoğan et al. 1996) and submarine environment conditions (Boztuğ et al. 1998) is determined on Çökelik volcanics. These units will be defined in the following paragraphs and will be represented in figure 5 undifferentially as the Central Anatolian Ophiolites.

2.1.2.1 Çicekdağ Ophiolites (CO)

According to previous studies, these ophiolitic rocks formed during the Cenomanian and belong to a juvenile ensimatic arc on MORB–type oceanic crust (Göncüoğlu and Türeli 1993; Tüysüz et al. 1995) because of compression in the Tethyan realm resulted from the rapid convergence between Eurasia and Africa in the early Cretaceous. Due to the compression, ophiolitic nappes formed and caused crustal thickening and early stage syncollisional granitoids (Erler and Göncüoğlu 1996). The SSZ –type oceanic crust was formed by the partial melting of MORB–type lithosphere. The reason of this partial melting is the generation of the trench rollback on subduction of the forearc basin and the extension of the overlying forearc region (Yalınız et. al. 2000). The extension in the forearc region turned the compression during the Campanian due to the ending of the subduction of the old oceanic slap along the buoyant margin of the CACC and the new hot SSZ–type oceanic crust was not subducted but obducted onto the CACC (Yalınız et al. 2000, Yalınız 2008). The CACC and the obducted SSZ–type ophiolites were cut by the late Cretaceous post–collisional intrusions.

The CAO tectonicaly overlies the CACC basement with northward dipping thrust fault located south of Çiçekdağ (Yalınız et al. 2001). According to Yalınız et al. (2001) typical ophiolitic sequence can be observed in this area. From bottom to top it includes layered to isotropic gabbros, sheeted dyke complex, massive and pillow basalts, intercalations of Turonian–Santonian (Erdoğan et al. 1996) pink pelagic cherty limestones within the pillows basalts.

2.1.2.2 Çökelik Volcanics

This unit was firstly named by Erdoğan et al. (1996) and is exposed in the study area around Çökelik and Akçakent villages. It is unconformably overlaid by Paleogene basin infill units in the south and east of the study area and tectonically overlain by the Akçakent gabbro along an N-S-striking thrust fault (tf5 in Figure 4) (Boztuğ et al. 1998). It comprises some well–preserved basaltic pillow lavas intercalated with pelagic sediments indicating submarine magnetism. According to Erdoğan et. al. (1996), the pelagic units are of Turonian-Santonian age. These units are intruded by alkaline dykes composed of syenite, monzonite and monzogranite. According to Erler and Bayhan (1995), Çökelik Volcanics are part of Upper Cretaceous ophiolitic mélange.

2.1.2.3 Akçakent Gabbro

This unit was firstly named by (Boztuğ 1998), and forms the oldest and lowest part of Çiçekdağı Ophiolite. It is exposed around Akçakent village (Figure 4). It is characterized by isotropic gabbro and rarely cumulate gabbros. It is inruded by alkaline intrusives.

It tectonically overlies the Çökelik volcanics along a N-S thrusting fault in the west and covered by Upper Paleocene to Oligocene basin infill and Neogene units.

This unit is thought to be part of an ensimatic arc within the İzmir-Ankara ocean (Göncüoğlu & Türeli 1993). According to Erler and Bayhan (1995), it is a part of Upper Cretaceous ophiolitic melange.

2.1.3 Central Anatolian Granitoids (CAG)

The granitoids of CACC were emplaced into the metamorphic and ophiolitic rocks of the CACC and are nonconfromably overlaid by the Upper Paleocene to Oligocene basin infill and Neogene-Quaternary units. These granitoids are products of the crustal thickening resulted from arc to arc or arc to continent collision (Göncüoğlu et al. 1992, 1993, Kaymakci et al. 2009). They are generally S-type and both S- and I-type varieties are also present within the CACC. S-type granitoids represent the syn-collision tectonomagmatic settings and have 95±11 Ma radiometric ages (Göncüoğlu, 1986). This duration can be considered as the obduction of MORB–type ophiolites onto CACC (Göncüoğlu et al. 1992, Yalınız et al. 1996). The granitoids with both S- and I–type signatures are post-collision origin and are thought to be emplaced during exhumation of the metamorphic rocks in post-collisional extension setting at the end of Cretaceous to Earliest Paleocene (Erler et al. 1991; Göncüoğlu et al. 1993; Erler and Göncüoğlu 1996).

In the central part of the study area, CAG are represented by the Halaçlı monzogranite and Eğrialan Synite.

2.1.3.1 Halaçlı Monzogranite

This unit was firstly named by Boztuğ et al. (1998) and is exposed in the central part of the study area (Figure 4). It intrudes the Çiçekdağı Ophiolites and is nonconformably overlaid by the Cenozoic deposits. According to trace and major element geotectonic diagrams, the emplacement of this unit is directly related to the post-collisional extension (Boztuğ et al. 1998).

2.1.3.2 Eğrialan Syenite

This unit was firstly named by Boztuğ et al. (1998). It is exposed in the central part of the sudy area. It intrudes into the Çiçekdağı ophiolite and Halaçlı monzogranite, and is unconformably covered by the Late Palaeogene basin infill. It is characterized by phanaritic and equant syenitic rocks. According to trace and major element geotectonic discrimination diagrams, it was formed under alkaline conditions and syn–collisional settings (Boztuğ et al. 1998).

2.2. Cover Units

Two different cover sequences are exposed in the study area (Figure 5). The lower sequence includes the true basin infill and comprise Baraklı, Kocaçay, Boğazköy, İncik, Güvendik formations. The second and the youngest sequence include Neogene and Quaternary units. Since the post-Miocene units are not constrained into the basin, they are not separated from the true basin fill units. All of these units unconformably overlies the basement units which is constituted by CACC.

2.2.1 Baraklı Formation

It is named by Kara and Dönmez (1990) and exposed around Baraklı and Harmanpınar villages (Figure 4). It is the oldest basin fill unit in the study area and nonconformably overlies the basement units and conformably overlain by the Kocaçay Formation. Its thickness ranges between 800-1600 metres.

Baraklı Formation is characterized by reddish to grayish locally laminated, rarely cross–bedded, poorly cemented conglomerates with subangular to subrounded pebbles, gray to greenish sandstones and mudstones. It contains detritus derived from ophiolitic melanges, other magmatic and metamorphic rocsk and re-worked sedimantary rocks. It has coarsening upward sequence characteristics and contains economical coal seams.

The age of this formation is Early to Middle Eocene (Yüksel 1970, and Ünalan 1976) and Late Palaeocene to Middle Eocene in the north (Kaymakci et al. 2009).

It is correlated with the Hacıhalil Formation (Birgili et al. 1975) in the Çankırı Basin, Kartal Formation (Oktay 1981, Seymen 1982) in rest of the central Anatolia.

2.2.2 Kocaçay Formation

This formation was named by Birgili et al., (1975) in the Çankırı Basin. It is exposed in the south part of the study area near Dulkadirli and Hüseyinli villages. It is vertically and laterally grades into the underlying Baraklı Formation. Its upper contact is also conformable with the İncik formation of Late Eocene-middle Oligocene age. It is composed of nummulitic limestones intercalated with bluish marls, greenish to gray sandstone, and locally with conglomerates. The thickness of the unit varies from few meters to 100 m in the study area and in the Çankırı Basin (Oktay, 1981, Kaymakci et al. 2009).

From bottom to top, it is composed of grayish, thinly bedded to laminated sandstone, siltstone, and sandstone with conglomerate lenses. Towards the top it grades into thickly-bedded massive to nodular limestone (Figure 6). Further up in the section the limestones grades into bluish to greenish massive mudstone. Ophiolitic, magmatic and rarely metamorphic clasts are observed in the coarse clastic levels of the formation.

It includes abundant pelecypoda, mollusks and especially nummulites. The age of the unit is Early to Middle Eocene (Lutetian) (Oktay, 1981, Kaymakcı et al. 2009).

Figure 6. General view of Kocaçay Formation (view to east, location: south of Harmanpınar village).

It is correlated with the Çayraz Formation of Yüksel (1970), Arzılar Limestone of Oktay (1981), Dulkadirli limestone member of Kara (1991).

2.2.3 Boğazköy Formation

This formation was firstly named Özcan et al. (1980). It is exposed in the north of the study area. Siltstone, mudstone, sandstone, rarely conglomerate, and limestone characterize this unit. It unconformably overlies the basement units and grades upwards into the İncik Formation.

From bottom to top, it is composed of grayish, rarely reddish conglomerates and sandstone, grayish well-cemented sandstone and siltstone, sandy and clayey limestone, graded sandstone and greenish mudstone. The measured section along m1 and m2 of the formation is given in figure 7. The limestone horizons are indistinguishable from the limestones in the Kocaçay Formation which indicates vertical gradation with the Kocaçay Formation.

Although, no characteristic fossils have been found in the unit, the age of the Boğazköy Formation is Late Eocene due to its stratigraphical position conformably overlying the Middle Eocene Kocaçay Formation and conformably being overlied by the Late Eocene-middle Oligocene İncik Formation.

It is correlated with the Çevirme Formation of Kara and Dönmez (1991) and Kocaçay Formation of Yüksel (1970).

2.2.4 İncik Formation

This formation was firstly named by Birgili et al. (1975). It is one of the most widespread unit exposed in the study area. It is characterized by reddish, brownish, rarely grayish, cross-bedded, rarely laminated, continental red clastics including conglomerates, sandstones, and mudstone.

Thickness of the unit varies from 150 m (at the southern margin) to 700 m (at the northern margin). It unconformably overlies the basement units and conformably overlies the Boğazköy, Kocaçay, and Baraklı formations. It is unconformably covered by the Neoegene and Quaternary alluvial units.

From bottom to top, it is composed of reddish, brownish, thinly to thick layered, cross-bedded intercalations of sandstone and mudstone with rarely conglomerate lenses, reddish, brownish, rarely grayish, medium- to thick-bedded, graded and cross-bedded sandstone with conglomerate lenses, reddish, brownish, grayish, coarse grained, partly consolidated conglomerate and sandstone intercalations. Magmatic, ophiolitic, rarely metamorphic (only in the southern margin) and re-worked limestone fragments and reworked nummulites are the main constituent fragments of the İncik formation. The measured section along m1 and m2 of the formation is given in figure 7.

The age of the formation is not known precisely due to the lack of diagnostic fauna; however, based on its gradation with the Boğazköy and Middle Eocene Kocaçay formations and gradational contact with the overlying middle Oligocene Güvendik Formation (Kaymakci et al. 2001, 2009), the age of the İncik Formation is constrained to be post-Middle Eocene and middle Oligocene.

The İncik Formation is correlated with the Mezgit Group of Uygun *et al*. (1981).

2.2.5. Güvendik Formation

Güvendik Formation is first named by Kaymakcı et al. (2001) in the Çankırı Basin. It is exposed mainly in the northern Çiçekdağı Basin around Delice, Kilimli, Boğazevci and Kabaklı villages. In the south, around Dulkadirli village it is represented by few tens of meters thick gypsum horizons. It is conformable with the underlying İncik Formation and unconformably covered by the Neoegene to Quaternary units. Its maximum observable thickness is around 100 m.

It is characterized by alternation of gray to green, buff marl, siltstone, sandstone and gypsum (Figure 8). In the NW part of the study area around Kaleevci village halite occurrences are also encountered.

No diagnostic fossils have been found in the formation; however, the age of the Güvendik Formation is middle Oligocene according to Kaymakci et al. (2001, 2009).

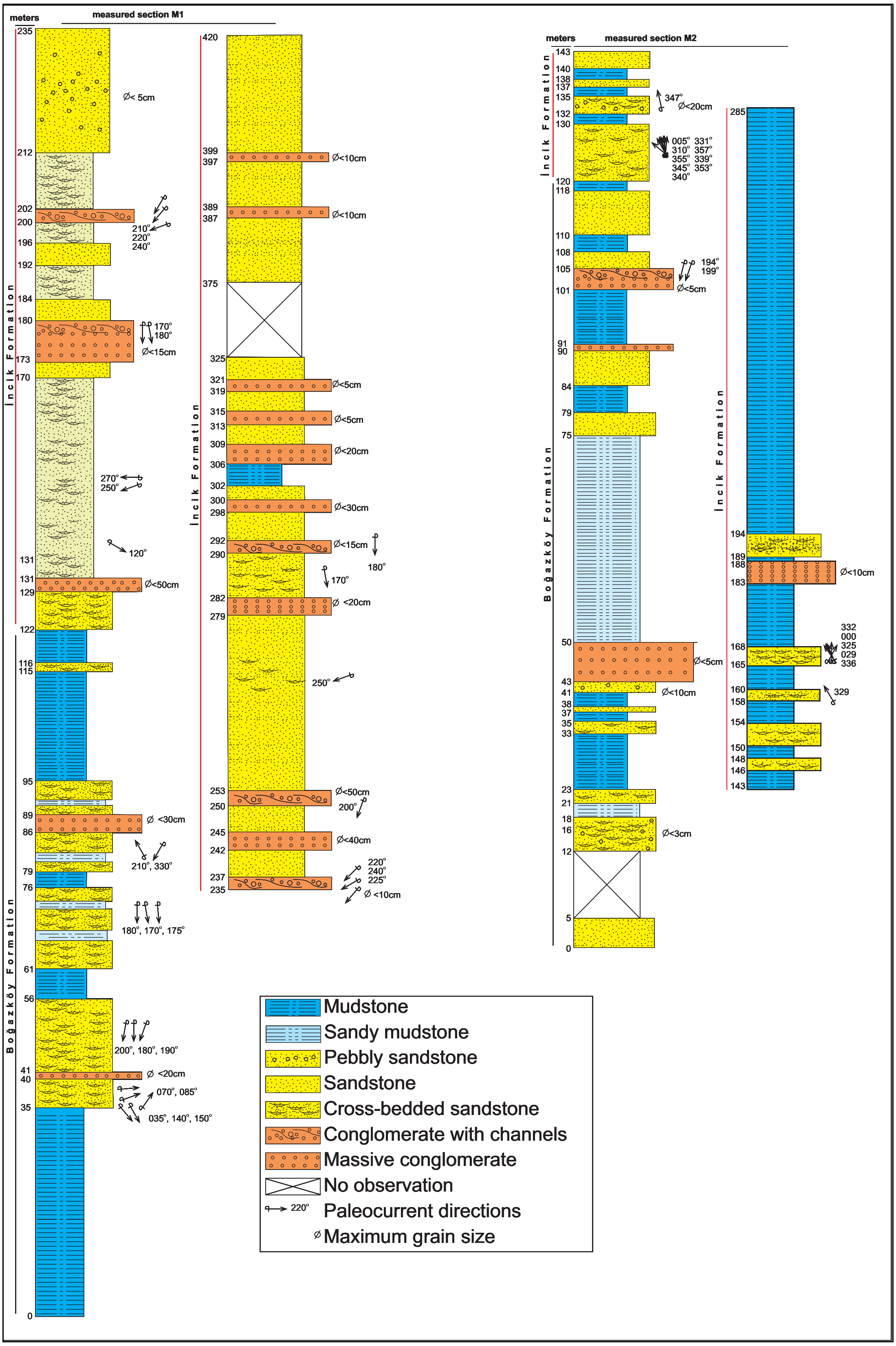

Figure 7. Measured stratigraphical sections along transect M1 and M2 (see Figure 4 their locations)

Figure 8. Close-up view of gypsum horizons in Güvendik Formation (view to east, location: southeast of Dulkadirli village).

2.2.6. Neogene Units and Quaternary Alluvials

Neogene units are exposed mainly in the western and southern part of the study area. These units are out of scope of this study so no detailed study was carried out on these units.

Alluvial units represent the youngest unit of the study area and are observed mainly in the central and northern parts of the study area along the major streams.

CHAPTER 3

STRUCTURES

The studied structures in the study area comprise paleocurrents directions, unconformities, bedding and folding, and faults ranging from mezoscopic to large scales.

3.1 Paleocurrents

Paleocurrent analysis provides direct information about orientation of the sedimentary systems and paleoslope and it is also used for defining the geological setting to which it was formed. Cross-beds, pebble imbrication, groove casts, flute casts and ripple crest orientation are used as paleocurrent indicators. These indicators are defined into two groups as unidirectional and bidirectional indicators. Cross-beds, pebble imbrication, flute casts are unidirectional indicators whereas groove casts and ripple crest orientation are bidirectional indicators. The orientation of paleocurrent indicators is measured in the field with a brunton compass or other measuring tools. Paleocurrent indicators can be planar as cross-beds and linear as flute casts. For planar indicators, direction of paleocurrent is defined as the dip direction of the planar surface, but for linear indicators, the long-axis of the indicator is assumed as parallel to the flow directions. In this study, the paleocurrent data were mainly gathered from planar indicators.

Paleocurrent directions analysis was carried out only in the Boğazköy and İncik formations in the southern and northern parts of the basin in order to understand provenance of the clastics and sediment dispersal patterns within the basin (Appendix-A, Figures 7). These two formations were selected for this analysis because they were considered as key formations keeping information directly related to the tectonic evolution of the basin.

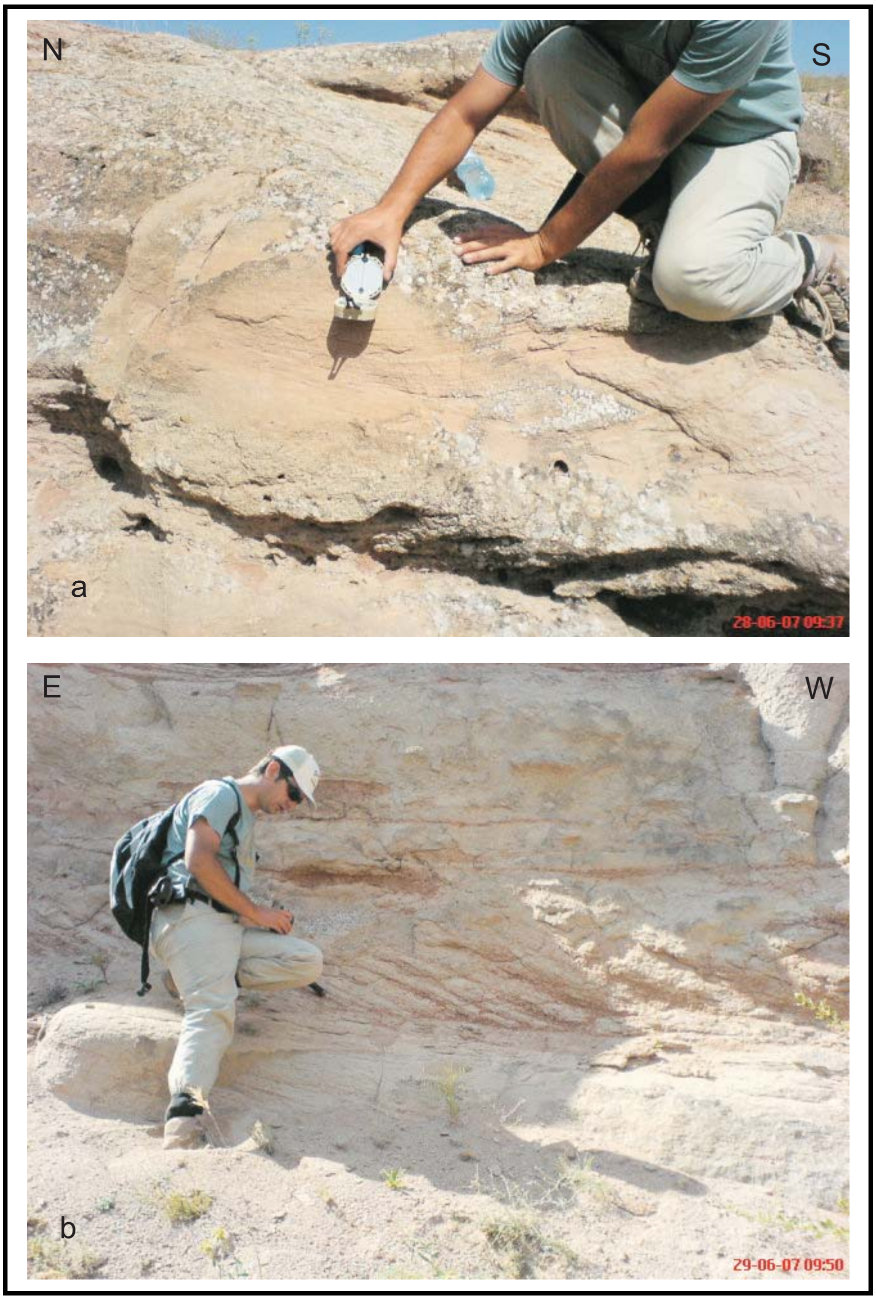

Figure 9. Example of cross-beds measured for paleocurrent analysis in the İncik Formation. a) view to east, location: west of Yerköy village b) view to north, location: south of Harmanpınar village.

For the paleocurrent directions, mainly cross beds were measured (Figure 9). As seen in Figures 7 and 10, the dominant paleocurrent directions, in the southern part of the basin are from north to south; however, the paleocurrent directions in the northern part of the basin are bimodal. As seen in the measured section-M1 (Figure 7), in the lower parts of the measured section (in the Boğazköy Formation) paleocurrent directions are due south; however, in the upper parts of the section (ca. 120 m and above in the İncik Formation) paleocurrent directions are due north.

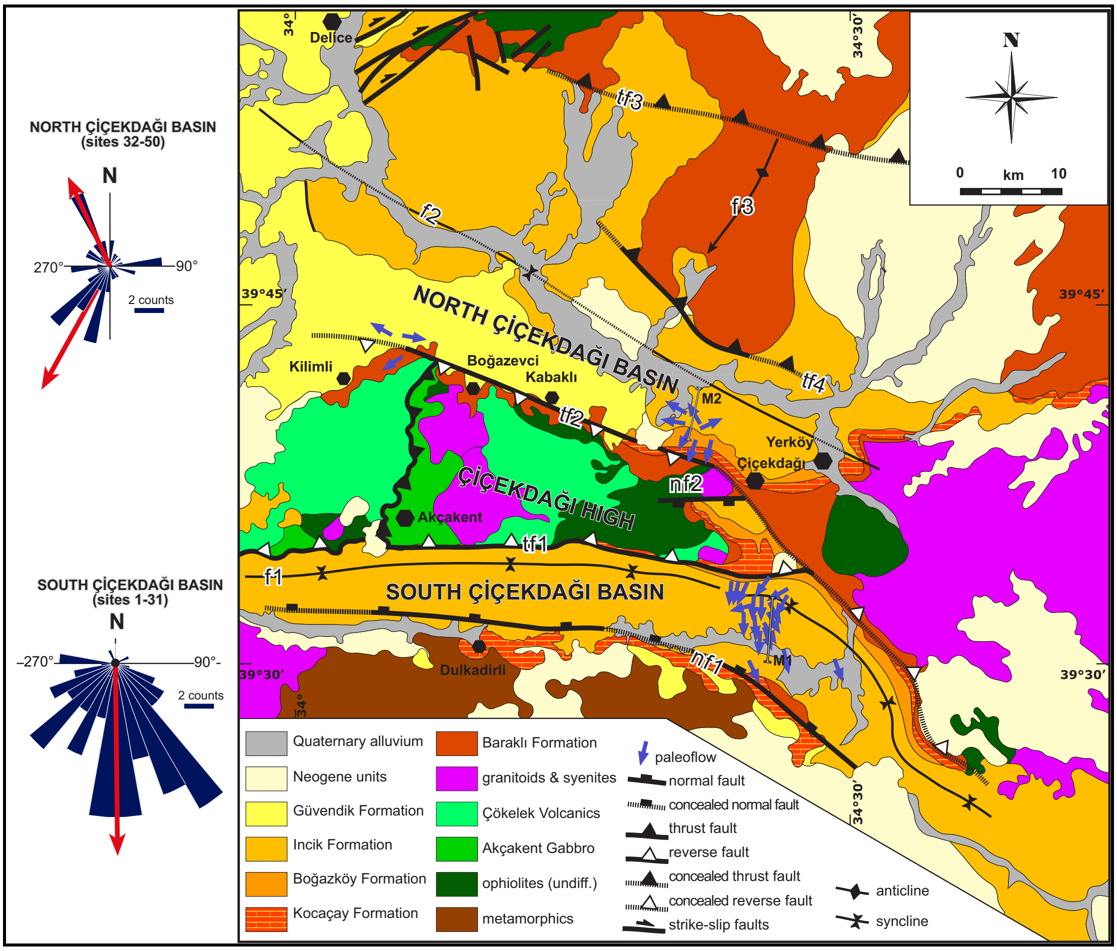

Figure 10. Paleocurrent directions in the study area. Note bi-directional flows in the northern Çiçekdağı Basin.

3.2. Unconformities

In the study area three different unconformities are recognized. These include 1) nonconformities, 2) angular unconformities and 3) progressive unconformities.

Nonconformities are observed all through the basin between the basement rocks (CACC) and the cover units. This indicates that at least few kilometers of rocks must have been removed before the deposition of the cover units by the beginning of Late Paleocene.

Angular unconformities are observed between the underlying Paleogene basin infill units and the overlying Neogene and Quaternary units. These unconformities indicate that a major folding and faulting activity must have been occurred before the deposition of the Neogene units.

Progressive unconformities developed due to coupling of tectonics and coeval sedimentation (Riba 1976). Such structures are very important in order to understand nature of tectonic activity during their formations, because their geometry are directly affected by tectonic regime and they record characteristics of tectonic activity during their formation (Figure 11).

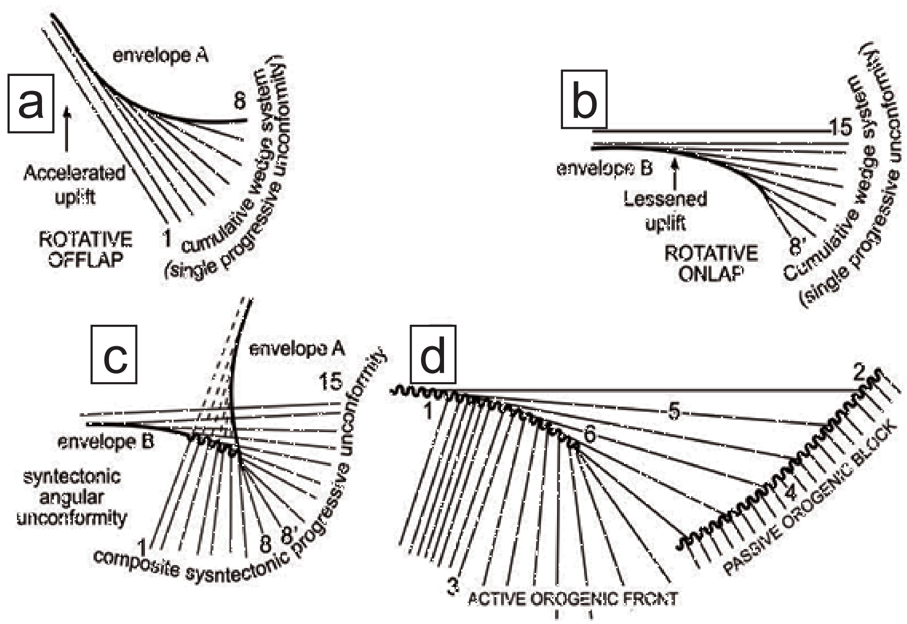

Figure 11. Conceptual configuration of progressive unconformities in area where tectonic activity and sedimentation are coupled. The numbers 1-15 are time lines (adopted from Riba 1976).

Progressive unconformities are observed within the İncik Formation together with coarsening upwards pattern of the formation (Figure 12).

The dips of the units below the unconformities are always higher than the dip of the overlying units (Figure 12b). Based on this information, it is concluded that these unconformities indicate migration of the source area towards the basin center possibly under compressional deformation. In the mean time previously deposited horizons were tilted and partly eroded, then new horizons were deposited on them.

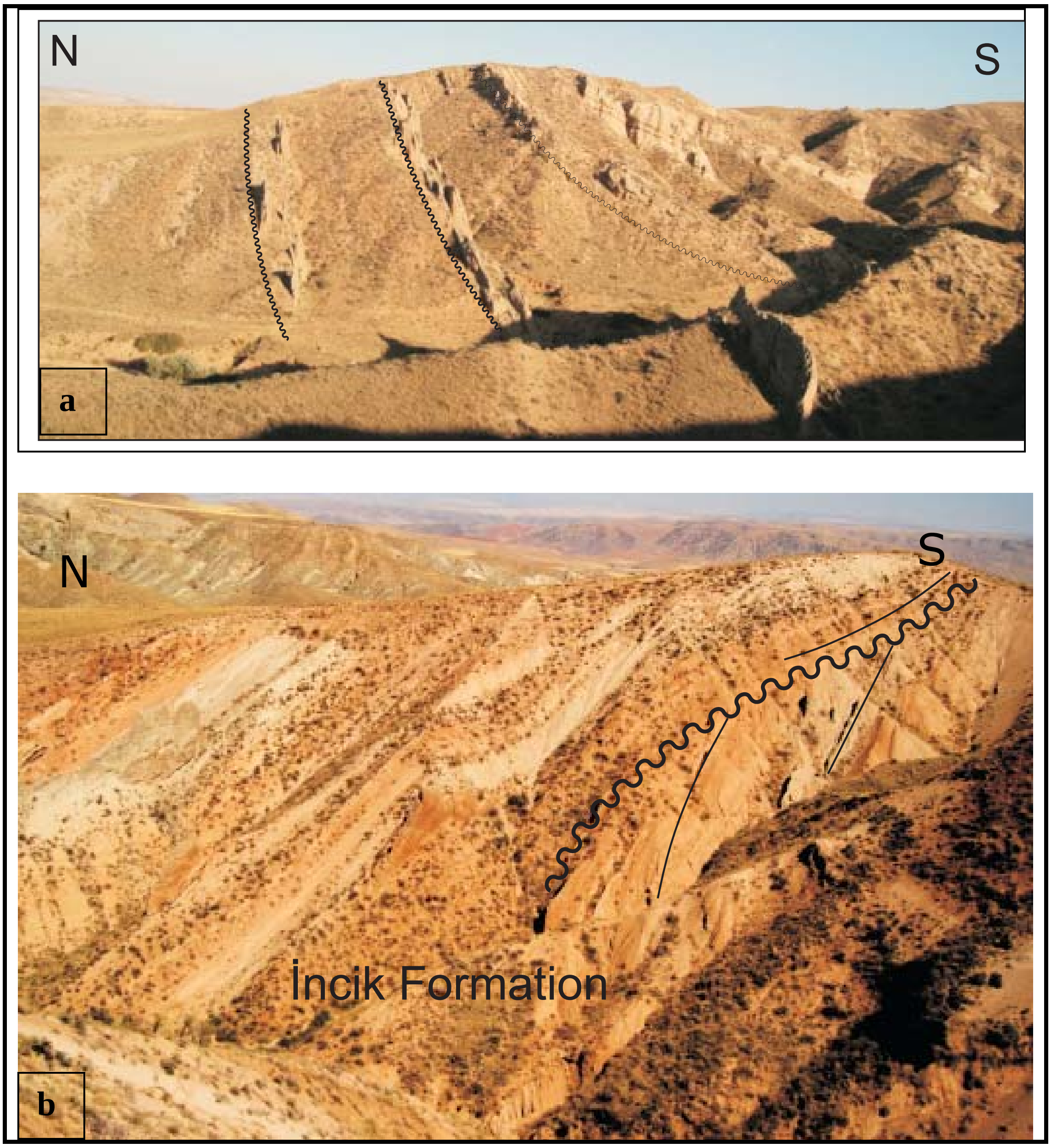

Figure 12. Progressive unconformities observed within the İncik Formation. Note angular relationships in lower figure (view west to east, location: south of Baraklı village).

3.3 Folds

Three major folds were observed in the study area. These from south to north include f1, f2 and f3. The f1 is an asymmetric syncline developed along the extend of the southern sector of the Çiçekdağı basin parallel to the tf1. This implies that the f1 was developed due to the activity of the tf1.

The f2 is an asymmetric syncline developed all along the center of the northern sector of the Çiçekdağı basin. The f3 is a symmetrical anticline developed within the Baraklı Formation in the northern part of the study area. It trends NE-SW and plunges southwestwards. It was developed transverse to the major faults and folds of the study area.

In addition to major folds, 68 systematical bedding attitude data were collected from the southern sector of the basin. The β- and π-diagrams prepared from these data indicate that the southern sector of the basin is a large, gently east plunging (084°N/05°) asymmetric syncline as indicated in Figure 13. As indicated in Figure (13c) the number of measurements on the gentler limb are more than the number of measurements on the steeper limb which is due to the outcrop width of the both limbs (compare the widths between S-A and A-N in Figure 13c).

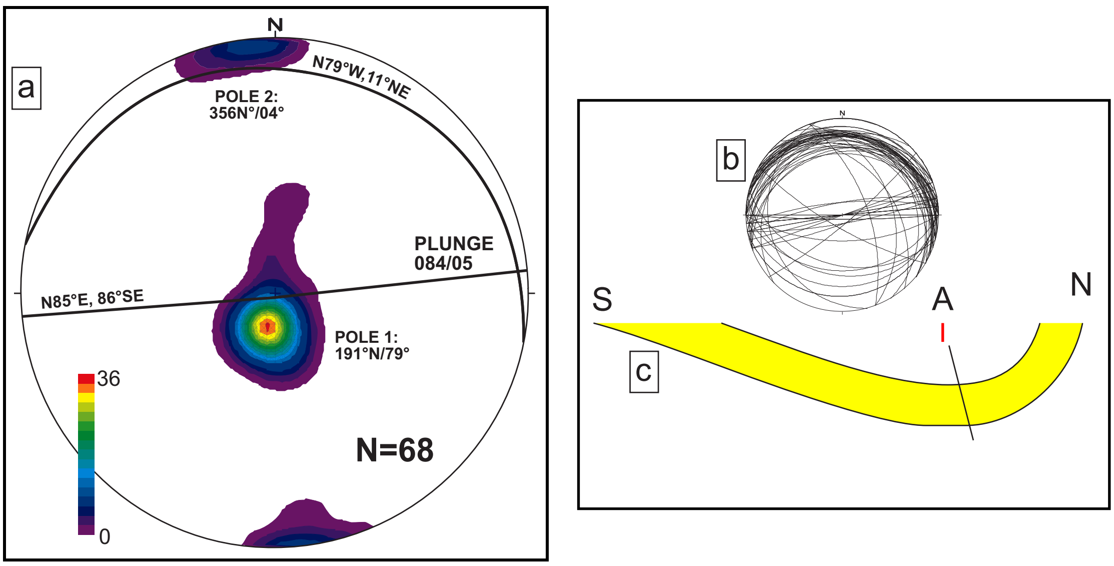

Figure 13. a) π-contour and b) b-diagram prepared from the bedding attitudes in the southern sector of the Çiçekdağı Basin. c) interpretation of the diagrams. Note the surface area difference between S-A and A-N.

3.4 Faults and Fault Kinematics

In the study area, four approximately E-W- to NW-SE- trending major thrust and reverse faults and two normal faults were recognized and are delineated on the map.

3.4.1 Faults

The tf1 is the southernmost observed at the northern margin of the southern sector of the Çiçekdağı basin. Along the tf1 the basement units thrust over the basin-fill units from north to south. The tf2 delineates the southern margin of the northern sector of the Çiçekdağı basin. Along the tf2, basement units thrust over the basin fill from south to north. In the east, it meets the tf1 in southeast of Çiçekdağı town. The tf1 and tf2 defines the margins of Çiçekdağı high as pop-up structure. Along the tf1 and tf2, overprinting slickensides were observed. The older slickensides indicate normal sense of shear while the younger ones indicate reverse sense of shear. This implies that tf1 and tf2 are inverted normal faults.

Although, tf3 is not directly observed in the field, however, marked linear E-W topographical high and sudden change in the dip of the beds are the circumstantial evidences for the presence of tf3. In addition, there must be major thrust fault that separated the Tauride-Anatolide Block from the Pontides, therefore, there must be a thrust fault approximately at the position of tf3. Therefore, it must be the main boundary thrust fault.

The tf4 is observed between Baraklı Formation and the İncik Formation at the central parts of the northern sector of the Çiçekdağı basin.

The tf5 is observed between Çökelik volcanics and Akçakent gabbro. All the structures are trending almost E-W; although, tf5 is trending N-S as f3 and it is cut by tf2 and tf1.

All of the thrust faults except from tf5 displace the İncik Formation and area sealed by Neogene units. Although, their exact age is not known, it is bracketed between Late Eocene to pre-Neogene.

In addition to thrust faults, two normal faults were also observed in the study area. The nf1 is observed at the southern margin of the southern sector of the Çiçekdağı basin. It is dipping due north and the İncik and older units are displaced while Neogene units are sealing the unit. This implies that the fault is post-Late Eocene to pre-Neogene age similar to the thrust faults.

The nf2 is observed within the Çiçekdağı high. It is trending E-W and dipping southwards. Along the nf2, İncik formation is the youngest displaced unit therefore, its age is post-Late Eocene-Oligocene.

In addition, a number of normal growth faults (Figure 14c) are observed in Baraklı, Kocaçay and İncik formations. These faults are very important in order to understand tectonic evolution of the basin. Their paleostress configurations are discussed in the next section.

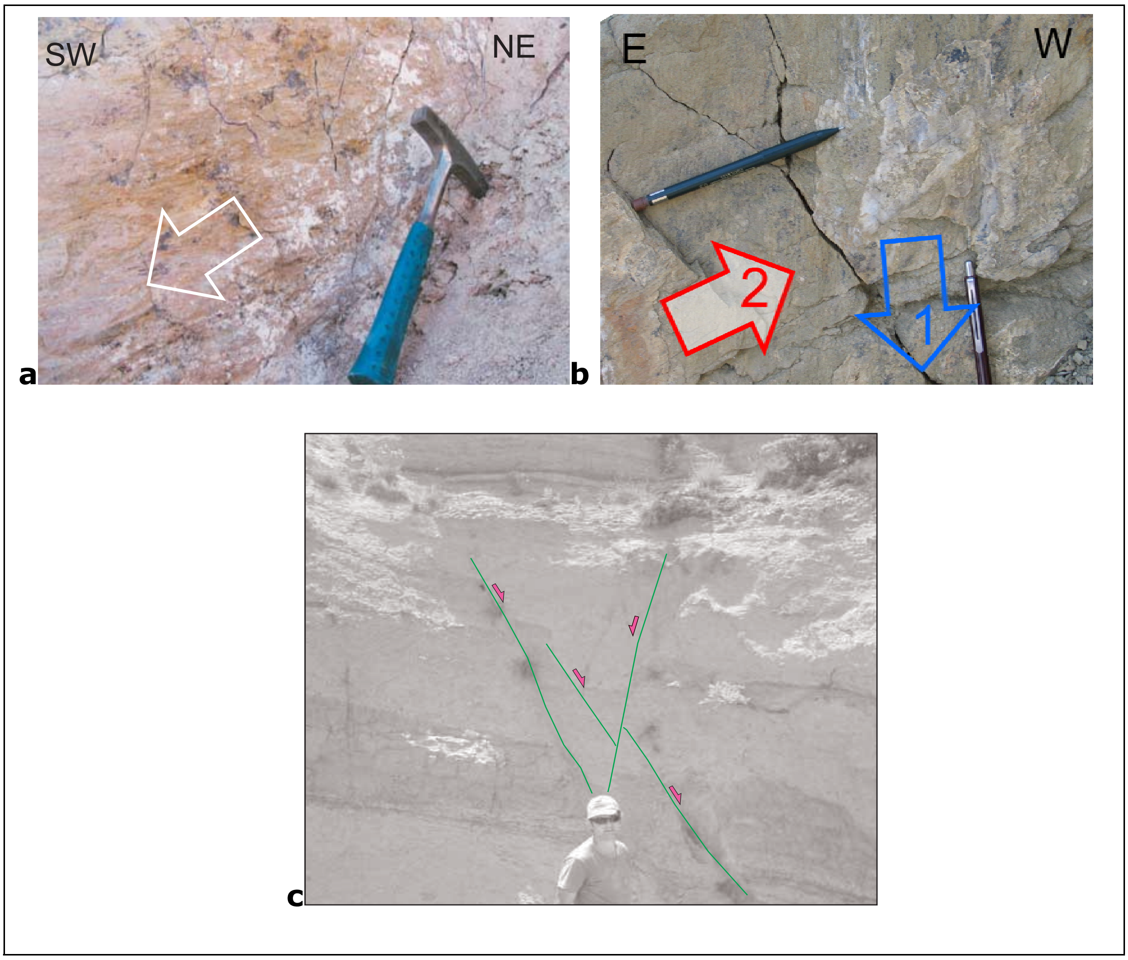

Figure 14. a) Example of slickensided surface on the normal fault (nf2) with strike-slip components (view E-W, location west of Baraklı village). b) Overprıntıng slickensides observed on the tf1 (view to southwest, location: 39º30'N, 34º35'). Note that first movement (1) is normal and indicated by calcite fibres, the second movement (2) is sinistral-strike-slip with reverse component and indicated by striations. c) Example of growth fault observed in the İncik Formation (view to southwest, location south of Harmanpınar village).

3.4.2 Paleostress

In order to understand the kinematic history of the study area from six locations 50 fault slip data were collected (Appendix-B,Figure 14). From each sites at least 7 data were collected in order to obtain reasonable paleostress configurations. After analysis, 11 of the collected data (23%) were found to be spurious and were not used for paleostress inversion. Among the remaining 39 data reasonable paleostress configurations were obtained (Table 1 and Figure 15). Among the six sites, two of the sites (B and F) did not produce reliable paleostress configurations using direct inversion method. In these sites reduced tangent fitting criterion (R2DT) of Angelier (1988) were applied. According to this method, one of the paleostress axes is assumed to be vertical and the inversion is run according to this assumption. The results for the R2DT are somewhat similar to the solutions for the other sites with similar compressional stress configurations.

Although, the number of sites are not sufficient to derive paleostress evolution of the region, the constructed paleostress configurations indicated that three different local stress configurations were operated in the region. These include approximately NW-SE extensional (strike-slip) and NE-SW compressional regimes.

Table 1. Paleostress orientations

SITE	σ_1	σ_2	σ_3	ϕ	number of faults
A	308°N/ 79°	056°N/03°	146°N/10°	0.188	6
B	224°N/00°	314°N/00°	360°N/90°	0.001	4
C	41°N/12°	284°N/65°	136°N/22	0.073	8
D	191°N/11°	316°N/71°	098°N/16°	0.514	5
E	280°N/63°	066°N/23°	162°N/13	0.651	8
F	075°N/00°	165°N/00°	360°N/90.	0.606	6

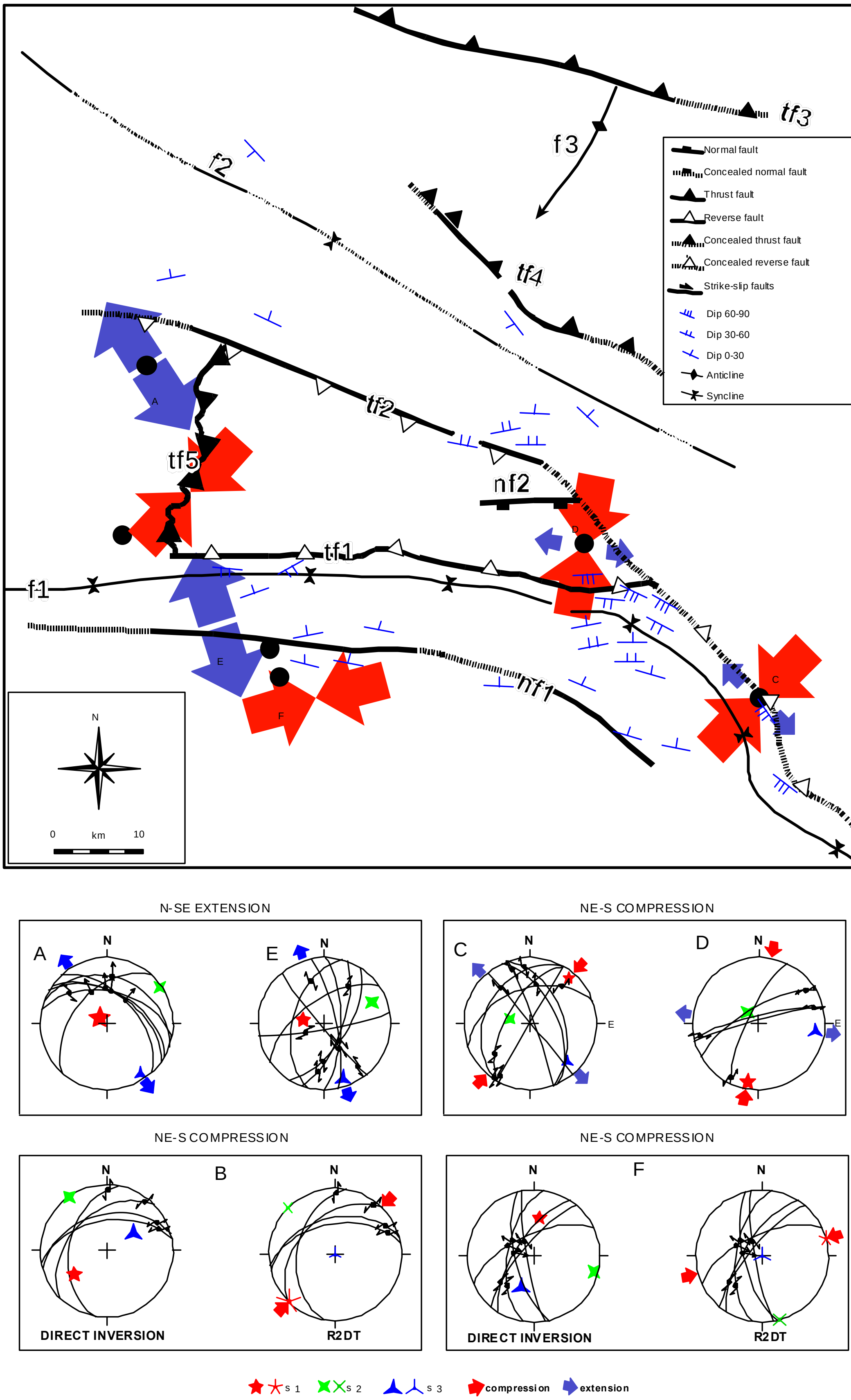

Figure 15. a) Major structures and paleostress orientations. b) Cylographic traces, slickensides and constructed paleostress configurations. Note that R2DT method yielded more reliable results than Direct Inversion methods of Angelier (1988).

CHAPTER 4

DISCUSSION

4.1. Tectono-stratigraphical Characteristics

Çiçekdağ basin was developed on the Central Anatolian Crystalline complex, which was part of the Anatolide-Tauride Block, during the Late Paleocene to Oligocene as an integral part of the Çankırı Basin. It is a flexural basin developed as a foreland basin of the İzmir-Ankara-Erzincan suture zone and comprises thick marine to continental red clastics with general coarsening upwards sequence and comprise progressive unconformities that are indicative of coupling of tectonics and coeval sedimentation.

As presented in the previous sections, basin fill units of the Çiçekdağı basin is divided into two sequences based on their sedimentological and stratigraphical characteristics. First sequence includes Late Paleocene to Middle Eocene Baraklı, Kocaçay and Boğazkoy formations and the second sequence includes the İncik and Güvendik formations.

Baraklı, Kocaçay, Boğazköy, İncik and Güvendik formations were formed both northern and southern sectors of the Çicekdağı basin.

The Late Paleocene-Middle Eocene sequence (first sequence) unconformably overlies the CACC (Figure 16) and represents a regressive sequence with shallowing and coarsening upwards characteristic (Oktay 1981, Seymen 1982 and Kaymakci et al. 2009) i.e. Baraklı Formation represents deeper marine turbidites, Kocaçay Formation represents shallow marine environment and Boğazköy Formation represents marine to continental transition. They are observed largely in the both southern and northern sectors of the Çiçekdağı basin and out of the study area especially in the Çankırı, Tuzgölü and Sivas basins. This implies that the first sequence was deposited in a very large single basin far beyond the present boundaries of the Çiçekdağı basin. However, the thickness of the Baraklı Formation decreases from north to south. In the southern margin of the Çiçekdağı basin it completely pinches out and to the south of the Çiçekdağı basin, Kocaçay Formation directly onlaps on to the CACC while the thickness of the Baraklı Formation reaches up to 1000 m in the north in the Çankırı Basin (Kaymakcı et al. 2009). No such wedge-shaped geometry is observed in the Kocaçay Formation; however, it becomes more limestone dominant from north to south and in the north it is intercalated with conglomerates and sandy limestones. This implies that in the north, it comprises more proximal facies while in the south, it comprises more distal facies.

Likewise Baraklı Formation, similar wedge-shaped geometry is also observed in the Boğazköy Formation. It is thicker in the north and becomes thiner southwards. In addition, it is represented by more proximal facies in the northern sector and more distal facies in the southern sector of the Çiçekdağı basin. Moreover, paleocurrent directions obtained from the Boğazköy Formation both in the northern and southern sectors of the Çiçekdağı indicate southwards transport directions.

Kocaçay Formation is widely observed unit in the study area and it is characterized by 10 to 50 m thick nummulitic limestone layers. These limestone layer are exposed and observed at northern, southern, and central parts of the study area. The outcrop distribution of this layer has allowed us to determine the geometry of the structural elements of the Çiçekdağı basin, because it recorded the effect of all the structures such as folds or faults. The sign of the re-deposition of it was observed in the younger units and this also gives us information about the evolution of the basin. The unit was deformed in regionally compressional regime with W-E trending tf1, tf2, tf4, and locally extensional regime with W-E trending nf1 and nf2. It is the youngest marine deposits in the region. This implies that the marine inundation ended at the end of Middle Eocene and the basin turned into a continental basin.

Boğazkoy Formation is observed both southern and northern sectors of the Çiçekdağı high. However, paleocurrent directions both in the northern and southern sector of the basin consistently indicate south directed flows (Figures 8 & 11). In addition, it includes (in both sectors) clasts derived from the Kocaçay Formation. In addition, the thickness and grain size of the unit gradually decreases southwards. It is worthwhile to note that around the Çiçekdağı high, it has finer clastics like in the southern sector. Based on this information, it is speculated that the Boğazköy Formation was deposited before the uplift of the Çiçekdağı high along tf1 and tf2. This implies that the tf1 and tf2 postdates the Boğazköy Formation.

İncik Formation is the most important unit of the study area because it has helped us to understand the age relationships between the units and structural elements. Paleocurrent data obtained from this unit show variation in northern and southern sectors. It has bimodal paleocurrent directions in the northern sector of the basin while unimodal paleocurrent directions flow in the southern sector of the basin. Paleocurrent directions in the northern sector indicate both due south flows close to the northern margin and due north close to the southern margin. This implies provenance located both in the northern and southern margin of the northern sector of the basin. However, paleocurrents in the southern sector of the basin indicate dominantly south-directed palaeoflows indicating provenance located in the north. In addition to these, mainly in the southern sector of the basin, a number of progressive unconformities were observed in the İncik Formation. All of this information implies that during the deposition of the İncik Formation Çiçekdağı high was uplifted along tf1 and tf2.

Güvendik Formation is the youngest unit of the Çiçekdağı basin. This formation is observed in both northern and southern sector of the Çiçekdağı basin. This was dominated by gypsum, marl, siltstone and sandstone indicating restriction of the basin as an evaporate producing fluvio-lacustrine basin.

The other cover units include the Neogene units and Qauternary alluvial deposits. These units are angular unconformably overlying the basement and Paleogene deposits. They are less deformed and extend far beyond the limits of the Çiçekdağı basin. It is thought that they represent completely different tectonostratigraphical and evolutionary history which is out of scope of this thesis.

4.2. Paleogene Evolutionary Scenarios

Considering wedge-shaped geometries of Baraklı and Boğazköy formations and organization of facies proximal in the north and distal in the south indicates that the Çiçekdağı basin was an asymmetric basin during the Late Paleocene to Eocene. Consistent southwards paleocurrent directions in the Boğazköy Formation indicates that the active margin of the basin was in the north, outside of the study area possibly southern margin of the Çankırı Basin (Kaymakcı et al. 2009), which provided detritus to the basin. Such asymmetric basin geometry implies that during the Late Paleocene to Eocene Çiçekdağı basin was either a half graben or foreland basin where the main boundary fault was in the north.

Half grabens are associated with extensional deformation, migration of the source away from the basin axis that result in fining upwards sequences all of which implies a transgressive cycles and progressive unconformities in half grabens develop on the opposite margin of the main boundary fault; however, Çiçekdağı basin has regressive and coarsening-upwards characteristics and progressive unconformities are developed in the north and associated with the main boundary faults. Presence of thrust faults in the northern margin of the basin and its stratigraphical characteristics imply that the Çiçekdağı Basin basin was a foreland basin and possibly constituted the southernmost margin of the Çankırı Basin as proposed by Kaymakcı (2009). However, extensional growth faults within the Kocaçay and Boğazköy formations indicate that extensional deformation was also prevailed in the basin during its development. Extensional deformation in the foreland basins is observed generally in their distal parts where down-going plate is extended due to flexural bending (cf. Allen & Allen 1990). Therefore, we speculate that the extensional growth faults are the result of flexural bending of the CACC as the thrust faults in the north advanced southwards (Figure 16a).

During the Paleocene to Middle Eocene interval, the basin was extending possibly from the Çankırı Basin in the north to at least present southern margin of the basin in the south. During this time interval, the Çiçekdağı high area was a graben in the central part of the basin (Figure 16a). During the deposition of the İncik Formation, the northern sector and Çiçekdağı High areas become part of the thrust propagation and involved in thrusting. This resulted in inversion of the graben which resulted in the uplift of the Çiçekdağı high (Figure 16b). This gave way to compartmentalization of the basin and Çiçekdağı High became site of erosion that provided detritus to both northern and southern sectors of the basin.

As the south-vergent thrust propagation continued, the İncik Formation continued its deposition while it was caught within the thrust faults that gave way to its deformation, erosion and hence development of progressive unconformities possibly during the Late Eocene to middle Oligocene. During the deposition of Güvendik Formation, compressional deformation reached its climax and the basin become hydrologically isolated that gave rise to the deposition of the evaporates.

After the deposition of Güvendik Formation, compressional deformation was replaced by completely different tectonic regime which gave way to the deposition of Noegene deposits and basin reached its present geometry (Figure 16c).

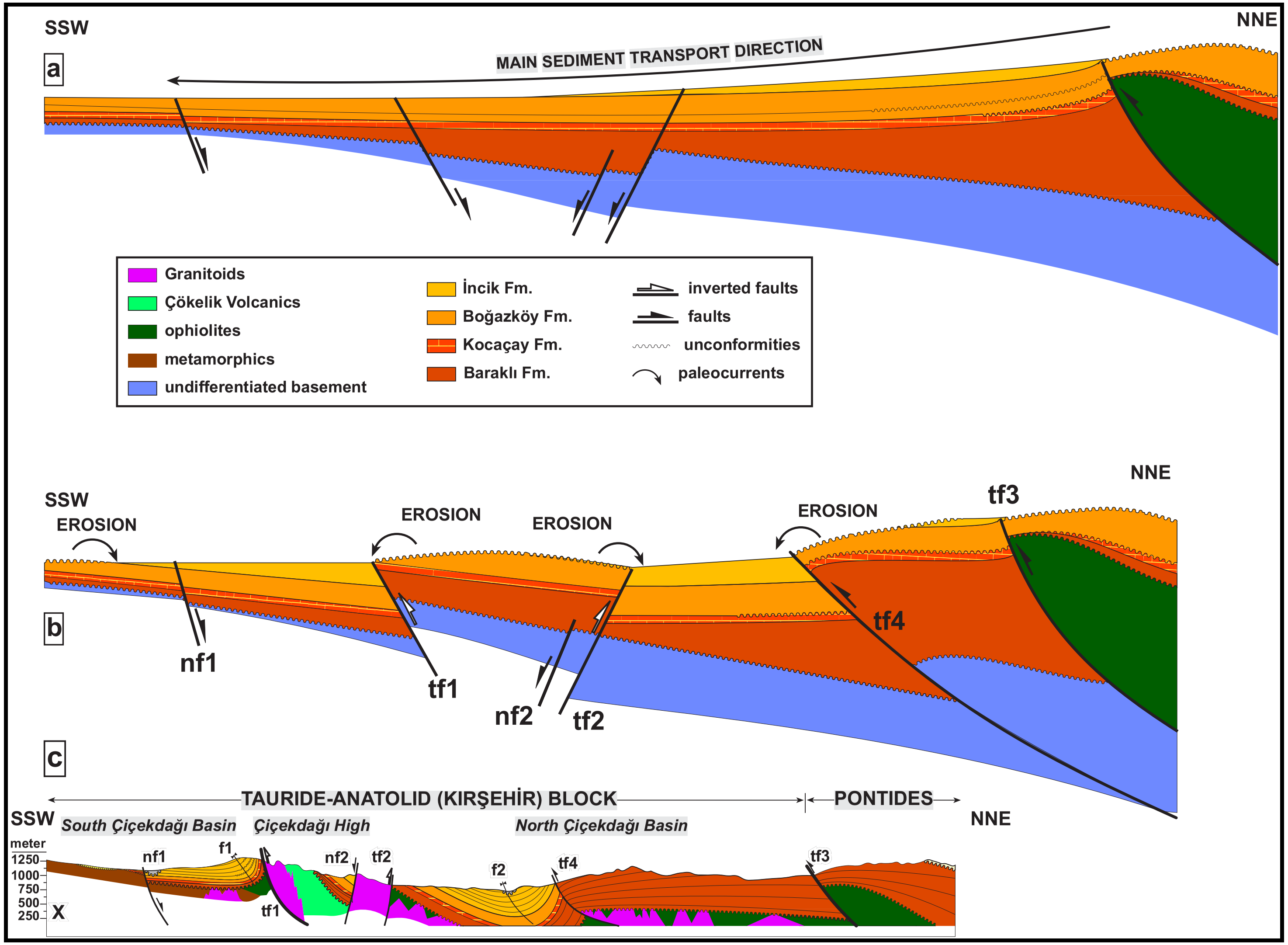

Figure 16. Evolutionary scenarios of Çiçekdağı basin.

CHAPTER 5

CONCLUSIONS

This study has reached following conclusions.

Çiçekdağı basin was developed on the Central Anatolian Crystalline Complex and comprises two sectors; the northern and southern sectors.

It is flexural (foreland) basin developed during the Late Paleocene to middle Oligocene.

The basin comprises two depositional cycles.

The first cycle includes Upper Paleocene to Middle Eocene Baraklı, Kocaçay and Boğazköy formation,

The second cycle comprises Upper Eocene to middle Oligocene İncik and Güvendik formations.

The basin fill units are regressive in nature and has wedge-like geometry, thicker at the north and thinner in the south.

The marine inundation ended at the end of Middle Eocene and post Middle Eocene basin units are deposited in continental settings.

The thrust faults tf1 and tf2 are inverted normal faults.

The basin fill units has uniform south-vergent paleoflow directions in the Upper Paleocene to Middle Eocene units and Late Eocene to middle units have bivergent paleoflow directions that indicate the uplift of the Çiçekdağı high.

The Çiçekdağı high was a graben during the Late Paleocene to Middle Eocene and was inverted due to ongoing compression starting from the end of Late Eocene. This gave way to compartmentalization of the basin into northern and southern sectors and the uplifted area became site of erosion that provided detritus to İncik Formation and younger units.

During the middle Oligocene, the basin become hydrologically restricted and produced evaporates.

Çiçekdağı basin displays most of the characteristic features of a foreland basin and southernmost integral part of the Çankırı Basin.

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APPENDIX A

Table A. Paleocurrent measurements.

kod	x	y	Flow direction															
spc1	622116	4376097	175	130	140	165	220	250	185	200								
spc2	622142	4376139	110	170	120	205	240	260	145	125	150	140	125	160	115	140	138	170
spc3	622072	4376114	160	150	140													
spc4	622056	4376265	160	145	135													
spc5	621554	4372284	160	100	155	220	140											
spc6	623914	4374878	155	160	235	190	140	230	140									
spc7	622091	4376071	130	120														
spc8	622075	4376113	200	145	115													
spc9	622026	4376428	150	180	175	150	200	210										
spc10	622115	4376480	170	150	200	190												
spc11	622120	4376990	210	200	160	220	180											
spc12	621996	4377202	180															
spc13	621701	4376733	170	180														
spc14	628031	4374382	140	150	170	180												
spc15	622625	4378443	150	220	230	240												
spc16	622645	4378635	270	240														
spc17	622527	4378879	270	190														
spc18	622348	4379143	180															
spc19	620123	4379876	180	230	270	60												
spc20	3952445	3442062	135	140	150													
spc21	3952456	3442062	200	180	190													
spc22	3952512	3442089	180	175	170													
spc23	3952528	3442092	210	330														
spc24	3952643	3442172	220															
spc25	3952719	3442151	270	250														
spc26	3952755	3442208	170	180														
spc27	3952875	3442377	210	220	240													
spc28	3952911	3442479	220	240	225													
spc29	3953000	3442621	250															
spc30	3953146	3442597	170															
spc31	3953146	3442597	180															
spc32	593562	4397143	300															
spc33	593642	4397142	100															
spc34	593665	4397139	220	250														
spc35	616213	4392139	300	290	230	260	330											
spc36	616221	4392219	190	210														
spc37	616280	4392050	290	260														
spc38	616346	4391915	330															
spc39	616359	4392033	30	80	80													
spc40	616584	4391520	50	80														

Table A. Cont'd

spc41	620817	4379436	190								
spc42	620830	4379527	220								
spc43	620854	3479538	190	220							
spc44	622284	4379480	210								
spc45	622362	4379393	225								
spc46	622398	4375899	215	200	190	160	140				
spc47	622414	4375981	240	180	210	200	220	150			
spc48	622816	4376287	270	265							
spc49	622910	4376419	105	85	70	220	235				
spc50			194	199							
spc51			5	310	355	345	340	331	357	339	353
spc52			332	1	325	29	336				
spc53			329								

APPENDIX B

Table B. Paleostress measurements

Strike	Dip	Rake	Type of Fault	Location (X,Y)		Location Code
N70W	30NE	78N	Normal	36S 0590816	4394810	A
N42E	48NW	75N	Normal	36S 0590816	4394810	A
N60W	50NE	68N	Normal	36S 0590816	4394810	A
N43W	53NE	85N	Normal	36S 0590816	4394810	A
N55W	52NE	72N	Normal	36S 0590816	4394810	A
N80E	66NW	10S	Left Normal	36S 0590816	4394810	A
N78W	49NE	38N	Right Normal	36S 0590816	4394810	A
N79W	62NE	21N	Right Normal	36S 0590816	4394810	A
N10E	42NW	12N	Left Reverse	36S 0589456	4383289	B
N75E	44NW	20N	Left Reverse	36S 0589456	4383289	B
N45E	42NW	10N	Left Reverse	36S 0589456	4383289	B
N45E	40NW	70N	Reverse	36S 0589456	4383289	B
N55E	39NW	70N	Reverse	36S 0589456	4383289	B
N80E	52NW	20N	Left Reverse	36S 0589456	4383289	B
NS	85W	50S	Reverse	36S 0589456	4383289	B
N40W	80NE	30N	Right Reverse	36S 0632985	4372744	C
N30E	32NW	5S	Right Reverse	36S 0632985	4372744	C
N30E	80NW	10S	Right Reverse	36S 0632985	4372744	C
N20W	85NE	15N	Right Reverse	36S 0632985	4372744	C
N20W	48NE	20N	Right Reverse	36S 0632985	4372744	C
N70E	46NW	45N	Reverse	36S 0632985	4372744	C
N20W	46NE	10S	Right Reverse	36S 0632985	4372744	C
N25W	57NE	50N	Reverse	36S 0632985	4372744	C
N30E	60NW	45S	Reverse	36S 0632985	4372744	C
N70E	53SE	60S	Reverse	36S 0620664	4383288	D
N60E	70NW	15N	Left Reverse	36S 0620664	4383288	D
N77E	80NW	10S	Right Reverse	36S 0620664	4383288	D
N15W	85NE	10N	Right Reverse	36S 0620664	4383288	D
N42W	85NE	12N	Right Reverse	36S 0620664	4383288	D
N25E	75NW	10S	Left Reverse	36S 0620664	4383288	D
N75E	85NW	15N	Left Reverse	36S 0620664	4383288	D
NS	70E	60S	Normal	36S 0599343	4375631	E
N12W	76NE	65S	Normal	36S 0599343	4375631	E
N20E	68SE	30S	Right Normal	36S 0599343	4375631	E
N40W	85SW	20S	Left Normal	36S 0599343	4375631	E
N80E	83SE	65S	Normal	36S 0599343	4375631	E
S05E	60NW	40N	Normal	36S 0599343	4375631	E
N15E	50NW	45N	Normal	36S 0599343	4375631	E
N32E	62SE	50S	Normal	36S 0599343	4375631	E

Table B. Cont'd

N10E	46NW	80S	Reverse	36S 0600184	4374086	F
N09E	57NW	50S	Reverse	36S 0600184	4374086	F
N10W	81SW	70N	Reverse	36S 0600184	4374086	F
N14W	67SW	65N	Normal	36S 0600184	4374086	F
N60E	80SE	30N	Left Normal	36S 0600184	4374086	F
N33E	67NW	60S	Reverse	36S 0600184	4374086	F
N55E	80SE	75S	Reverse	36S 0600184	4374086	F
N25E	65SE	75N	Normal	36S 0600184	4374086	F
N65E	63NW	57S	Reverse	36S 0600184	4374086	F
N40E	75NW	40S	Right Reverse	36S 0600184	4374086	F