GEOARCHAEOLOGICAL INVESTIGATIONS AROUND KÜLTEPE (KAYSERI)

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

IŞIL ÖMEROĞLU

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
GEOLOGICAL ENGINEERING

SEPTEMBER 2011

Approval of the thesis:

GEOARCHAEOLOGICAL INVESTIGATIONS AROUND KÜLTEPE (KAYSERI)

submitted by **IŞIL ÖMEROĞLU** 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**

Prof. Dr. G. M. Vedat Toprak ____________
Supervisor, **Geological Engineering Dept., METU**

Prof. Dr. Fikri Kulakoğlu ____________
Co-Supervisor, **Archaeology Dept., A.U**

Examining Committee Members:

Prof. Dr. M. Cemal Göncüoğlu ____________
Geological Engineering Dept., METU

Prof. Dr. G. M. Vedat Toprak ____________
Geological Engineering Dept., METU

Prof. Dr. Fikri Kulakoğlu ____________
Archaeology Dept., A.Ü

Prof. Dr. Asuman Türkmenoğlu ____________
Geological Engineering Dept., METU

Assoc. Prof. Dr. M. Lütfi Süzen ____________
Geological Engineering Dept., METU

Date:09.09.2011

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: Işıl, Ömeroğlu

Signature:

ABSTRACT

GEOARCHAEOLOGICAL INVESTIGATIONS AROUND KÜLTEPE (KAYSERI)

Ömeroğlu, Işıl

M.Sc., Department of Geological Engineering
Supervisor: Prof. Dr. G. M. Vedat Toprak
Co-Supervisor: Prof. Dr. Fikri Kulakoğlu

September 2011, 84 pages

The purpose of this study is to investigate the effect of geology on ancient Kültepe settlement located in a tectonically active area, namely Sarımsaklı basin, shaped by Central Anatolian Fault Zone.

Four main data sources used in this study are geological map, digital elevation model (DEM), slip plane and the borehole data. Geological maps are used for the determination of key horizons and the faults shaping the basin. Slip data measured in the field are used to identify the nature of the faults. Borehole data are used for the preparation of Quaternary thickness map and the borehole-to-borehole sections across the basin. Morphology of the area is investigated using the DEM with a particular emphasis on the drainage characteristics of the basin.

The analyses have shown that the faults shaping the basin are still active suggesting vertical movements today as well as during the historical period. According to morphological analysis, the basin is drained by a

single channel (Karasu river) which is controlled by the western segment of the fault zone. If the fault activates, the channel is elevated resulting in the formation of a lake behind the channel. Accordingly, the present morphological configuration suggests that a water level elevated for 70 m will totally bury Kültepe.

Keywords: Geoarchaeology, GIS, borehole correlation, Kültepe

ÖZ

KÜLTEPE (KAYSERİ) DOLAYINDA JEOARKEOLOJİK ARAŞTIRMALAR

Ömeroğlu, Işıl

Yüksek Lisans, Jeoloji Mühendisliği Bölümü

Tez Yöneticisi: Prof. Dr. G. M. Vedat Toprak

Ortak Tez Yöneticisi: Prof. Dr. Fikri Kulakoğlu

Eylül 2011, 84 sayfa

Bu çalışmanın amacı tektonik olarak aktif bir saha olan ve Orta Anadolu Fay Zonu tarafından şekillendirilen Sarımsaklı havzasında yer alan antik kent Kültepe'yi etkileyen jeolojik olayları araştırmaktır.

Bu çalışmada dört tip ana veri kaynağı mevcuttur. Bunlar; jeoloji haritası, sayısal yükseklik modeli (SYM), kayma düzlemi verileri ve kuyulardır. Çalışma esnasında; jeoloji haritaları, anahtar birimlerin ve havzayı şekillendiren fayların tespiti maksadıyla kullanılmıştır. Kayma düzlemi verileri yardımıyla, fayların davranış biçimleri tanımlanmıştır. Kuyu verilerinden, Kuvaterner kalınlık haritası hazırlanırken ve havza içerisinden alınan kuyudan kuyuya kesitlerin üretilmesi esnasında faydalanılmıştır. Çalışma alanının morfolojisi SYM kullanılarak incelenmiş ve buradan yola çıkarak havzanın drenaj özellikleri tespit edilmiştir.

Yapılan analizler, havzayı şekillendiren fayların dikey atımları olduğunu göstermiş ve bu fayların tarihte olduğu üzere bugün de aktif olduklarını kanıtlamıştır. Morfolojik analizlere göre; havza ana fay zonunun batı segmenti tarafından kontrol edilen ince bir kanal (Karasu ırmağı) yardımı

ile boşaltılmaktadır. Bahsedilen bu fay aktive olduğu taktirde; drenaj kanalı yükselmekte ve arkasında kalan havza içerisinde göl oluşumu söz konusu olmaktadır. Buna bağlı olarak, havzanın bugünkü morfolojik konumu temel alındığında, havza içerisinde 70 metrelik su seviyesi artışı Kültepe'yi sular altında bırakacaktır.

Anahtar Kelimeler: Jeoarkeoloji, CBS, kuyu korelasyonu, Kültepe

In memory of my grandmothers,

Hatice Yılanlıoğlu and Mualla Ömeroğlu

ACKNOWLEDGEMENTS

I am deeply grateful to my supervisor Prof. Dr. G. M. Vedat Toprak for his precious guidance, support and encouragement throughout this study. This thesis would not be accomplished without his advices. It is an honor for me to have the chance to work with him.

I would also like to thank my co-supervisor Prof. Dr. Fikri Kulakoğlu for making my archaeological perspective wider with his valuable suggestions. He and his team have welcomed us with hospitality in their camp and this helped me in the course of field investigations.

I wish to thank my examining committee members, Prof. Dr. M. Cemal Göncüoğlu, Prof. Dr. Asuman Günal Türkmenoğlu and Assoc. Prof. Dr. M. Lütfi Süzen for sharing their valuable recommendations and critics with me.

Special thanks are extended to Murat Özkaptan for helping me out during my field studies and research. With his assistance, the field observations and ground measurements have been accomplished sooner and easier. I would like to thank him for his technical and moral support throughout my study.

I am thankful to Birce Bakdı, Emre Günay and my roommate Seda (Çiçek) Demirel for their valuable friendship and support. Additionally, I wish to thank Şule Gürboğa, Kıvanç Yücel and A. Mert Eker for sharing their experience while I was formalizing my study.

Especially, I would like to express my deepest gratitude to my dear parents; İnci and Hasan Ömeroğlu and my sister Seçil Ömeroğlu who supported me all throughout this study with their endless love and patience. The preparation of this thesis would not be possible without the courage and support they have given to me all through my life.

Last but definitely not least, my greatest thanks go to my grandmother, Hatice Yılanlıoğlu who encouraged me to apply to the master programme at the very beginning. She was the one who supported me all through this time with her everlasting love and compassion. I wish she was here with me today.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

CHAPTER 1

INTRODUCTION

1.1. Purpose and Scope

Kültepe is an ancient settlement located in Central Anatolia within a tectonically active area where one of the major fault zones of Turkey is operating. Although the effect of this active tectonism on the settlement is not documented so far, it is expected that an ancient site located in such a geologically active environment should have some records of this interaction. The main motivation behind this study is a piece of information provided by the excavations carried out in the site. The site although had been used as a settlement by ancient civilizations for a long time, there are evidences for an unsettled period of about 800 years between Colonial (1950-1700 BC) and Iron (900-700 BC) ages. This gap in the settlement history is not linked to any human affair such as war or fire. Considering the geological characteristics of the region, a research question can be raised whether this period can correspond to a geological event or not.

The purpose of this study, accordingly, is to investigate the possible geological processes that could interrupt the life in Kültepe and environs. Since the site is located in the middle of a pull-apart basin which is drained by a narrow channel (Karasu river), the purpose is limited to the investigation of a flood period that buries the site for a certain period.

The scope of the study, therefore, is defined by a set of questions as follows:

a) Are the faults around the site active? To answer this question a compilation of the seismic data in the region is made.

b) Can the faults block the Karasu river forming a barrier which will result in the development of a lake behind that can flood the site? For this question, the nature of the faults is investigated using some field data particularly the slip data combined with the information available in the literature.

c) Is there any geological evidence in the region that can confirm recent vertical movements? To understand the vertical movements occurred in the region both digital elevation model (for morphologic analyses) and 1/25.000 scale geological maps (for lithologic analysis) are investigated.

d) Is there any evidence from the Quaternary fill deposits of the basin that may confirm? To investigate the nature of the Quaternary deposits, the data from the boreholes drilled in the area are provided. The thickness of the Quaternary deposits is investigated using the borehole data.

The study will integrate two disciplines, namely, archaeology and geology. The expected outcomes of the study, on one hand, will solve a specific geological problem in an archaeological site; on the other hand, will form a case study for such interdisciplinary works.

1.2. Study Area

Kültepe is located to the NE of Kayseri (Central Anatolia) (Figure 1.1). The flat area represented by yellow color is known as Sarımsaklı basin which is the main focus in this study. The basin is fed mainly by Sarımsaklı river at its northeastern margin and is drained by the Karasu river at the west. The monumental Erciyes volcanic mountain is located to the south of the study area.

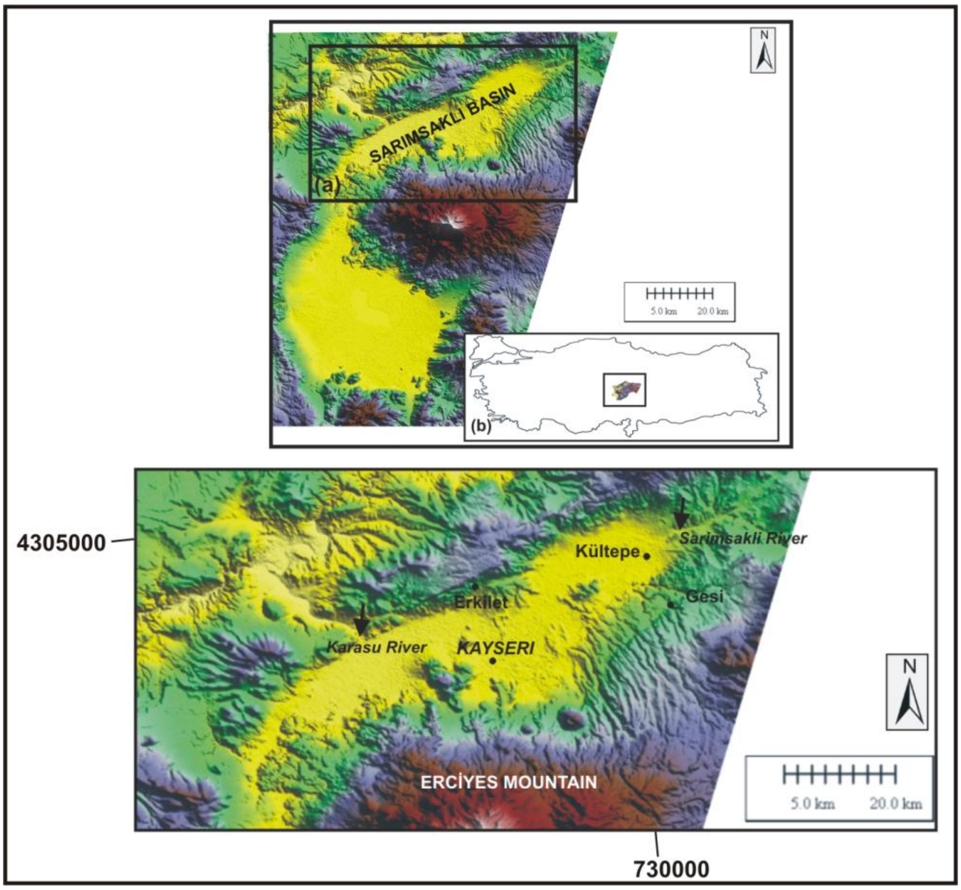


Figure 1.1. Location map of the Kültepe archaeological site. The rectangular area (a) represents the study area investigated in this thesis.

The study area is included within thirty-two 1/25000 topographic maps; namely K34-a1, a2, a3, a4, b1, b2, b3, b4, c1, c2, c3, c4, d1, d2, d3, d4 and K35-a1, a2, a3, a4, b1, b2, b3, b4, c1, c2, c3, c4, d1, d2, d3, d4.

1.3. Archaeological Background of Kültepe

Kültepe is defined as one of the most important ancient cities, known as Kanesh in the Near East with its eighteen different building phases (Figure 1.2). The cuneiform tablets revealed in Kültepe excavations are the earliest written documents discovered in Anatolia. Hence, Kültepe-Kanesh is defined as where the recorded history of Anatolia has begun (Emre, 2010).

Figure 1.2. The aerial photograph of Kültepe

The discovery of Kanesh goes back to 129 years ago associated with the cuneiform tablets referred to as “Cappadocian Tablets” introduced by T.G. Pinches in 1881 (Emre, 2010). However, T. G. Pinches was not the one who excavated these tablets out from the site but bought them in Istanbul from an antique market. He identified these tablets by citing the similar tablets exhibited in Paris Bibliotheque Nationale (Emre, 2010).

In 1893 through 1894, E. Chantre visited Anatolia in order to detect the location of the site where these tablets were from (Emre, 2010). He suggested that the tablets should be connected to the mound of Karahöyük-Kültepe situated in NE of Kayseri. However, by the excavation conducted by Chantre, no tablets were discovered across the mound.

Afterwards, two other excavations were performed throughout the site by W. Belck in 1901 and H. Winckler and G. Grothe in 1906 (Emre, 2010). However, both of these excavations could not reach any result.

In 1925, with the authorization of Turkish Republic, B. Hrozny who was a Hittitologist, was assigned as the director of Kültepe Excavations (Emre, 2010). The excavation had started at the mound, however, he was unsuccessful to reveal any tablets, but continued digging the lower city surrounding the mound and excavated out almost 1000 tablets there. He was also the one who introduced the ancient site to the literature through the cuneiform tablets (Emre, 2010). This connotation brought Kültepe/Kanesh to the centre of Old Assyrian studies in archaeology. Hence, it was thought that the main administrative center of Old Assyrian trade network was in Anatolia (Topçuoğlu, 2010).

Until 1948, no excavations had been conducted across the site. The systematic excavations began in 1948 by Tahsin and Nimet Özgüç with the support of Turkish Historical Association to define the characteristics of Kültepe/Kanesh in addition to revealing the commercial relations between Anatolia and Mesopotamia (Emre, 2010).

After the death of Tahsin Özgüç, the excavations continued under the directorship of Fikri Kulakoğlu until the present day in order to light the characteristic features of Anatolian culture.

Kültepe/Kanesh was a great administrative centre of the trade networks in Anatolia as well as Northern Syria and Mesopotamia beginning from Early Bronze Age to the Assyrian Trade Colony Period (Emre, 2010).

Accordingly, in the light of the studies conducted across the site, it has been revealed that the cultural strata of the ancient settlement consist of the historical levels varying from Early Bronze Age-I to Hellenistic-Roman Periods (Emre, 2010). Hence, Kültepe is represented by five different cultural and historical phases, namely, Early Bronze Age I, Early Bronze Age II, Early Bronze Age III, Assyrian Trade Colony Period, Iron Age, Hellenistic Period and Roman Period (Kulakoğlu, 2010). However, there is a sharp gap between some periods of the settlement. The very important gap is right after the end of Assyrian Trade Colony Period, a time when the Hittite Kingdom was established and lived for 500 years. No architectural evidence attesting to this phase has been found at Kültepe to date. Additionally, the last phase of Assyrian Trade Colony Period at Kültepe is a very weak settlement comparing to the earlier levels. The magnificence of the wealthy trading outpost lost its importance in this period and after the end of this level Kültepe had never been settled for 800 years which corresponds to the time of Hittite Kingdom and Empire.

Due to the existence of the imported pottery, cylinder seals and metal objects revealed during the excavations, it is discovered that the close relations had been started from Early Bronze Age II among Anatolia, Northern Mesopotamia and Northern Syria (Kulakoğlu, 2010). In this age, even if there was contact with the developed societies where the writing was invented, it is known that Anatolia had not developed any writing system (Kulakoğlu, 2010). However, the presence of Kanesh was mentioned in the legendary "King of Battle/*sar tamhari*" texts on the deeds of King Sargon of Akkad and his grandson Naram-Sin who lived in the 24-23th century BC (Kulakoğlu, 2010). According to the text, Pampa the King of Hatti and Zipani the King of Kanesh were stated among the coalition of 17 kings in the battle. Hence, the documentary is introduced as the proof of the entity of Kanesh at that time period before the writing in Anatolia.

After the Early Bronze Age III, in the Assyrian Colony Period as it is implied before; Kültepe became the centre of trade network in Anatolia and known as Kanesh Kingdom. Associated with the excavations on the mound, early palaces and Warshama Palace are introduced as the main markers of the ages. "Palace on the Southern Terrace", which was the earliest administrative building, represents the beginning of the Assyrian Colony Period at Kanesh Kingdom (Kulakoğlu, 2010). However, the "Lower Early Palace", the second administrative building was followed by the monumental building "The Palace of Warshama", belonging to the latest phase of Colony Age (Kulakoğlu, 2010). Throughout the Iron Age, the ruins of Late Hittite Period are denoted at the mound as being the Kanesh Kingdom under the reign of the Grand Land of Tabal. However, approximately at the end of the 8th Century BC Kültepe was invaded by the Assyrians like the other Late Hittite Kingdoms across the region.

Finally, the Colony Age was overlain by Hellenistic and Roman Periods in Kültepe as the last three construction levels unearthed. Hence, it is concluded that the mound was abandoned in the Late Roman Period depending on the excavations across the site (Kulakoğlu, 2010).

1.4. Method of Study

Method of study consists of two steps that include field investigations and office applications. The field study is conducted in two periods, one in the summer of 2009 which was mainly a reconnaissance, and the second one in the summer of 2010 for data collection and some ground truth studies.

The office work consists of literature survey, data compilation and preprocessing, analyses of the data and finally the organization of the thesis. All the data are converted to digital format as GIS files and processed mainly by the MapInfo software.

CHAPTER 2

REGIONAL GEOLOGY

This chapter is a review of the geology of the study area and its environ based on the published data in the literature. The chapter is divided into two sections. The first section describes evolution of Sarımsaklı basin in which the Kültepe archaeological site is located. In the second section the stratigraphy of the area will be explained based on the geological maps prepared by the General Directorate of Mineral Research and Exploration of Turkey (Dalkılıç, 2009; Dönmez et al., 2005).

2.1. Evolution of Sarımsaklı Basin

The major structural features of Turkey are illustrated in Figure 2.1 prepared by Koçyiğit and Beyhan (1998) for the zone known as Central Anatolian Fault Zone (CAFZ) passing through the study area. This fault zone runs parallel to the East Anatolian Fault Zone and is located between the North Anatolian Fault Zone and the Mediterranean Sea with a length of 730 km, and a width of 2 to 80 km. It is an active, left-lateral strike-slip fault.

The CAFZ is a very young neotectonic structure resulted from the reactivation and propagation of a paleotectonic structure known as Ecemis Corridor extending from NNE to SW directions across the Inner

Tauride Suture in the Plio-Quaternary times (Kocyigit and Beyhan 1998; Gans et al., 2009).

The CAFZ is dominated by well-developed stepovers, smooth to sharp bends, bifurcation and pull-apart basins according to Koçyiğit and Beyhan (1998). Erciyes pull-apart basin is mentioned in this study for the whole basin located to the north and south of the Erciyes volcanic complex formed by the two segments of the CAFZ. The Sarımsaklı basin is not referred to in this study but should correspond the northern part of Erciyes pull-apart basin.

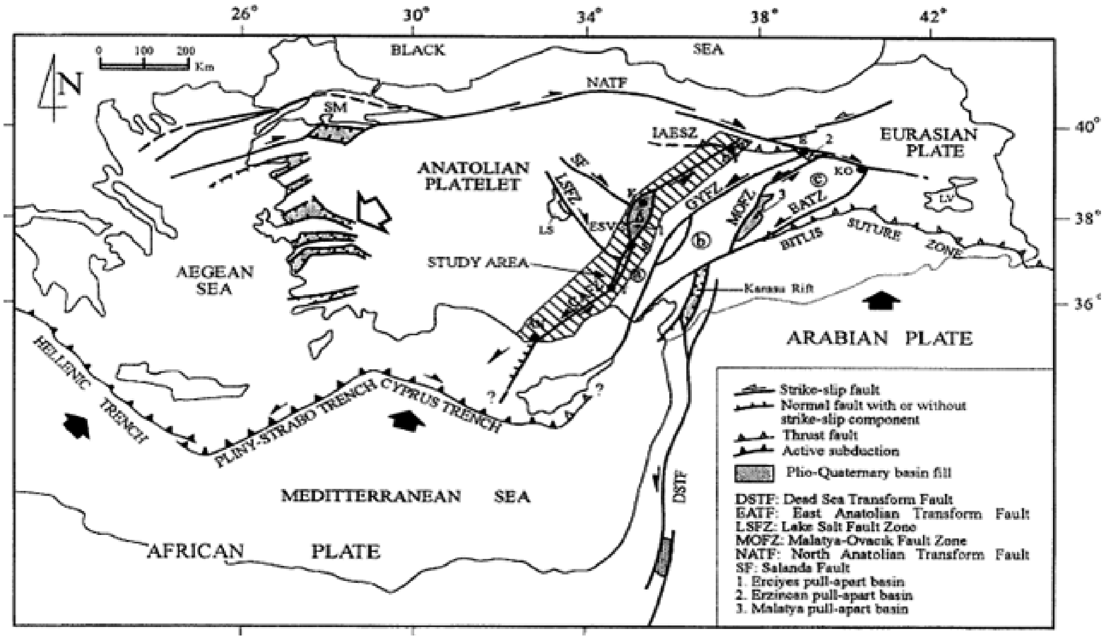


Figure 2.1. Neotectonic map of Turkey with a main emphasis on Central Anatolian Fault Zone that passes through the study area. AN: Anamur; DY: Duzyayla, E: Erzincan, K: Kayseri, KO: Karliova, LS: Lake Salt, LV: Lake Van, S: Sulucaova, SM: Sea of Marmara, T: Tekir, a: Adana-Sivas Block, b: Munzur Block, c: Keban Block, CAFZ: Central Anatolian Fault Zone, ESVC: Erciyes Strato Volcano Complex, GYFZ: Goksu-Yazyurdu Fault Zone, IAESZ: Izmir-Ankara-Erzincan Suture Zone. Dark enclosed arrows indicating the motion mechanism of Arabian and African Plates. Large light arrow shows the escape of Anatolian Platelet (Kocyigit and Beyhan, 1998).

A geological map prepared by the same authors is given in Figure 2.2 that shows the details of the geological structures observed around the Erciyes pull-apart basin. The outline of the pull-apart basin and the active faults that cut across the basin are illustrated in this map. The relatively longer faults parallel to the long axis of the basin (NNE-SSW direction) are claimed to be left lateral whereas the shorter NE-SW faults are right-lateral strike-slip faults. Four pull-apart basins are identified in the area and named as Erciyes, Lake Tuzla, Sarıoğlan and Tomarza-Elbaş basins. Lake Tuzla and Sarıoğlan basins are located to the northeast; Tomarza-Elbaş to the east of the area. The basin in the close vicinity of Kayseri is not defined as a separate basin which corresponds to Sarımsaklı basin in this study. Therefore, this part of the basin is considered as a part of Erciyes basin according to Koçyiğit and Beyhan (1998).

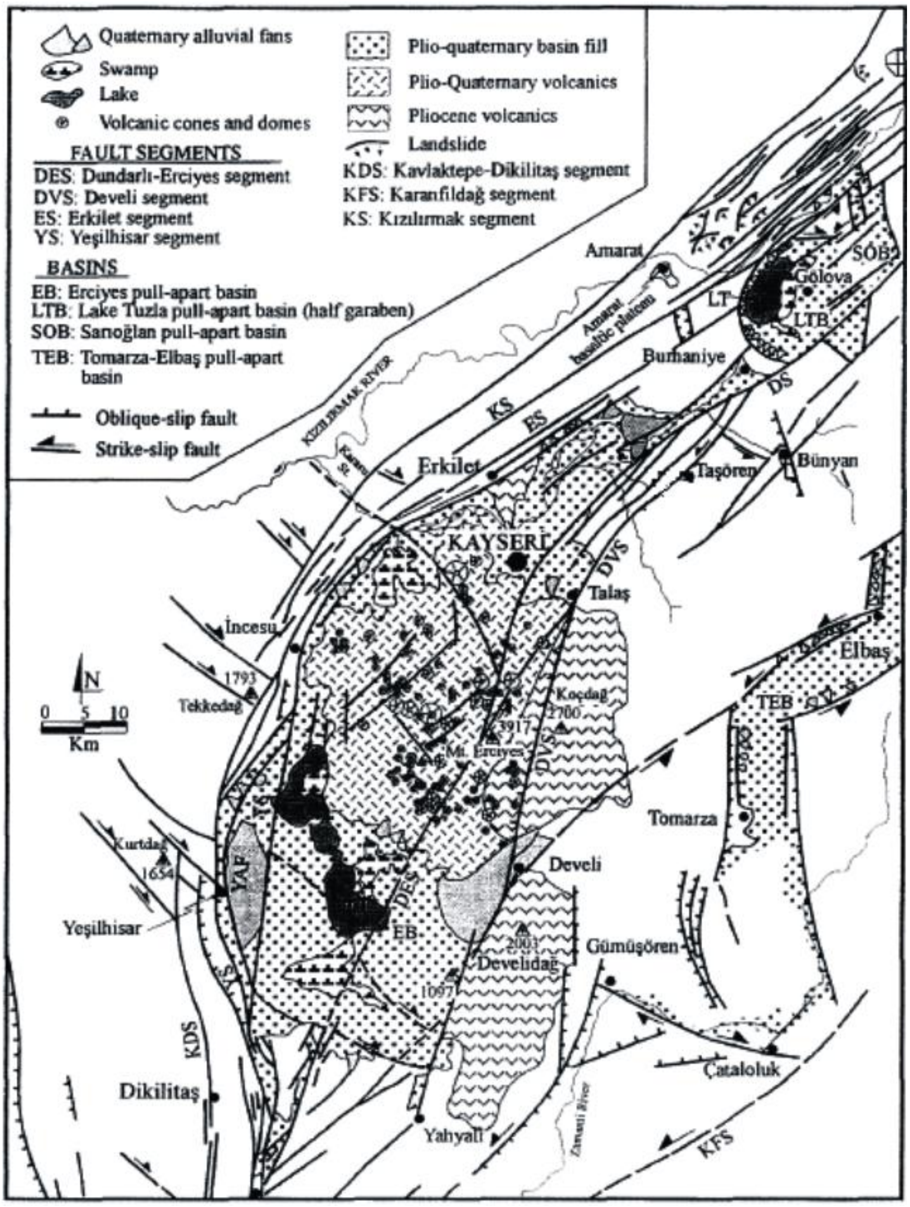


Figure 2.2. Gelogical map of Erciyes pull-apart basin and its vicinity developed within the CAFZ (Kocyigit and Beyhan, 1998).

Koçyiğit and Beyhan (1998) compiled the earthquakes occurred in the last century along the CAFZ. The earthquakes in the vicinity of area are illustrated in Figure 2.3. Accordingly four earthquakes (number 3, 28, 29 and 30 in the figure) are identified with magnitudes between 5 and 6. This is an important evidence for the active nature of the CAFZ.

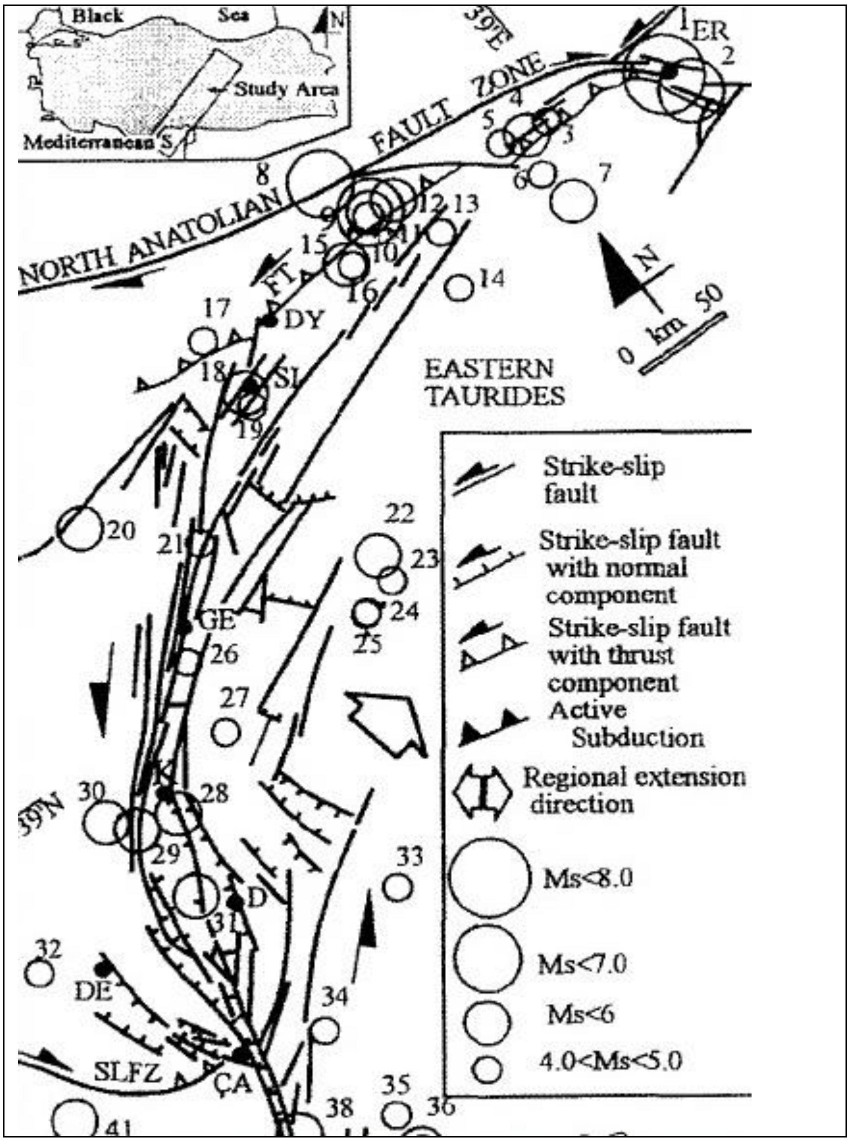


Figure 2.3. Earthquakes occurred in the vicinity of the study area. D: Develi, DE: Derinkuyu, DY: Düzyayla, ER: Erzincan, GE: Gemerek, K: Kayseri, SI:Sivas, (Koçyiğit and Beyhan,1998).

Toprak (1998) mapped the area at regional scale with an emphasis on the volcanic rocks of Cappadocian area (Figure 2.4). The depression around the Erciyes volcano named as Kayseri-Yeşilhisar basin is defined as a pull-apart basin developed over the left-lateral strike-slip Ecemiş fault zone (which is the local equivalent of CAFZ) during the period between Late Miocene to Quaternary. As the Kayseri-Yeşilhisar basin starts to develop between the two segments of the fault zone, it gradually expands in E-W direction. The Erciyes volcano is erected in the middle part of the basin dividing the basin into two parts. The northern part of the basin corresponds to Sarımsaklı basin in the middle of which Kültepe is located.

Another study related to the evolution of Sarımsaklı basin is carried out by Dirik (2001) focusing on the neotectonic development of the middle part of the Central Anatolian Fault Zone (CAFZ). Geological map of the area that he prepared is illustrated in Figure 2.5. Following observations can be made based on this geological map:

- Vicinity of Kültepe (Kayseri) is characterized by a basin filled during the Plio-Quaternary. He named this basin as "Sultansazlığı pull-apart basin". The filling material is composed of fluvial to lacustrine continental sedimentary deposits and volcanic rocks erupted from Erciyes volcanic complex.

- The faults that define the eastern and western margins of the basin are named as Gesi segment and Erkilet segment, respectively, which are fault sets within the CAFZ. Both fault sets are not continuous but rather are composed of several parallel to sub-parallel faults.

- Within the basin, the shorter faults are striking in NW-SE direction almost perpendicular to the general trend of the basin. The palaeo-high in the central part of the basin (north of Kayseri) is systematically cut by these faults.

- Based on the seismic data, he claimed that the faults that shape the basin are active.

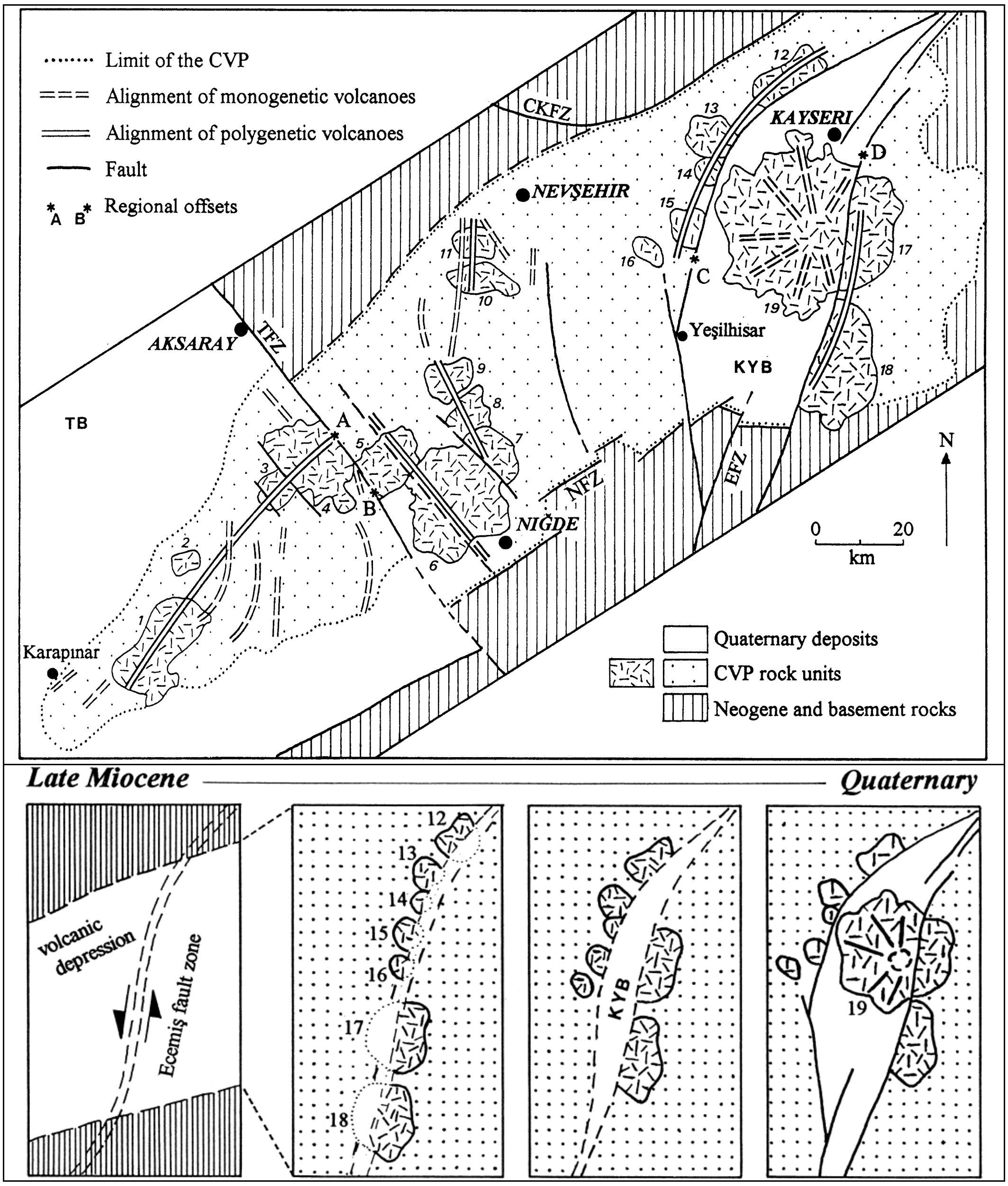


Figure 2.4. Development of Kayseri-Yeşilhisar basin (KYB) as a pull apart basin over the Ecemiş fault zone located in the eastern part of the Cappadocian volcanic province (CVP). Erciyes volcano divides the KYB into two as it is erected during Quaternary. Nos. 1 through 19 indicate the major volcanic eruption centers (Toprak, 1998).

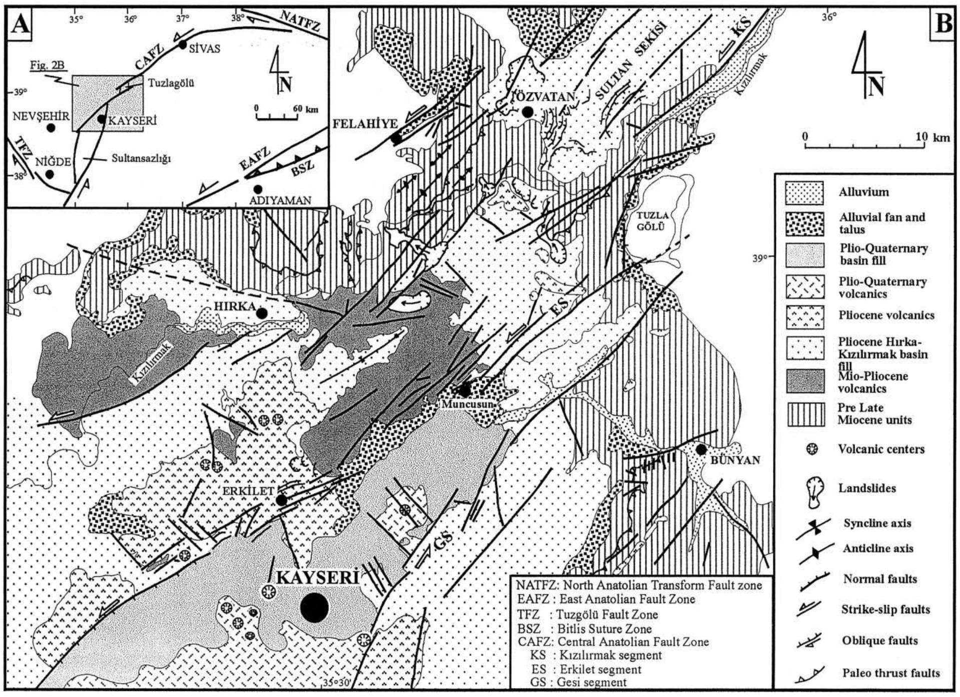


Figure 2.5. Geological map of Kayseri area and its vicinity (Dirik, 2001).

- Three lithological units exposed around the basin are Mio-Pliocene volcanics, Pliocene continental clastics (Hırka-Kızılırmak basin fill deposits), and Quaternary alluvium and alluvial fans. The volcanic rocks are sub-divided into three groups.

According to Dirik (2001) the Sultansazlığı pull-apart basin (Sarımsaklı basin) starts to develop in Late Pliocene (Figure 2.6). The age of the basin is after the eruption of Valibaba ignimbrite of 2.8 Ma implying that the basin is very young. The basin expands in E-W direction with a maximum width around future Erciyes volcano along the two segments of the CAFZ, namely, the Gesi fault in the east and the Erkilet fault in the west. In its later stages, the basin propagates in north and south direction and the Erciyes volcano is formed in the last stage of this evolution.

Based on the literature listed above about the study area following conclusions can be derived at regional scale:

- There is confusion in the name of the depression where Kültepe is located. Erciyes pull-apart basin (Koçyiğit and Beyhan, 1998), Kayseri depression (Toprak, 1998) and Sultansazlığı pull-apart basin (Dirik, 2001) are the names suggested so far. The first and the third names refer to the depression at a larger scale including the basin to the south of Erciyes volcano. Therefore these names will not be used in this study but rather the term "Sarımsaklı" will be used because the basin is mainly fed by Sarımsaklı river located to the NE of the area and because this is name used by local authorities.

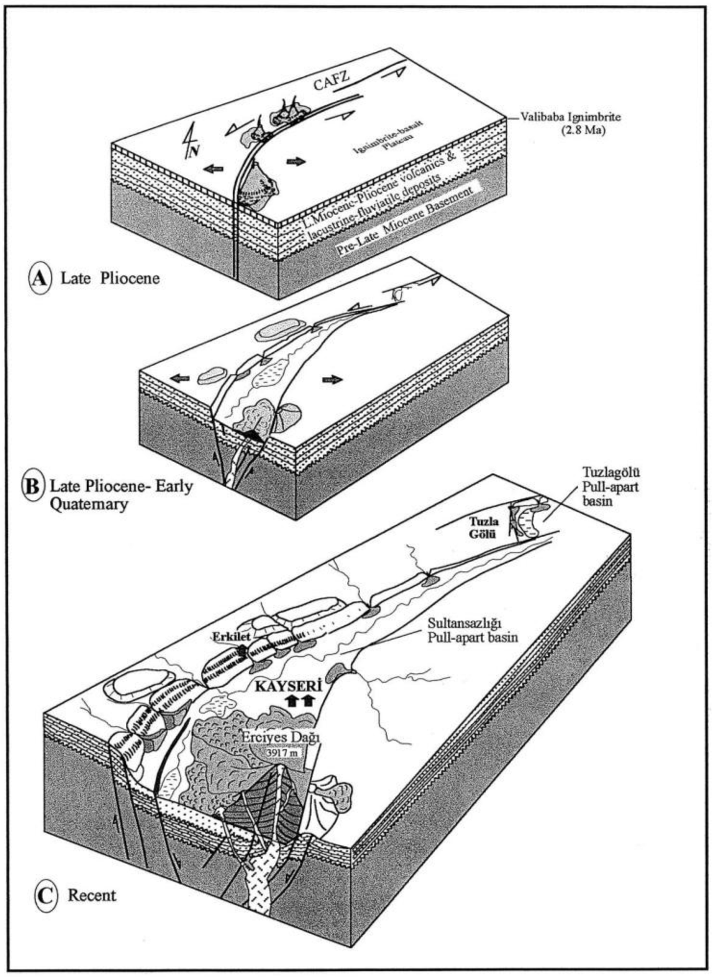


Figure 2.6. The block diagram showing the evolution of Sultansazlığı pull-apart basin (Sarimsakli basin in this study) according to Dirik (2001).

- All the literature agrees that the basin is a very young structure shaped by different segments of a major fault zone referred to as Central Anatolian Fault Zone. Two main fault sets in this zone are named as Gesi and Erkilet by Dirik (2001) defining the eastern and western margins of the basin. These faults are still active as indicated by the field and seismic data.

- The area between two segments of CAFZ subsided forming a depression filled with volcanic rocks of Erciyes volcanic complex and sedimentary rocks which are mostly transported to Sarımsaklı basin. The site of interest, the Kültepe archaeological site, is located in the middle of this basin.

2.2. Stratigraphy of the Area

Kültepe is located in the middle of a basin filled with sedimentary rocks of the Plio-Quaternary age as mentioned in previous section. Therefore, there is not any rock older than this exposed in the close vicinity of the site. However, towards the margins of the depression, older rock units are exposed in the high regions of the area elevated by active faults.

In this section a review of the stratigraphy of the area will be made and the rocks units exposed around the site will be introduced based on the literature data. This introduction will be made on a generalized columnar section of the region that covers geological maps of K34 and K35 sheets provided by MTA (Dalkılıç, 2009; Dönmez et al., 2005). Geological map of the area will be introduced later.

Generalized columnar section of the region (Figure 2.7) is reorganized and redrawn for this study. Considering the purpose of the study the rock units are oversimplified and categorized into four groups. These are from bottom to top; pre-Miocene basement, Mio-Pliocene Ürgüp formation, Plio-Quaternary Erciyes volcanics and Quaternary basin fill deposits.

Basement rocks: All rock types older than Miocene age are considered as basement rocks which include different lithologies of different age ranging from Paleozoic to Eocene-Oligocene. The oldest rocks belong to Kırşehir metamorhics represented by marbles, gneiss and calcschist overlain by the Jurassic Tavsancidagtepe Formation and Cretacaeous Karabogurtlen Formation with an angular unconformity (Dalkılıç, 2009; Dönmez et al., 2005). These sequences are unconformably overlain by Burunguz formation of Paleocene-Eocene. Eocene-Oligocene Baraklı and Incik formations unconformably overlie the older units (Dalkılıç, 2009; Dönmez et al., 2005). These rocks are usually located at a distance to Kültepe and will not be dealt in detail.

Ürgüp formation: This formation is one of the main rock sequences that will be investigated in detail in this study. The name is first introduced by Pasquare (1968) in Ürgüp (Nevşehir) area. The formation is composed of intercalations of continental sedimentary rocks and the volcanic rocks mainly of ignimbrites. Two points should be emphasized about this formation: 1) The names adopted here belong to the nomenclature used by MTA which may not be consistent with the names used by somebody else. There has been a confusion in naming both the ignimbrites and sedimentary intercalations in published literature (Pasquare, 1968; Innocenti et al., 1975; Dhont et al., 1998; Temel et al., 1998; Froger et al., 1998). The units listed here under Ürgüp formation may not be consistent with the type section defined for this formation. This is mostly because of the lateral variation of the units commonly observed in the area. This formation is deposited in a continental environment which is defined as Hırka-Kızılırmak basin by Dirik (2001) mentioned in the previous section. Among the rock units shown in the columnar section; Kışladağ limestone which is at the top of the sequence (Late Pliocene) and several ignimbrites are the main focus of this study.

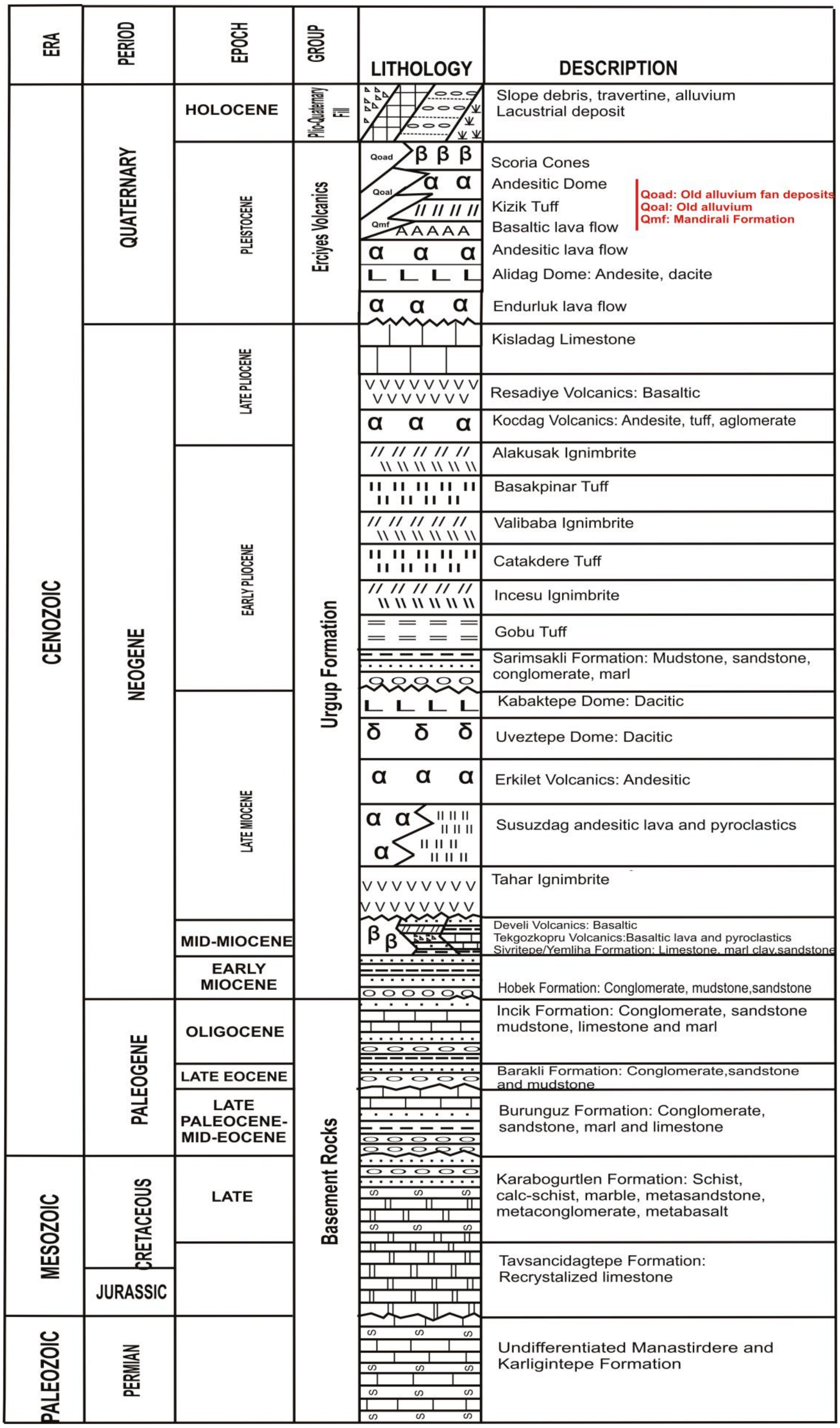


Figure 2.7. Columnar section of regional study area (compiled from Dalkılıç, 2009; Dönmez et al., 2005).

Erciyes volcanics: Erciyes volcanics are composed of various volcanic products associated with the Erciyes volcano which is one of the main eruption centers of the volcanic area. Andesitic lava flows, basaltic lava flows, andesitic domes, scoria cones are common rock types (Dalkılıç, 2009; Dönmez et al., 2005). The age of the main eruption phase is Quaternary although it might be dated back to Late Pliocene (Kuzucuoğlu et al., 1998; Kürkçüoğlu et al., 1998; Kürkçüoğlu et al., 2001). The latest products of this eruption phase are interfingering the sedimentary rocks deposited in Sarımsaklı basin. These rocks are mostly located to the south of the area and will not be dealt in detail.

Quaternary fill deposits: These deposits are the recent sedimentary rocks accumulated in Sarımsaklı basin. Kültepe is located over this sequence. In most of the studies this unit is referred to as either Plio-Quaternary or Quaternary deposits without any detail about its nature. The problems associated with this unit can be listed as follows:

- The exact age of the unit is not clear. The unit is accumulated in a pull-apart basin as mentioned in the previous section; therefore its age should be contemporaneous with the age of this basin. Since the basin is developed as suggested by Dirik (2001) after the eruption of Vaibaba ignimbrite of 2.8 Ma, the age of the basin can go back to Late Pliocene.

- Total thickness of the basin is not known. There is not a concrete evidence on the thickness and the variation of thickness throughout the area.

- Lateral variation of the lithologies within the sequence is not known.

The answers to these questions are closely related with the scope of this study. For this reason the borehole data are used in this study to extract possible information about these fill deposits.

CHAPTER 3

DATA AND METHODOLOGY

3.1. Data Used in the Study

The data used in this study consist of five layers. These are digital elevation model (DEM), geological map, borehole data, seismic data and the field data. This section explains the source and basic characteristics of these layers.

3.1.1. DEM

The term DEM (Digital Elevation Model) refers to data containing elevation values of a specified terrain at fixed grid interval over the surface of the earth.

The DEM in this study is retrieved from the topographic contours of 1/25000 scaled topographic maps provided from General Command of Mapping of Turkey (Harita Genel Komutanlığı). First the contours are digitized manually and converted to a vector file. Then a point data in the raster format is produced with a grid size of 25X25 m. As a last step, a DEM is generated from this point data as illustrated in Figure 3.1.

The vertical accuracy of the DEM is not assessed in this study. However, it is generally known that the error is not more than 2 m. The final map has a coordinate system of UTM ED 50 and is included in Zone 36.

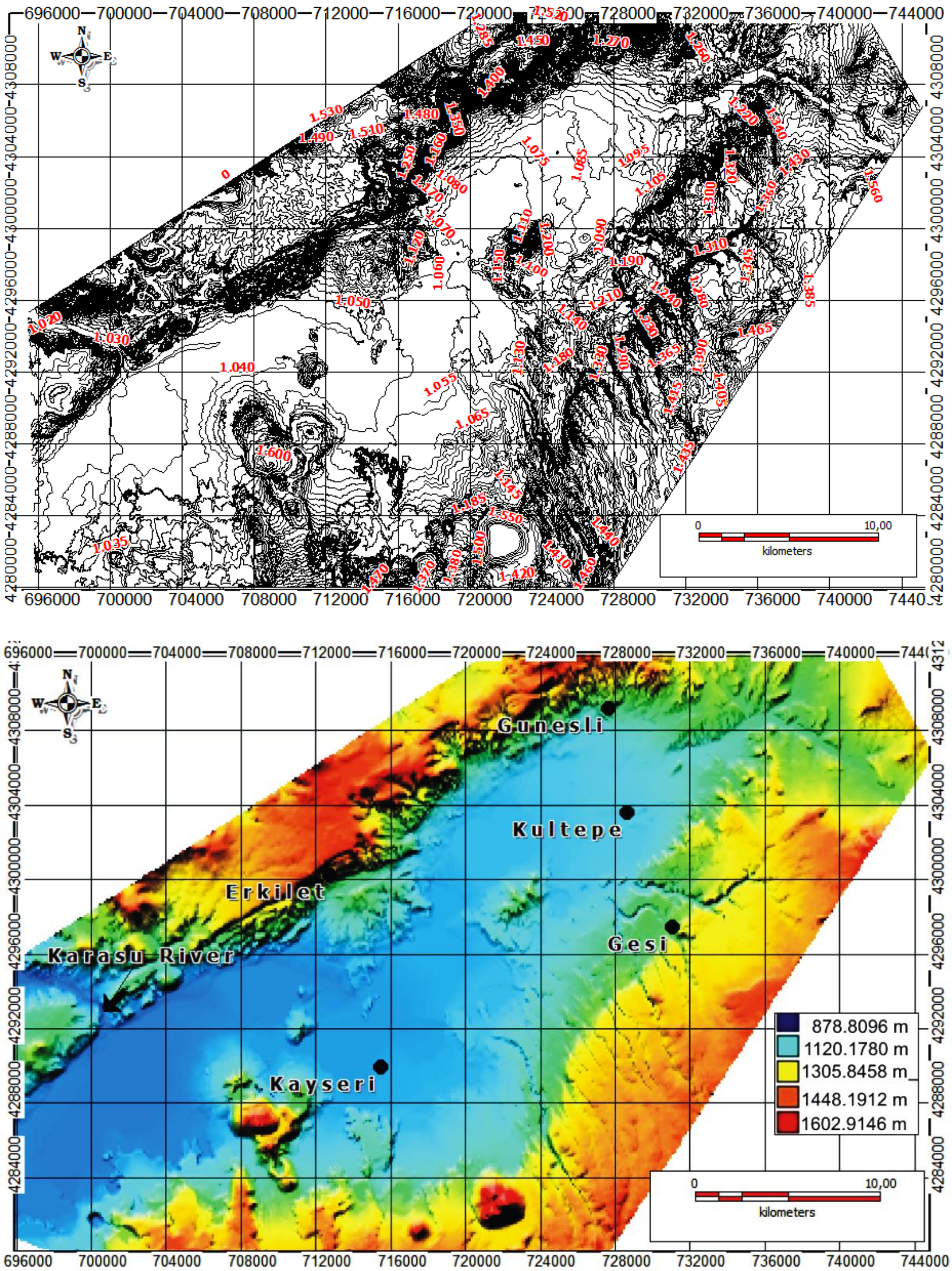


Figure 3.1. Contour map digitized from 1/25.000 scale topographic map with 10 m contour interval (above), and digital elevation map generated from contours (below) for the area investigated.

3.1.2. Geological Map

Geological maps of the study area are provided from General Directorate of Mineral Research and Exploration of Turkey (MTA). The maps are in digital format and belong the two sheets, namely, K34 and K35. The first step is to merge these already files into a single file using UTM ED 50 projection system (Zone 36).

The polygons in the map correspond to lithologic units provided by an attribute table that lists the properties of these units. Using the attribute tables, all the units are assigned a name and colored accordingly. Certain problems occurred due to inconsistent boundaries at the intersection of two sheets are solved by interpolating the boundaries.

The resultant map is illustrated in Figure 3.2 that consists of 41 rock units. This map will be simplified later by re-classifying the rocks units.

3.1.3. Borehole Data

The borehole data is acquired from DSI (State Hydraulic Works) Kayseri district in 2009. All available borehole data that belong to Sarımsaklı basin is provided. The data obtained is in PDF format which is scanned from the original logs. The whole data contains 506 files some of which belong to the areas beyond the limits of Sarımsaklı basin. The distribution of the boreholes is shown in Figure 3.3.

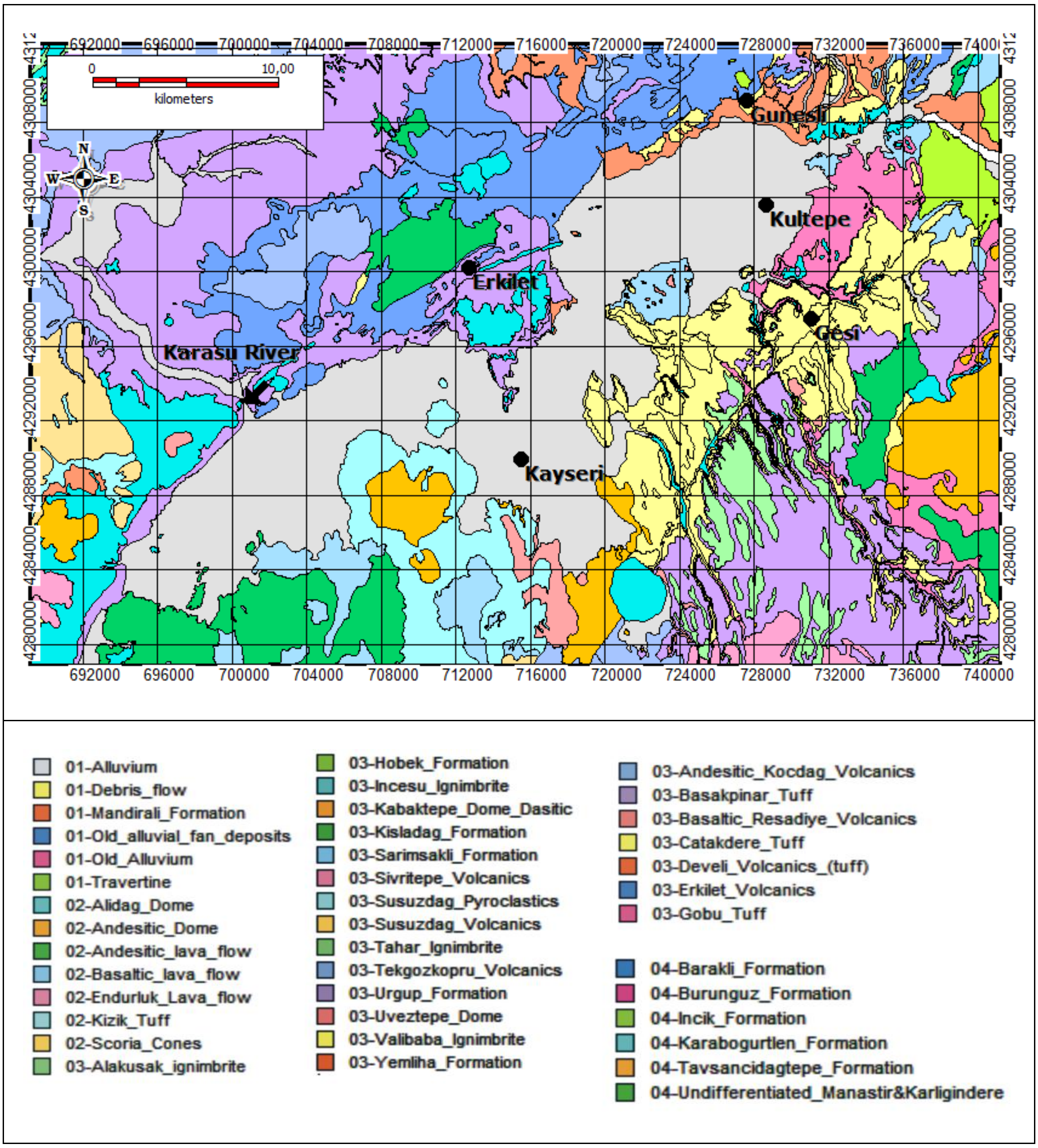


Figure 3.2. Geologic map of the study area provided from MTA (Dalkılıç, 2009; Dönmez et al., 2005).

3.1.4. Seismic Data

The seismic data is obtained for the last century that belongs to the earthquakes occurred in the vicinity of study area. The main reason using this data is to assess the presence of active faults that exist in the region.

The data is acquired from Kandilli Observatory and Research Institute and contain the information on the location, time and magnitude of the earthquake. The location is given in Latitude and Longitude which is converted to UTM to be consistent with other data used in the study.

The data contain the records of 338 earthquakes which will be used to assess the fault in Chapter 5.

3.1.5. Field Data

In the scope of the research, the field study was performed to identify the faults through the slip-plane data. This data has been collected from eight sites by measuring the strike, dip and rake values. The data is given in Appendix A in the Table A-1. The data will be processed in Chapter 5.

3.2 Methodology

The methodology of this study is composed of three steps (Figure 3.4). The first step is the preparation the data sets to be used in this study. For each data set necessary pre-processing such registration, tabulation (converting into a GIS file) is performed.

In the second step, certain analyses are carried out using different data layers. Generally each data layer is mentioned in a separate chapter. In the last step the results are integrated and the major outcomes of the study are discussed.

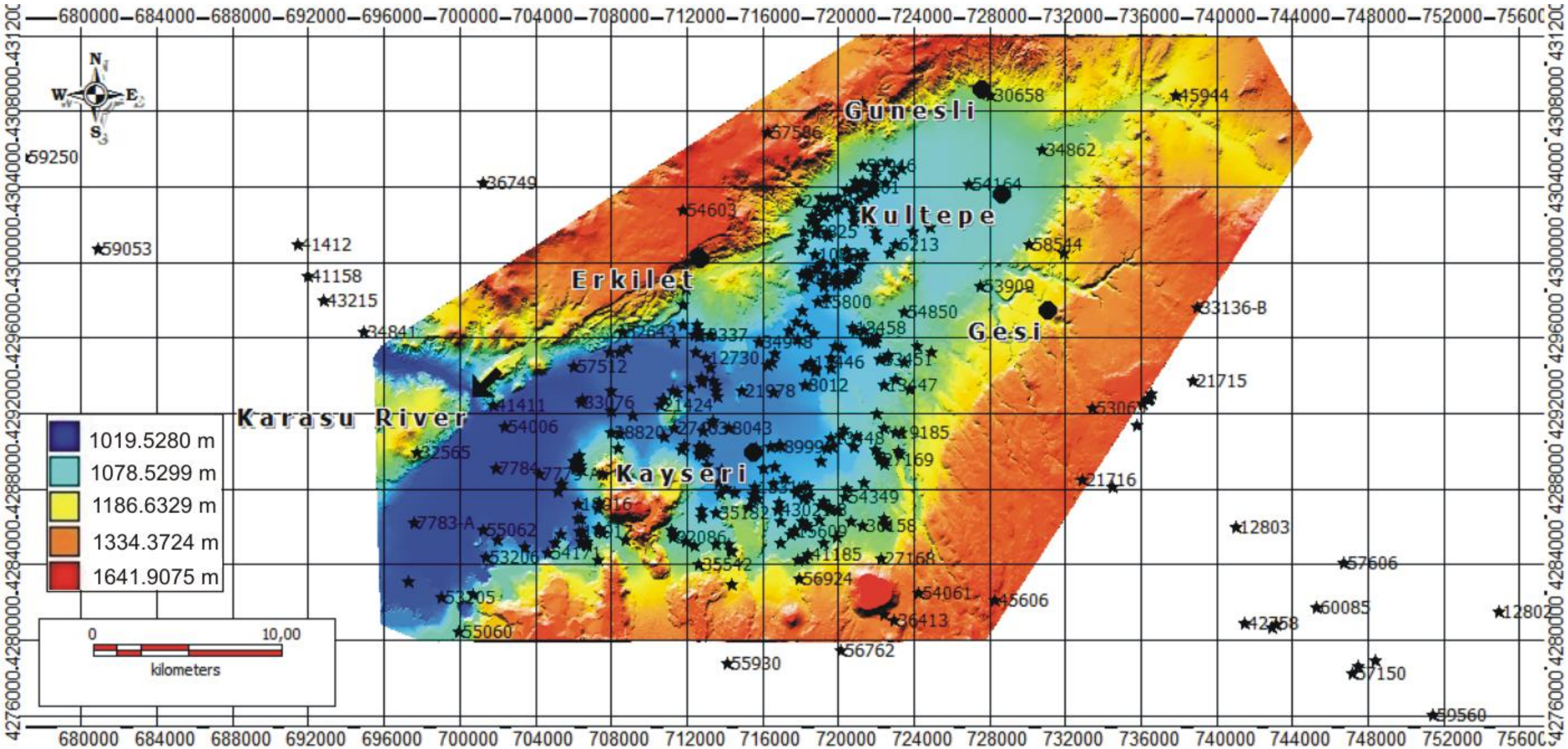


Figure 3.3. The map showing the borehole distribution used in this study.

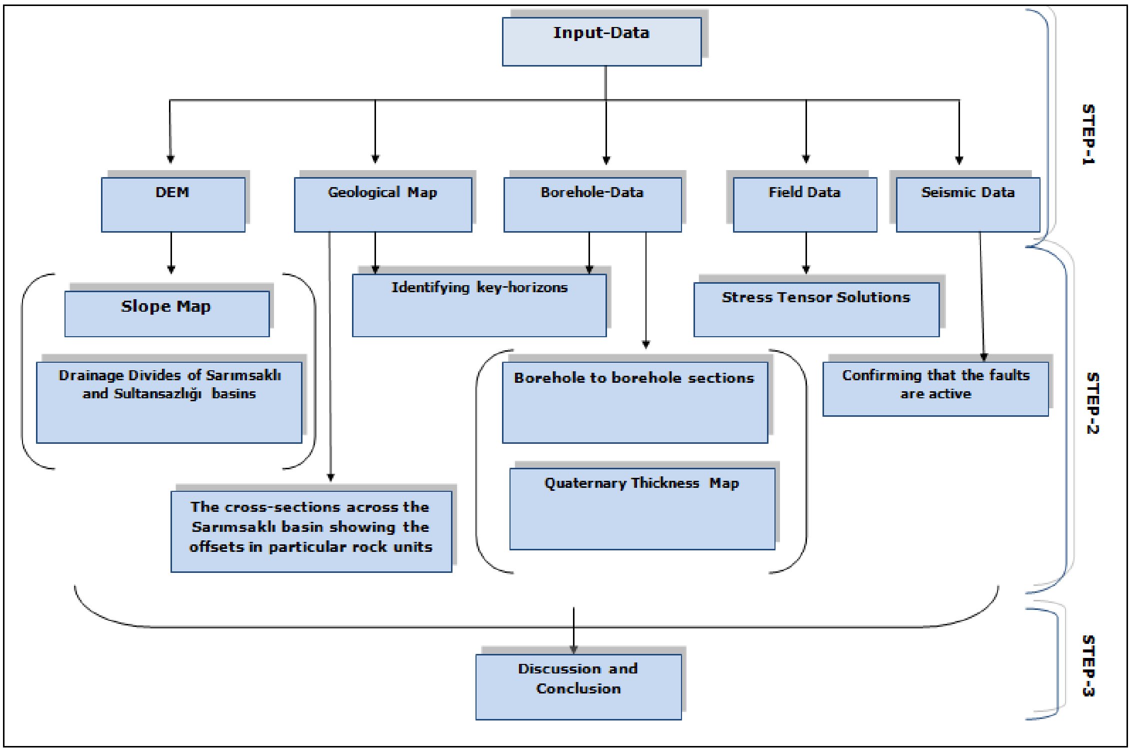


Figure 3.4. Flowchart showing the major steps performed in this study.

CHAPTER 4

MORPHOLOGICAL ANALYSIS

In this chapter, the geomorphologic features of the basin will be introduced to extract possible information on the geological structures of the study area. Figure 4.1 shows the topographic contours over the DEM of the area. The elevation shown in the western part (1028 m) is the lowest point of the Sarımsaklı basin. This is also the point where the basin starts to be drained by the Karasu river. After this point the basin is converted to a "fluvial valley".

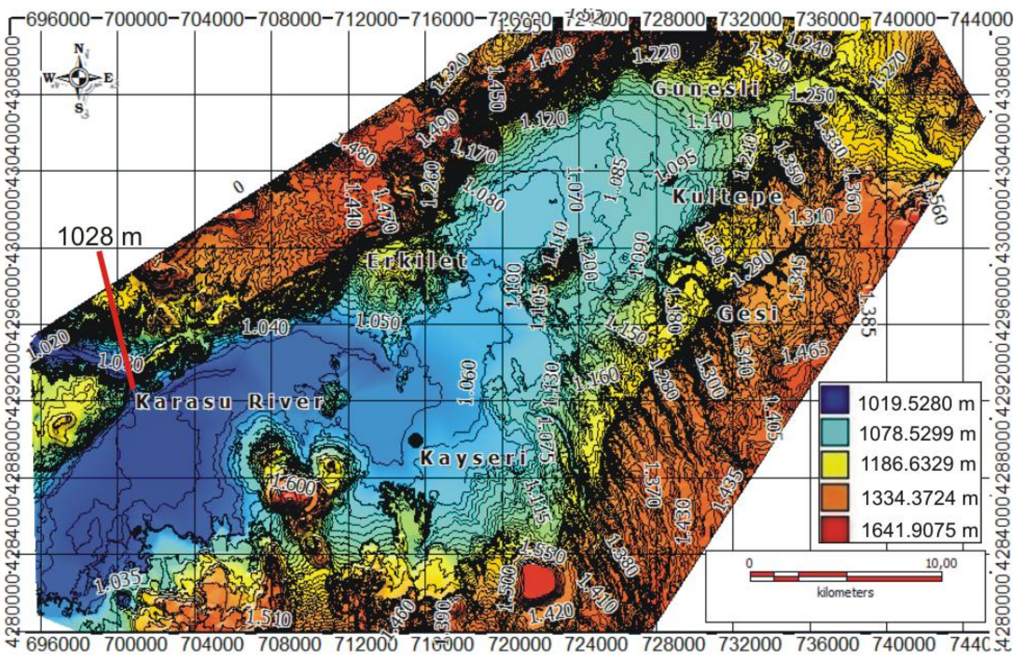


Figure 4.1. The DEM of the study area with the topographic contours at 10 m interval. The point with 1028 m elevation is the lowest elevation of Sarımsaklı basin where the Karasu river starts to drain the basin.

4.1. Geomorphology of the Area

Morphology of an area, in general, is the result of the geology of the area. The landform produced in an area may imply the geological structures existing in the area. For this purpose the DEM of the area is used to see possible geological elements. A slope map is added to the DEM because a sudden change in the slope supports the observation made in the DEM (Figure 4.2).

In the slope map the red color areas which represent the steep slopes make some well-defined patterns that imply the trends of the faults in the area. This is best illustrated by a linear concentration of red areas in certain directions both in the eastern and the western parts of the area. Around Gesi, for example, two such linear traces in NE-SW direction with red color are observed. Additionally, the small rivers flowing across these lines show a sudden change in the color as they reach these trends. Based on this, two faults are drawn which are almost parallel to each other. Both faults extend further south across the Erciyes volcanics.

A similar observation is made in the western part of the area and a fault is drawn based on the steepness of the topography. This fault passes through Erkilet and extends beyond the limit of the area in both directions. There might be several small faults parallel to each other in the western part, however a single major fault is drawn considering the purpose of this study.

The faults drawn on both sides define the margins of the Sarımsaklı basin. These faults correspond to two segments defined by Dirik (2001) as Gesi and Erkilet fault segments (Figure 4.2). The area between these two faults is characterized by blue color in the DEM that indicate lowered or subsided areas, whereas the shoulders by red color indicating elevated or uplifted regions.

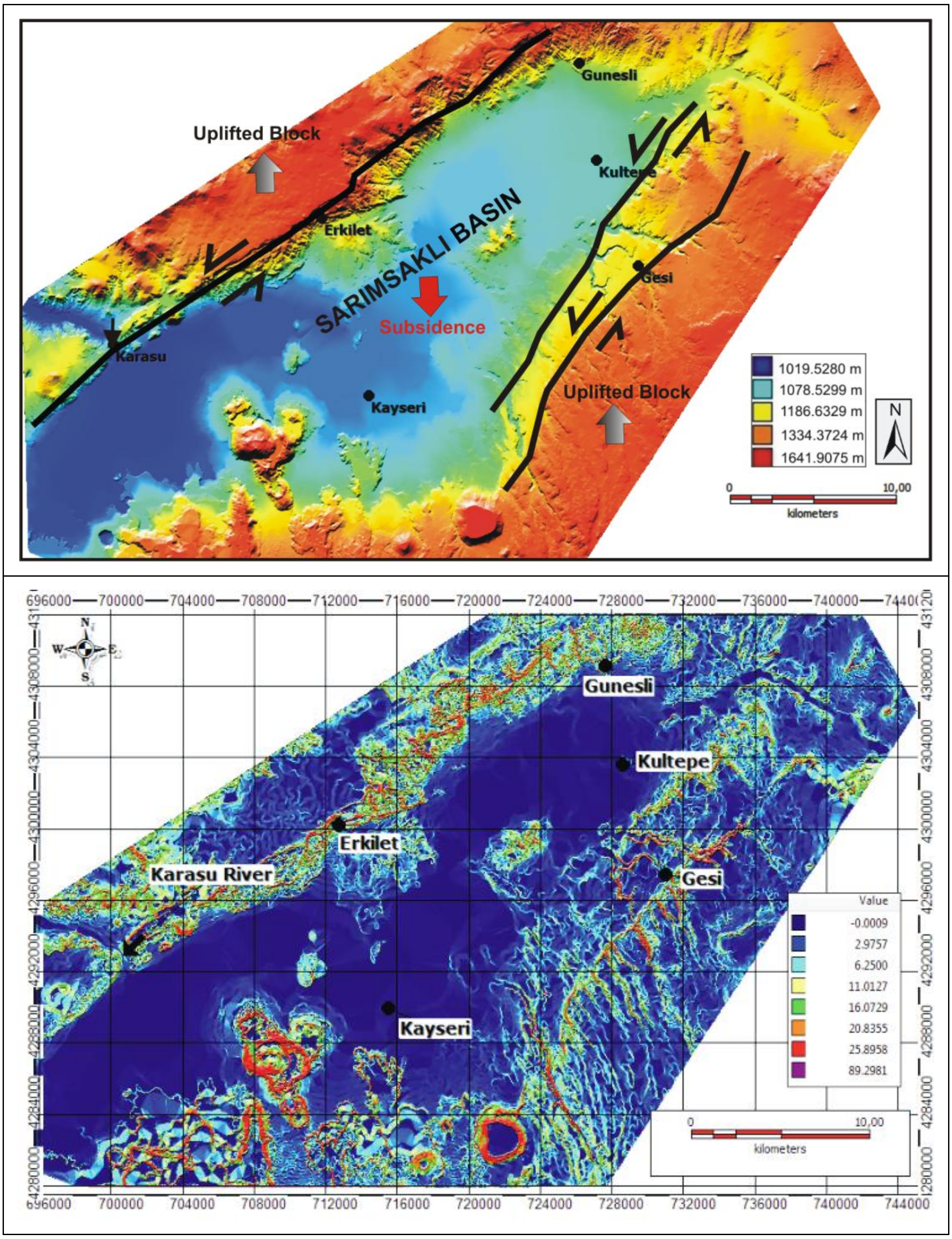


Figure 4.2. The DEM (above) and the slope map (below) of the Sarımsaklı basin. Blue color in the DEM indicates lower elevations while red color indicates higher elevations. The faults on the DEM are drawn using sudden changes in elevation marked by change in the color. Blue color in the slope map indicates gentle slopes and the red indicates the steep slopes.

4.2. Effect of Possible Flooding

Considering the facts that 1) the Sarımsaklı basin is bounded by active faults, 2) the basin is drained only by one channel at where Karasu river starts to develop, and 3) a fault is passing at this point, it can be easily claimed that the area can be flooded if there is a sudden movement along the western margin of the fault. In this section this possibility will be tested using the DEM of the area.

The drainage basin of the Sarımsaklı basin extracted from the DEM is illustrated in Figure 4.3. The red line in the figure shows the borders of region for the source of water and sediment that moves through the Sarımsaklı river and its tributaries. The area of the Sarımsaklı basin is 351 km^2 whereas the area of its drainage basin is 2246 km^2. Therefore the Sarımsaklı basin receives both water and sediment from an area of about 6 times greater than its size. Accordingly, it can be claimed that 1) the Sarımsaklı basin is not just fed by precipitation over its area; 2) the sediments accumulated today at the basin floor are not just derived from surrounding slopes but could be transported from long distances.

The drainage basin of the Sarımsaklı basin extends mostly towards east. This basin is bounded by Erciyes topographic high in the south and is separated from another basin at the south (Sultansazlığı basin) by a low barrier. It is connected to Kızılırmak river through Karasu river, therefore is a sub-basin of Kızılırmak river system.

To see the effect of flooding caused from the uplifting of the area due to faulting, the surface of hypothetical water body is elevated for three scenarios as illustrated in Figure 4.4. The fault that may be responsible for the flooding is shown in thick line in the figures in the western part of the area passing across the beginning of Karasu river. The flooded areas are indicated by dark blue color in the figures. The lowest elevation of the basin is 1028 m, therefore the elevations of three scenarios are 1038, 1058 and 1098, respectively.

The level is first elevated for 10 m above the basin floor. The area flooded at this elevation is confined to the close vicinity of Karasu valley and mostly extends to the south of the area (Figure 4.4-A).

In the second case the level is increased by 30 m which results in a flooding that covers a larger area by extending further south and northeast. Kayseri city is almost buried by this flood. There are small islands within the area particularly around Kayseri (Figure 4.4-B).

In the last scenario, the level is elevated for 70 m which produces an area including Kültepe (Figure 4.4-C). The boundary of this scenario defines almost the actual boundary of the Sarımsaklı basin. A big island is developed between Kayseri and Kültepe that might be a paleohigh in the middle of the basin.

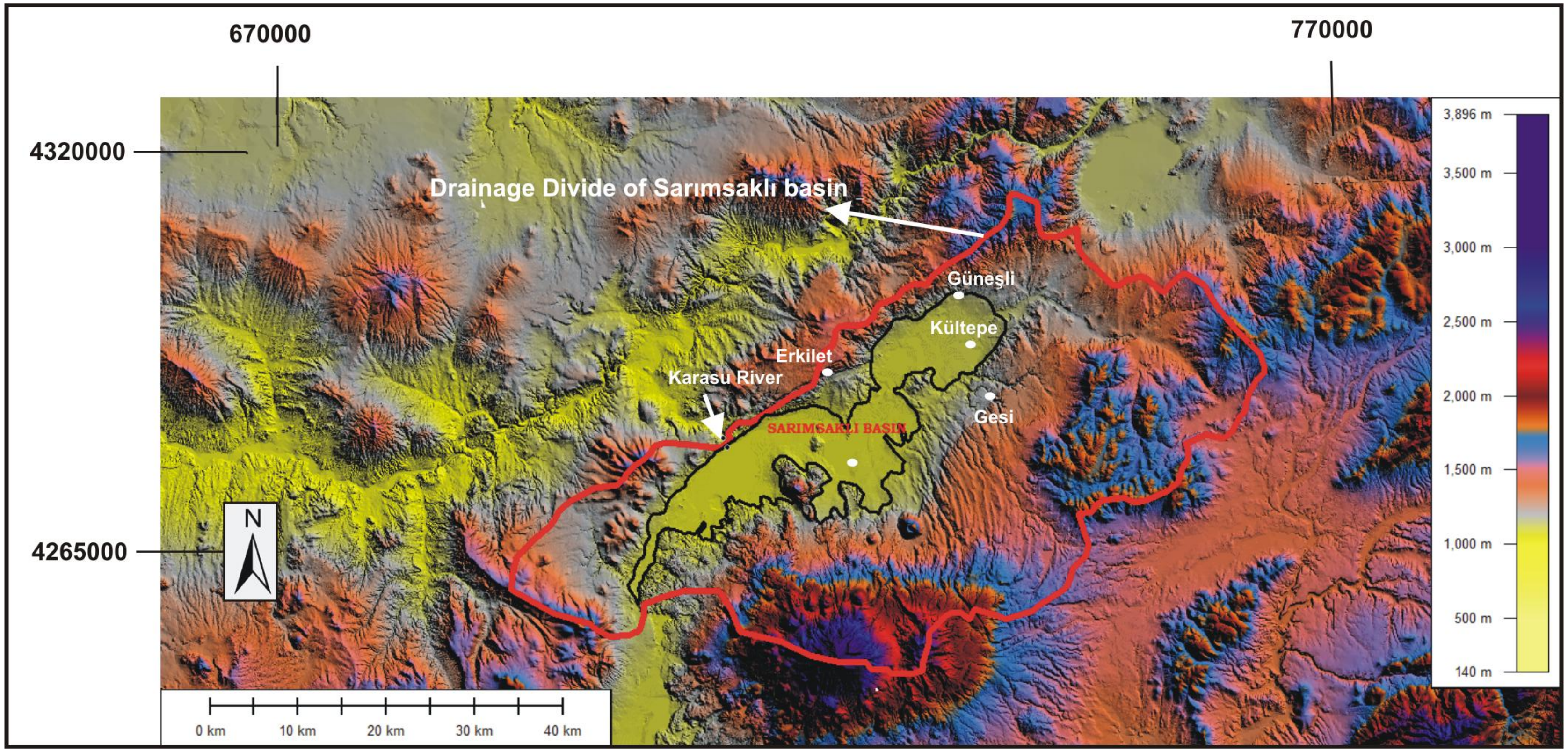


Figure 4.3. Drainage basin of the Sarimsakli basin

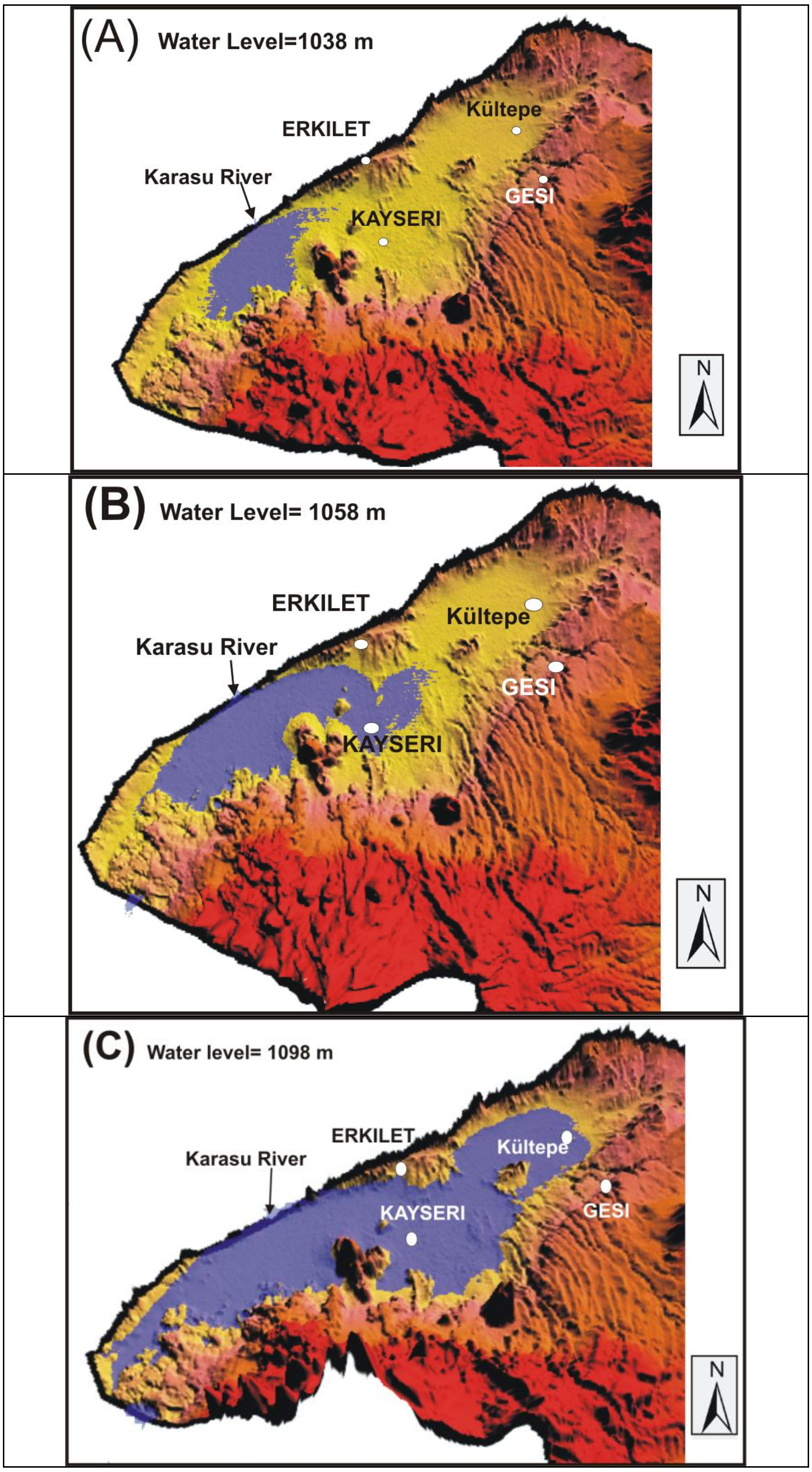


Figure 4.4. 3-D models generated to see the effect of flooding at different elevation. Dark blue areas show the area flooded if the level is raised for 10 m (upper), for 30 m (middle) and for 70 m (lower) above the present level.

4.3. Comparison with Sultansazlığı Basin

Sultansazlığı basin is another depression located to the south of Sarımsaklı basin. As explained in regional geology section these two basins together form a large pull-apart basin along the Central Anatolian Fault Zone. This basin is divided into two sub-basins (Sarımsaklı to the north and Sultansazlığı to the south) by the lava flows of Erciyes volcano. Contrary to the Sarımsaklı basin, the Sultansazlığı basin is a totally closed basin with an active lake almost in the central part.

To investigate the effect of flooding in the Sarımsaklı basin, the behavior of the Sultansazlığı basin should be considered in terms of excess water input. To understand this behavior, the drainage basins of both Sultansazlığı and Sarımsaklı basins are investigated and their elevations are compared. Drainage divides of both basins is illustrated in Figure 4.5. Table 4.1 displays the summary information about these two basins.

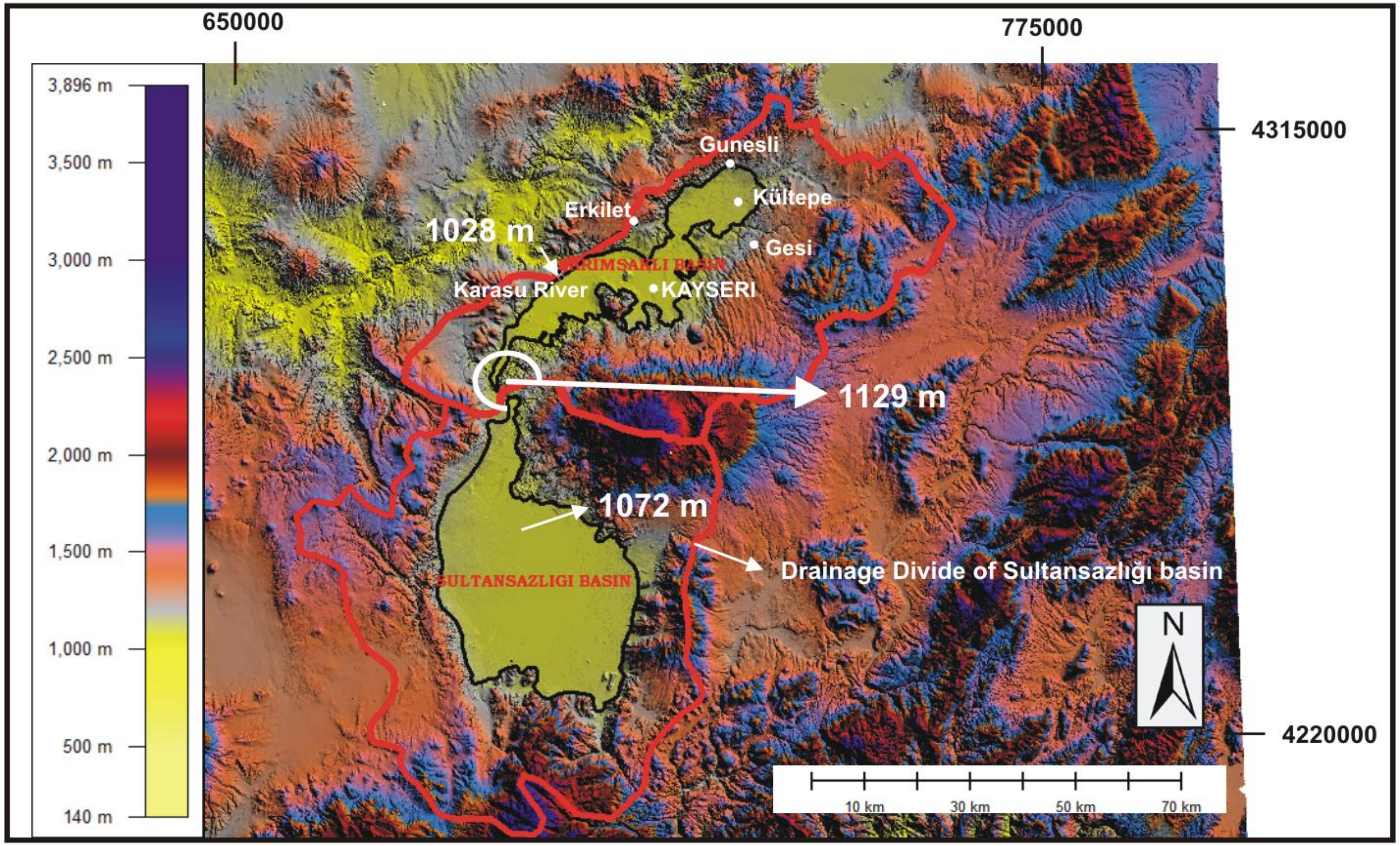


Figure 4.5. Drainage divides of Sultansazlığı and Sarımsaklı basins.

Table 4.1. Comparison of Sarımsaklı and Sultansazlığı basins

Basin	Area of basin (km^2)	Area of drainage basin (km^2)	Ratio (basin/drainage basin)
Sarımsaklı	351	2246	0.156
Sultansazlığı	860	3036	0.283

Although the area of Sultansazlığı basin is greater than the area of Sarımsaklı basin (Table 4.1), the ratio of basin area to its drainage basin area is larger indicating that the Sarımsaklı basin receives relatively a greater amount of water. Therefore it can be claimed that first the Sarımsaklı basin will be filled and water will be transported from Sarımsaklı to Sultansazlığı basin. However, since the Karasu river is the only channel to drain both basins, the order of the filling may not play an important role for the water transfer between two basins.

The lowest altitude of Sultansazlığı basin is 1072 meter whereas it is determined as 1028 meter for Sarımsaklı basin (Figure 4.6). The altitude of barrier between two basins is measured as 1129 meter. Therefore, if Sultansazlığı basin is first filled, 101 meter rise in water level is required to exceed over the barrier between the two basins. On the other hand, if first Sarımsaklı basin is filled only 70 m rise will be enough to make a connection with the Sultansazlığı basin (Figure 4.7). In both cases the water level is high enough to bury Kültepe. This is illustrated in Figure 4.7. If the level of the water is elevated to 1098 m in Sarımsaklı basin then Kültepe will be covered by water (Figure 4.7-A). The connection between two basins, on the other hand, is 31 m higher (1129 m) than this elevation.

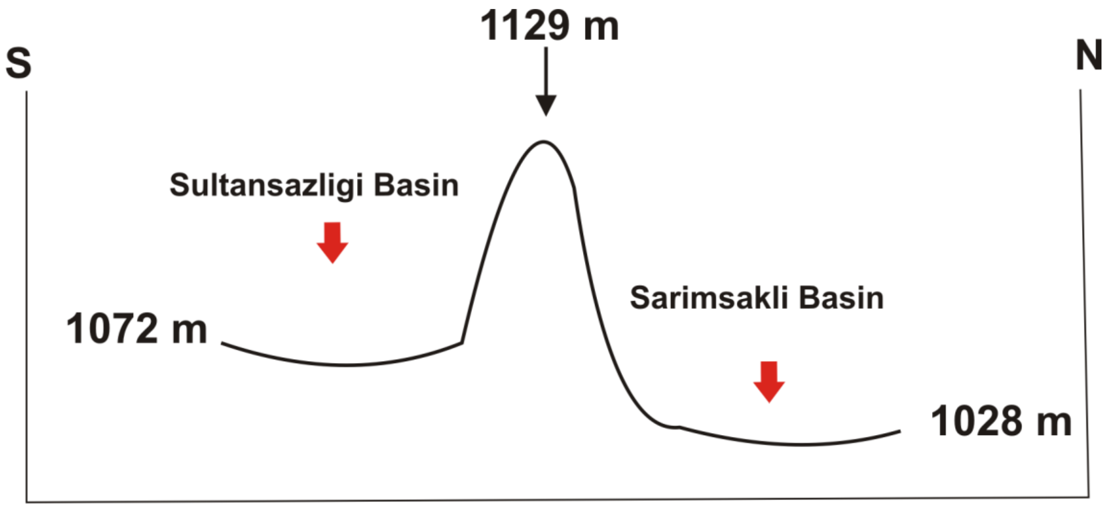


Figure 4.6. Profile illustrating basal elevations of Sarımsaklı, Sultansazlığı basins and the elevation of the barrier between two basins.

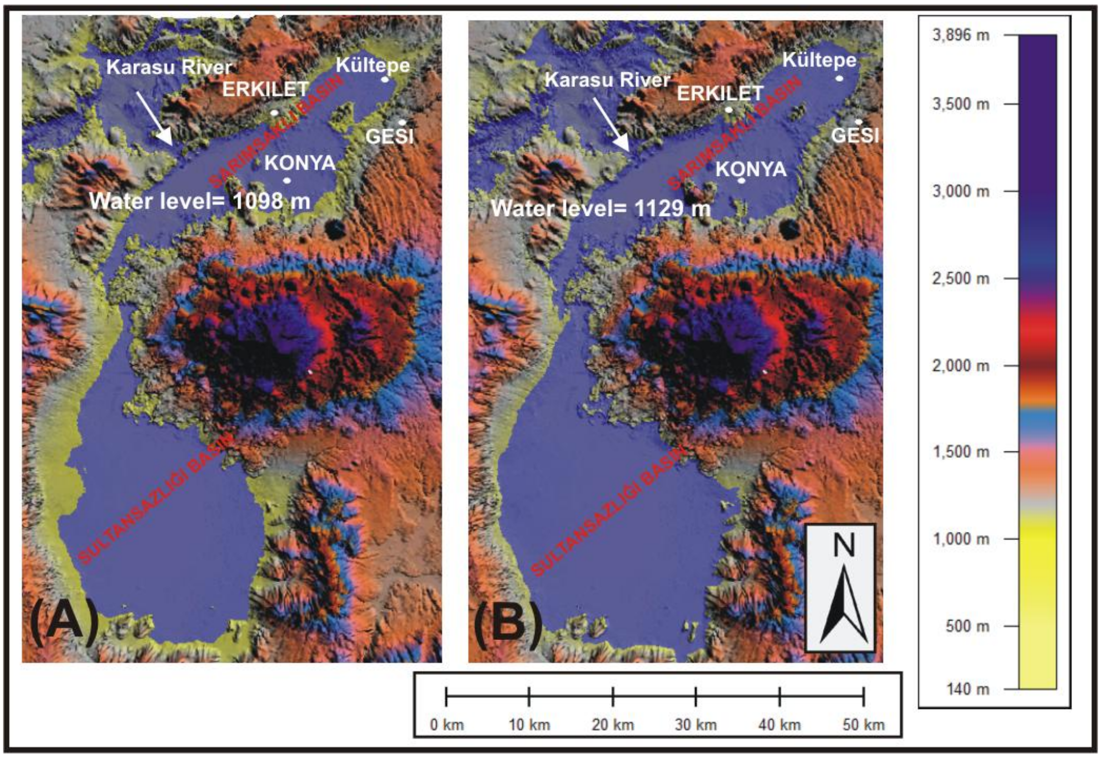


Figure 4.7. Two water levels showing probable effect of flooding in Sarımsaklı and Sultansazlığı basins. A) Water level is 1098 m that will bury Kültepe, B) Water level is 1129 m that will provide a connection between two basins.

CHAPTER 5

GEOLOGICAL INVESTIGATIONS

This chapter is divided in to two sections. In the first section the distribution of the rock units will be evaluated basing on the geological map of the area; in the second section the fault data collected in the field around the Sarımsaklı basin will be processed and evaluated.

5.1. Distribution of Rock Units

The main reason of the reevaluation of geologic map, particularly the distribution of the rocks in the area is to look for possible key-units in the area. This will contribute to the studies in two ways: 1) Elevation of these units on different parts of the area can be used to understand the vertical movements occurred due to the faults, and 2) These units can be used to correlate the borehole data that will be discussed in the next chapter.

The first step is to simplify the geology of the area in order to determine the target units. Original geology map provided from MTA (Dalkılıç, 2009; Dönmez et al., 2005) consists of 41 rock units which is a large number to handle for determination of key units. The classification mentioned in regional geology chapter is adopted and the rock units are reorganized into four meaningful groups which area from bottom to top:

1. Pre-Miocene Basement Rocks
2. Mio-Pliocene Ürgüp Formation
3. Plio-Quaternary Erciyes volcanics
4. Plio-Quaternary Sarımsaklı Fill Deposits

The main fact used in this classification is the genetic relations of the rock units. The Ürgüp formation consists of different units deposited or erupted into the same basin, Sarımsaklı basin-fill deposits are accumulated in the same environment and the Erciyes volcanics are erupted, more or less, from the same source.

Geological map prepared according to this classification is given in Figure 5.1. Following observations can be made based on the distribution of the rock associations in this map:

- Distribution of the Plio-Quaternary Units (Sarımsaklı basin deposits) defines the boundary of the basin. The basin with an irregular boundary north of Kayseri is consistent with the boundary of the pull-apart basin suggested in literature (Koçyiğit and Beyhan, 1998; Toprak, 1998; Dirik, 2001). This boundary suggests an almost totally closed basin with a narrow connection through the Karasu river which is today draining the basin.

- The most common rock group surrounding the Sarımsaklı basin is Ürgüp formation. These units are exposed over the shoulders on the eastern and western parts of the area. Therefore the immediate rock units in the boreholes after the Sarımsaklı deposits should be expected to be Ürgüp formation.

- Erciyes volcanics are confined to the southern part of the area. They form a barrier that separates the Sarımsaklı basin from the southern Sultansazlığı depression. The age of these volcanics is contemporaneous with the Sarımsaklı basin deposits. This is best illustrated by the intercalations of volcanic and sedimentary rocks around Kayseri. However, considering the location of the eruption centers and the distance to Kültepe, the presence of these volcanics is not expected in the boreholes except for the ones between Kayseri and Karasu.

- Basement rocks are confined to the eastern part of the area. They are observed at high elevations due to the uplifting by the faults.

Based on these observations it can be concluded that the main lithology expected in the boreholes should belong to the Sarımsaklı basin deposits. Depending on the thickness of the basin fill deposits and the depth of the borehole the next candidate lithology should be Ürgüp formation. For the key horizons exposed at the surface the most suitable lithology is the ignimbrite. There are several ignimbrites in the area located at different positions in the Ürgüp formation.

Three distinguishing features of the ignimbrites that can be considered as an advantage of these units for correlation purposes are: 1) the ignimbrites extend for long distances, 2) They are emplaced mostly in a regular sequence as flat layer therefore should indicate the same depositional elevation, 3) They are mostly horizontal over the whole area and are only locally disturbed in the close vicinity of the faults.

There is a main problem, however, associated with the nomenclature of these ignimbrites. The original geological data belong to two separate sheets which may not be consistent in the nomenclature as well as the boundaries. The problem related to the boundary can be solved easily. However, a different name in different sheets is still a problem and might create confusion. For example, there is a possibility of mis-use of the one of the ignimbrites exposed in the eastern part of the area with another ignimbrite in the western part.

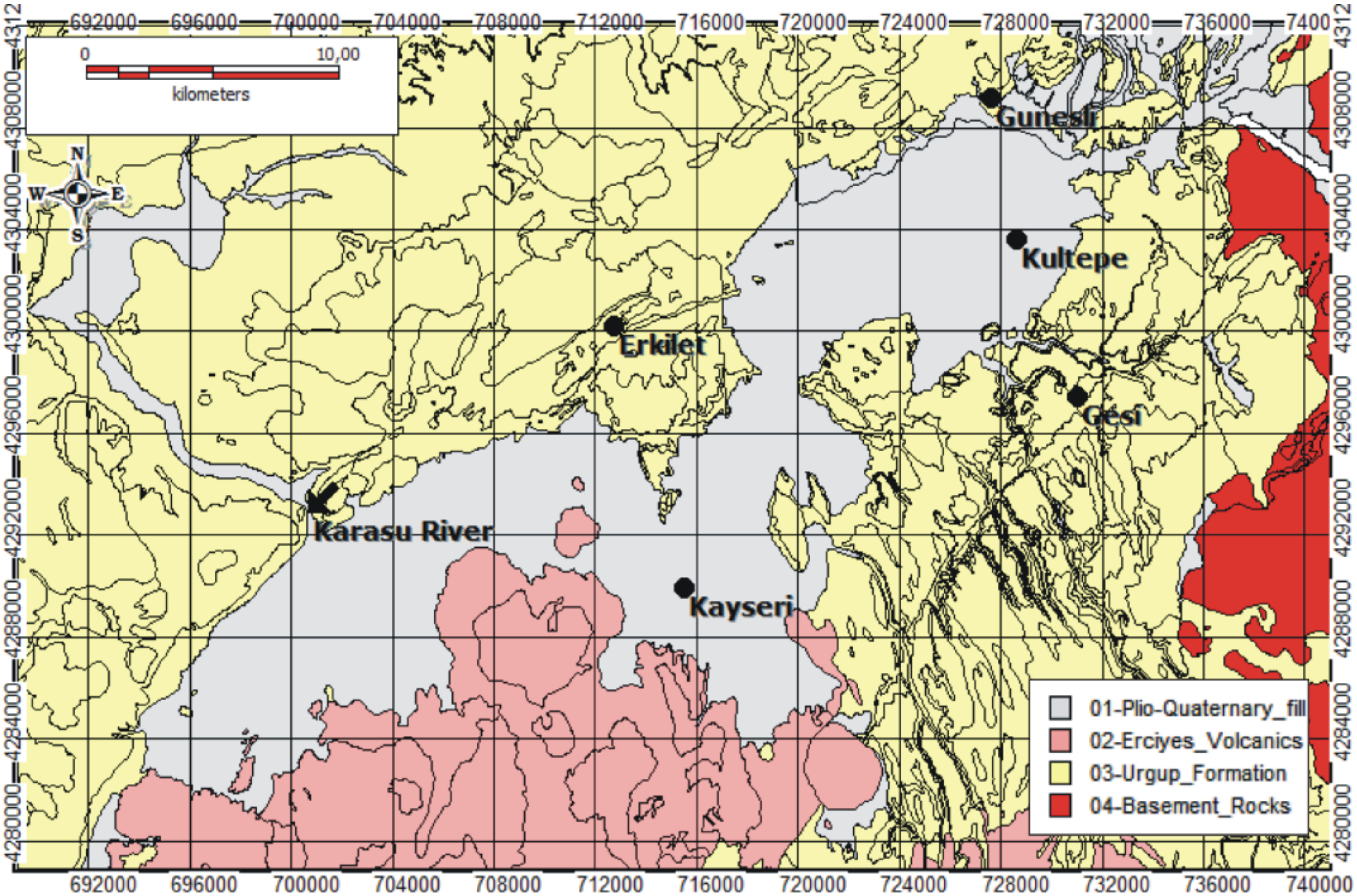


Figure 5.1. Simplified geological map of the region (Dalkılıç, 2009; Dönmez et al., 2005).

A geological map is given in Figure 5.2 that shows distribution of the ignimbrites exposed in the region. Accordingly, four ignimbrites existing in the area of interest are Tahar, Incesu, Valibaba and Alakuşak ignimbrites. Two cross-sections are drawn across the basin to correlate elevations of the units exposed at both sided of the basins (Figure 5.2). In both cross sections only the target units are highlighted and other units are not shown. The base elevations of the units are measured to keep the consistency.

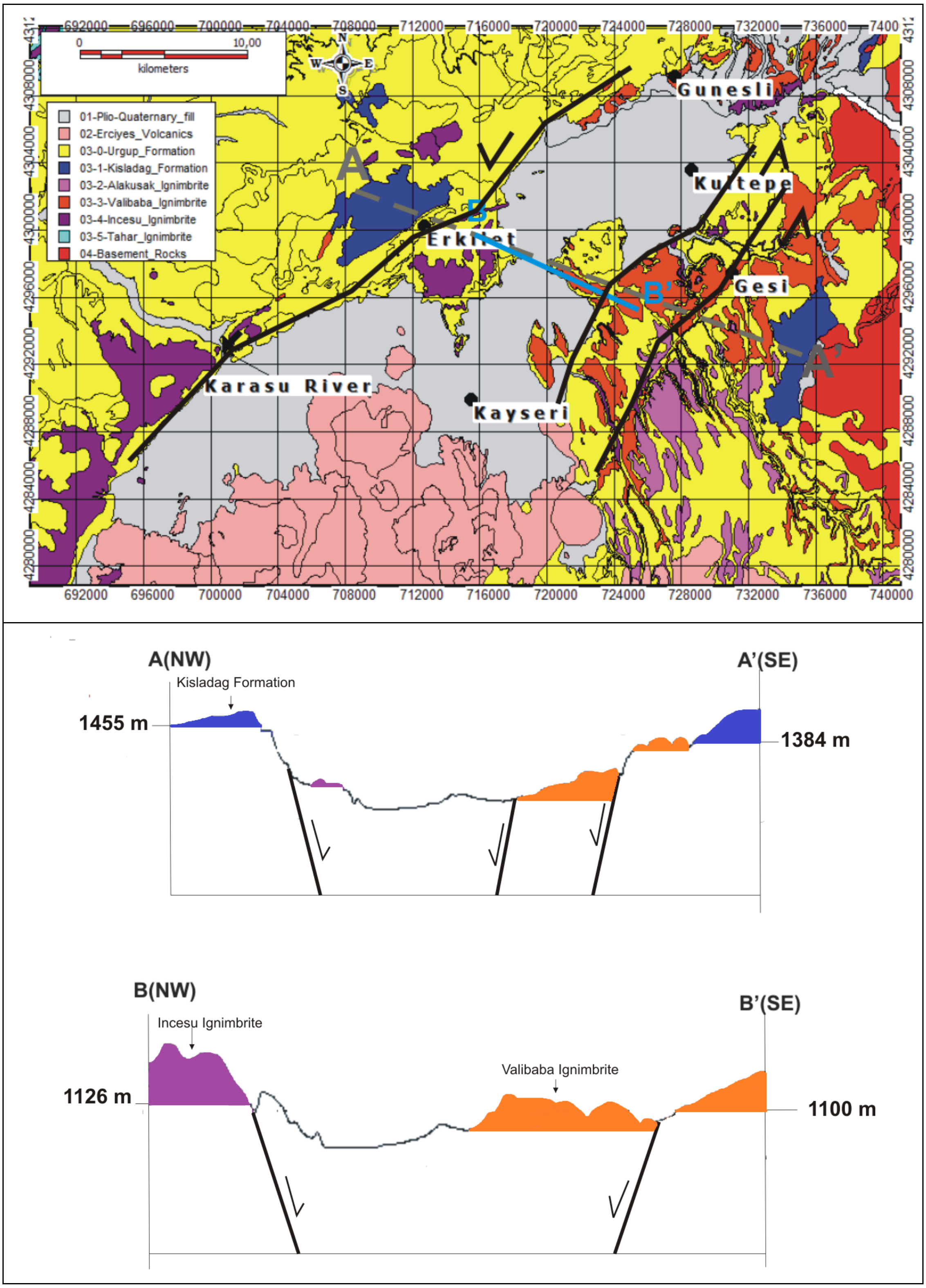


Figure 5.2. The cross-sections across the Sarımsaklı basin showing the offsets in particular rock units. Line of sections are given in the map above.

The first cross-section shows bottom elevations of Kışladağ formation (lacustrine limestone) which is a horizontal unit located stratigraphically at the top of Ürgüp formation. The cross-section is taken to include the main western and the two eastern faults. Location and sense of the faults are shown in the figure. The basal elevation of Kışladağ formation is 1455 m at the west and 1384 m in the east. Accordingly, the western part of the area is elevated for 71 m. It should be kept in the mind that, Kışladağ formation is located on the upthrown blocks of two faults. Therefore this is only a relative vertical movement between to sides of the area.

The second cross-section is drawn across Incesu and Valibaba ignimbrites. It should be noted that Valibaba ignimbrite is stratigraphically above Incesu. The main fault on the western and one of the two faults in the eastern part are included in the cross section. According to the cross section, first of all, the eastern faults cuts and displaces Valibaba ignimbrite 11 m on the eastern part of the area. Secondly, a total displacement of 37 m occurs at the basal elevations of Valiababa and Incesu ignimbrites.

5.2. Evaluation of Fault Data

In this section the field data collected during the field survey periods will be introduced, processed and evaluated. The data consist of fault-slip data measured along the major active fault surrounding the basin. At the end of the section the data will be justified by seismic data compiled for the area.

Location of the sites where data are measured is shown in Figure 5.3. A total or 66 fault-plane data are measured in 8 sites. The data measured in the field are given in Appendix A, Table A-1. For each measurement the following parameters are noted:

- Geographic location, Easting and Northing
- Strike, dip and rake of the fault plane
- The letter "C" of "P". The first term stands for "certain" indicating the there is no doubt on the nature of the fault; the latter on the other hand stands for "probable"
- One of the letters of "I", "N", "S" and "D" that refer to the sense of the fault, namely, inverse (reverse), normal, sinistral (left-lateral) and dextral (right-lateral), respectively.

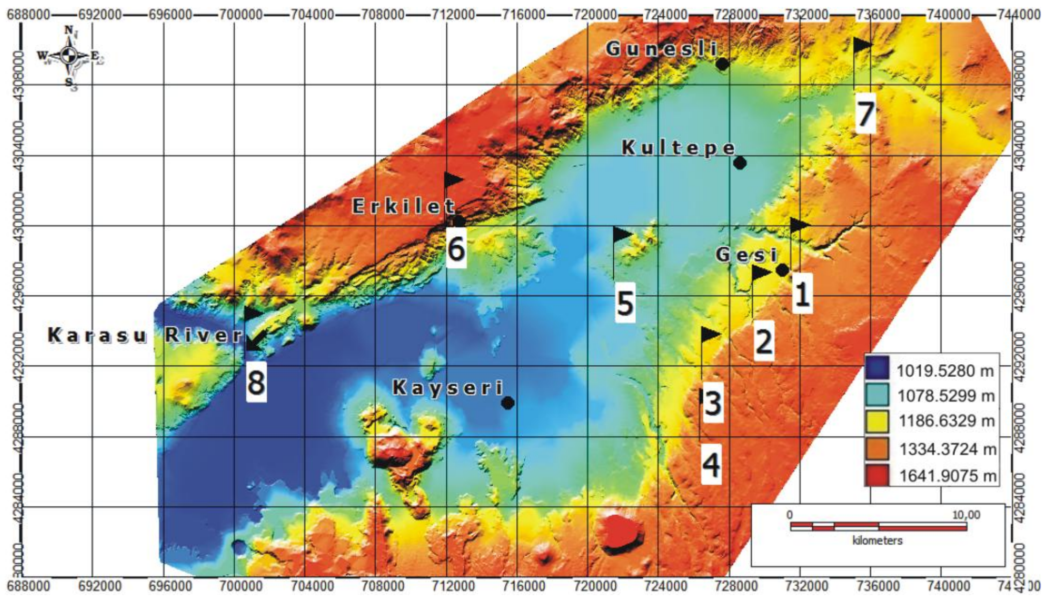


Figure 5.3. Location map where slip data are measured.

As can be seen in the table all measurements belong to either sinistral or normal faults. Types of the faults are probable in some measurements in sites 2, 5 and 6. If amount of rake is greater that 45° this fault is considered as normal, otherwise it is classified as sinistral fault.

All the data are processed by the software *"Stress Angelier"* in order to get the *"Tensor Solutions"* of this site. The results of these fault plane solutions will contribute to understand the nature of the faults that shape the Sarımsaklı basin. A short description for each site is given below.

Site 1: This site is located near Gesi village. Four fault planes are measured in this site. The faults strike NE-SW and dip NW with 58-81° (Figure 5.4). The rake measured on the faults indicates a normal fault with left-lateral strike-slip component (Figure 5.6).

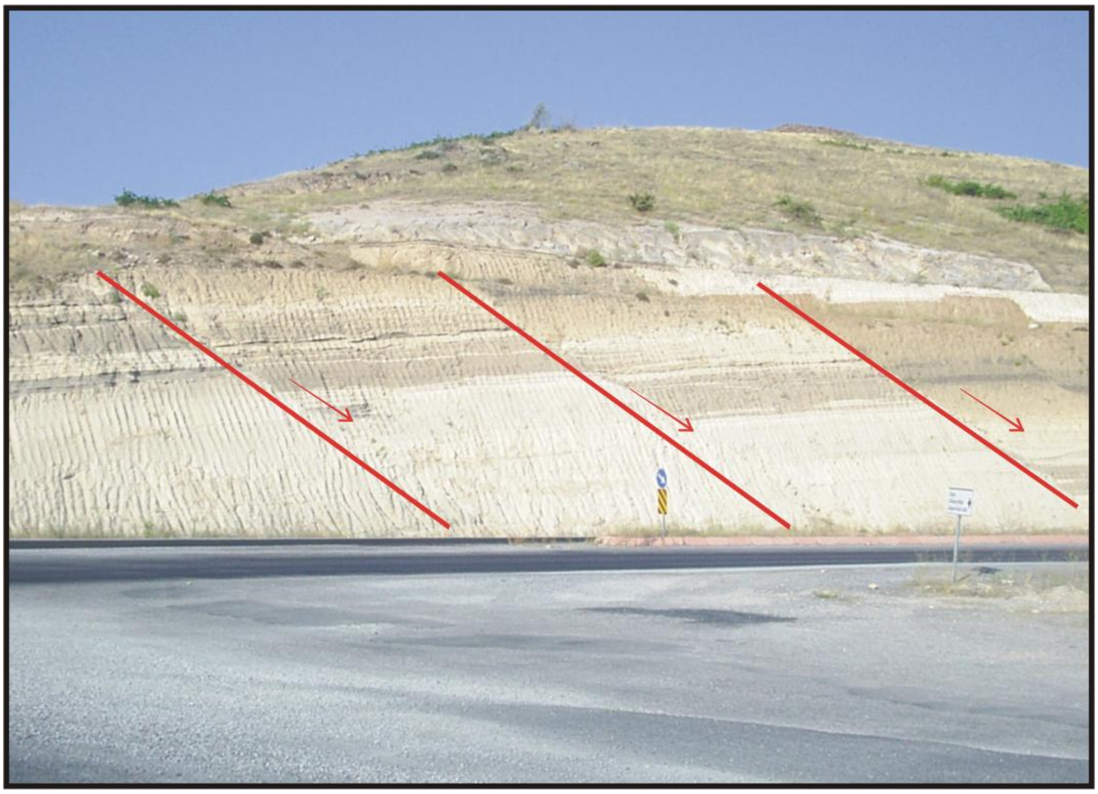


Figure 5.4. Normal faults at Site 1 near Gesi.

Site 2: The second locality is in the vicinity of Kayabağ settlement located to the south of Gesi. Four faults are measured in this site. All the faults are striking NE-SW with three vertical and one dipping NW (Figure 5.6). The vertical faults have almost pure strike-slip whereas the other with normal character.

Site 3: Seven fault measurements are taken at this site located to the south of Gesi. All the faults are striking in NE-SW direction and dipping

NW with 55-74 degrees (Figure 5.6). According to the rake data all the faults can be classified as normal faults.

Site 4: This is located to the south of Gesi. A total of 13 measurements are taken with diverse fault characteristics. Two sets of the faults are striking NW-SE with some dipping NE and others SW (Figure 5.6). The rake values on these faults indicate that they are pure normal faults. Four of the NE-SW striking faults are either normal or sinistral type (Figure 5.6).

Site 5: This site is located in the middle part of the area around the high hills. Total number of the faults measured in this site is 14. Eleven of the faults are normal faults with minor sinistral movements. Two of the faults strike in NW-SE direction (Figure 5.6).

Site 6: This site is located next to Erkilet on the major fault that bounds the western margin of the Sarımsaklı basin. Fifteen faults are measured here consistently strike in NE-SW direction and dips SE (Figure 5.6). The rakes are towards the SW (Figure 5.5) indicating normal fault with left-lateral strike-slip component.

Figure 5.5. A normal fault measured at Site 6

Site 7: This site is located in the northeastern part of the area close to Sarımsaklı river. Five measurements are taken in this site which consistently strike NW-SE and dip NE (Figure 5.6). According to the rakes, four of the faults are normal and one dextral.

Site 8: This site is located close to the Karasu river on the main fault. Four faults measured in this site are consistently striking NE-SW and dipping NE (Figure 5.6). They are all normal faults with some left-lateral strike-slip component.

Results of the tensor solutions of the slip data are shown in Figure 5.6. Most of the diagrams suggest that the maximum principal stress is located almost in the central part indicating normal faulting. Only at one site, Site 2, a pure left-lateral strike-slip faulting is observed.

5.3. Seismic Data

Seismic data (earthquakes) for the last century is provided from Kandilli Observatory and Research Center is used to justify the faults mentioned in this study. The earthquakes are divided into 4 groups based on their magnitudes. A total of 338 earthquakes are plotted over the DEM of the area to illustrate the relationship with the faults.

Distribution of the earthquakes form a cluster extending in NE-SW direction parallel to the trend of the Central Anatolain Fault Zone within which the Sarımsaklı basin is developed (Figure 5.7). The location of some earthquakes are consistent with the main structures that shape the Sarımsaklı basin.

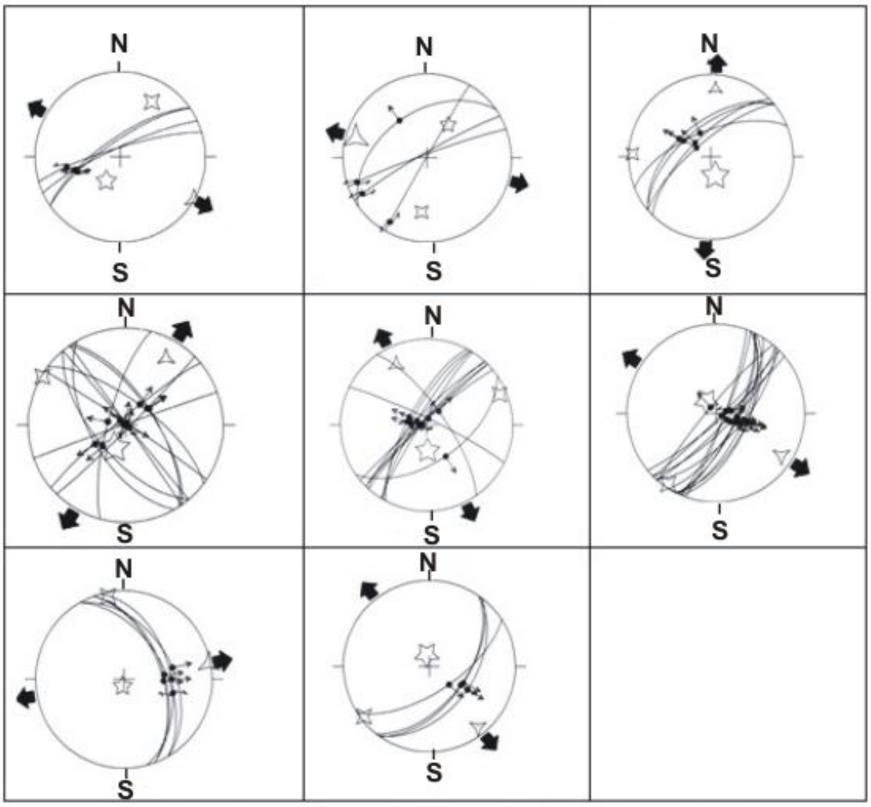


Figure 5.6. Stress tensor solutions of the slip data for 8 sites.

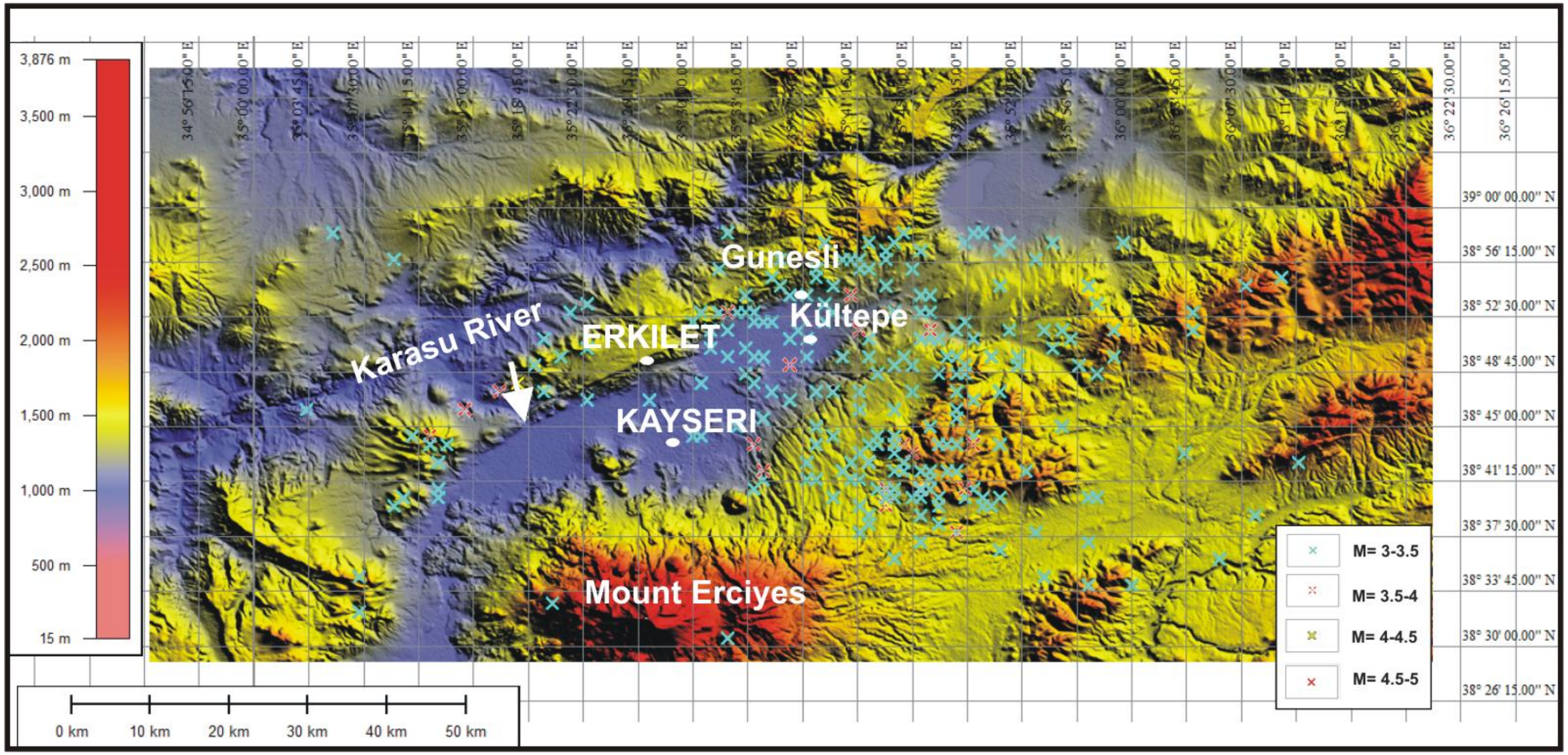


Figure 5.7. Distribution of seismic data over the DEM of the region

CHAPTER 6

BOREHOLE ANALYSIS

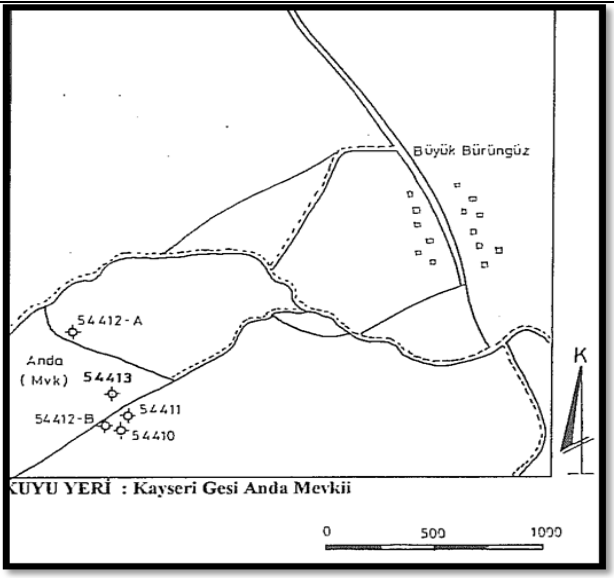
In this chapter, the borehole data distributed throughout the basin are used to investigate the nature of the Sarımsaklı basin fill deposits. A total of 506 borehole data are obtained from DSI. The main target in the analysis of the boreholes is to identify the key horizons particularly the ignimbrites in the Ürgüp formation. This will be used to identify the faults that cut across the basin and the base level of Quaternary deposits. This base, in turn, can be used to prepare a thickness map of the area.

6.1. Content of the Borehole Data

The borehole data is transferred into digital media by DSI through scanning the original well-logs. The date of drilling dates extends from 1960s to 2000s. The main purpose for the drilling is to probe the water potential of the Sarımsaklı basin.

For each borehole, there is a location map and an introductory information chart attached to the report (Figure 6.1). These two charts are important for this study because the locations of coordinates of the well locations are given here. If location is not clear for a borehole, it is deleted from the database.

Quality of the report in some cases is very bad to read the information given. These boreholes are also deleted from the borehole database. A total of 170 boreholes are not used either due to the lack coordinates or because of the quality of the report.



A.GENEL BİLGİLER

Bölgesi	XII	Kuyu no	54413
İli	KAYSERİ	Amacı	Araştırma
İlçesi	Melikgazi	Makina tipi	TAMROCK
Yeri	Gesi Anda Mevkii	Mak.DSİ no	91-4002
Ovası	Sarımsaklı Ovası	Talimat tarih/no	20.5.1999-1397
Koordinatı	K35-a3	Baş.tarihi	24.9.1999
	(736508 D- 4293093 K)	Bitiş tarihi	28.9.1999
Kot (m)	1499,22 m	Açan Şube	10 Sondaj Şube Müd.

Figure 6.1. Examples of location map (above) and introductory information (below) provided by the borehole data.

The main part of the report is the lithological description of the units provided with other information such as geophysical log (Figure 6.2). The description comprises two basic parameters, namely the thickness and the rock name. The rocks are mostly described in the shortest phrase without a detail such as "silty sandstone", brown clay", "dark ignimbrites etc. There is no data that will help to understand if the unit belongs to Quaternary deposits or to an older sequence. If it is older than Quaternary in the case of ignimbrites, it is not possible to correlate the unit with the stratigraphy of the area.

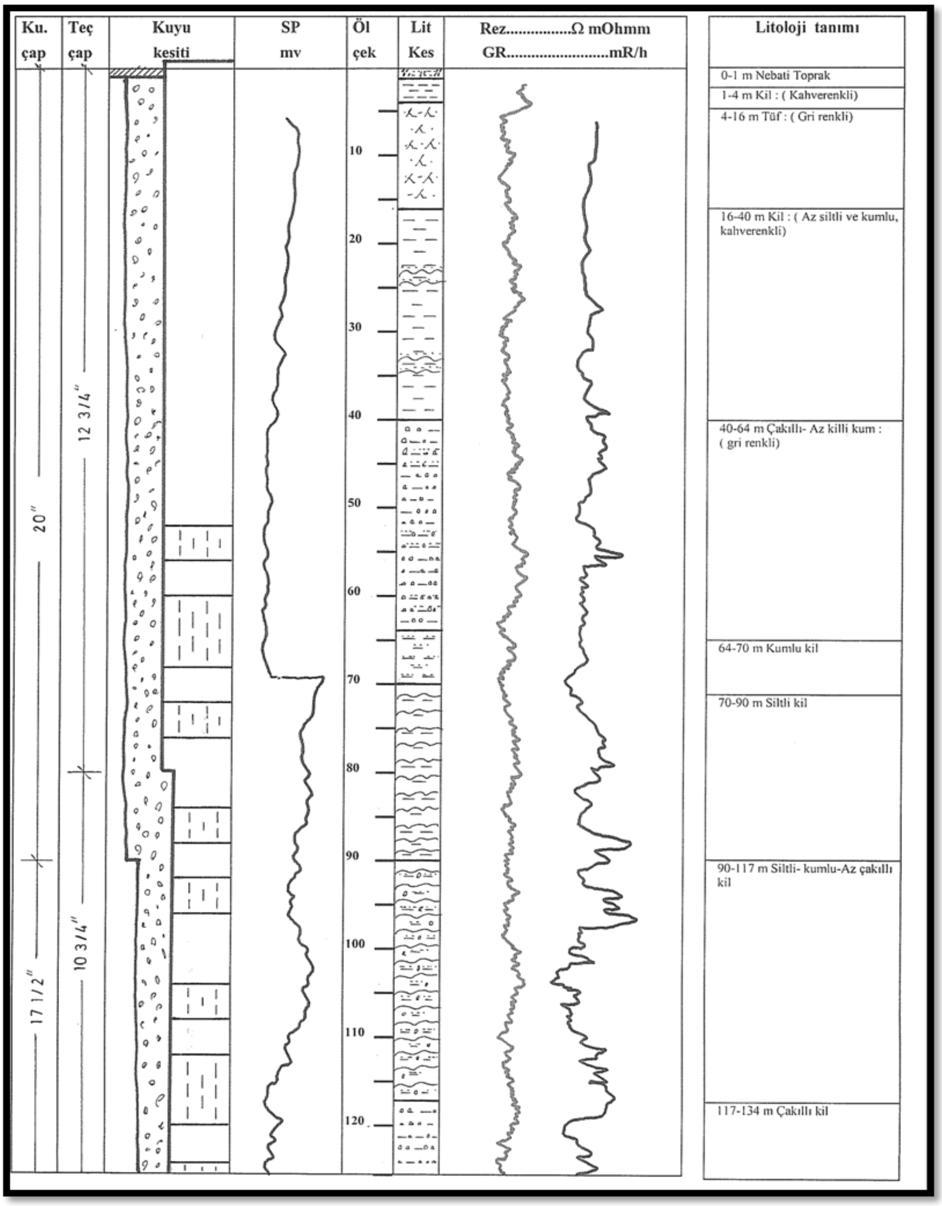
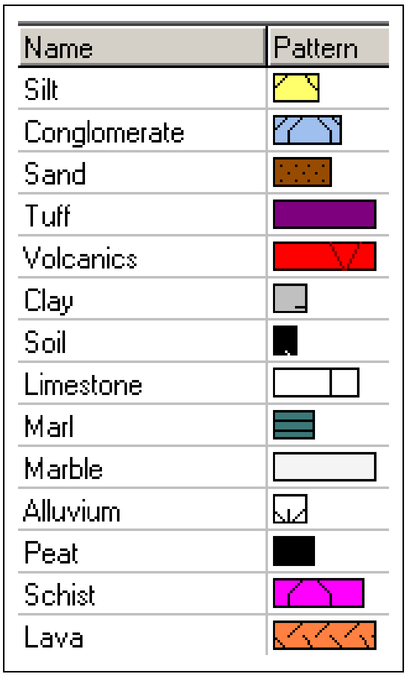


Figure 6.2. The sample for lithological description of borehole no. 60020.

6.2. Creation of Database

All the boreholes are processed by the “Borehole utilities” of RockWare software. First the thickness intervals are input and a short lithologic description is assigned to the units. Total number of the rock names assigned for all boreholes is 14 (Figure 6.3). In order to reduce the total number of the rock names some lithologic descriptions are simplified. For example, the descriptions as “conglomerate”, “sandy conglomerate”, “silty conglomerate” are all considered as conglomerate. The term “ignimbrite” does not exist in the descriptions. Therefore, the “tuff” in the list should represents the ignimbrites in the area.



Name	Pattern
Silt	
Conglomerate	
Sand	
Tuff	
Volcanics	
Clay	
Soil	
Limestone	
Marl	
Marble	
Alluvium	
Peat	
Schist	
Lava	

Figure 6.3. Lithologic units identified in the boreholes.

The depth and lithologic data are stored in the database together with the Id-number, coordinates and geographic description of the boreholes. For each borehole a columnar section is prepared to be used in the analysis (Figure 6.4). A total of 332 boreholes are stored in the database. Figure 6.5 shows the distribution of these boreholes over the area.

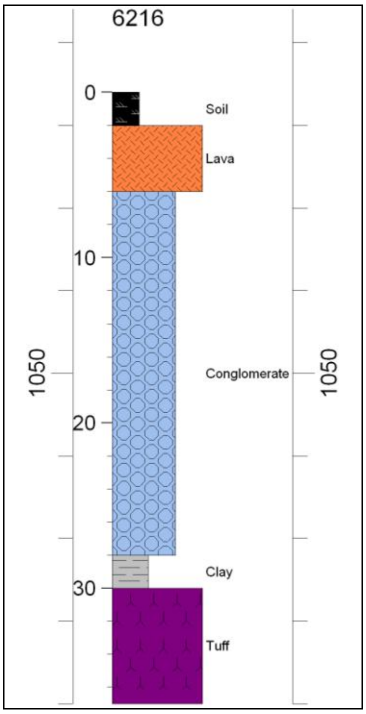


Figure 6.4. A sample columnar section prepared for boreholes.

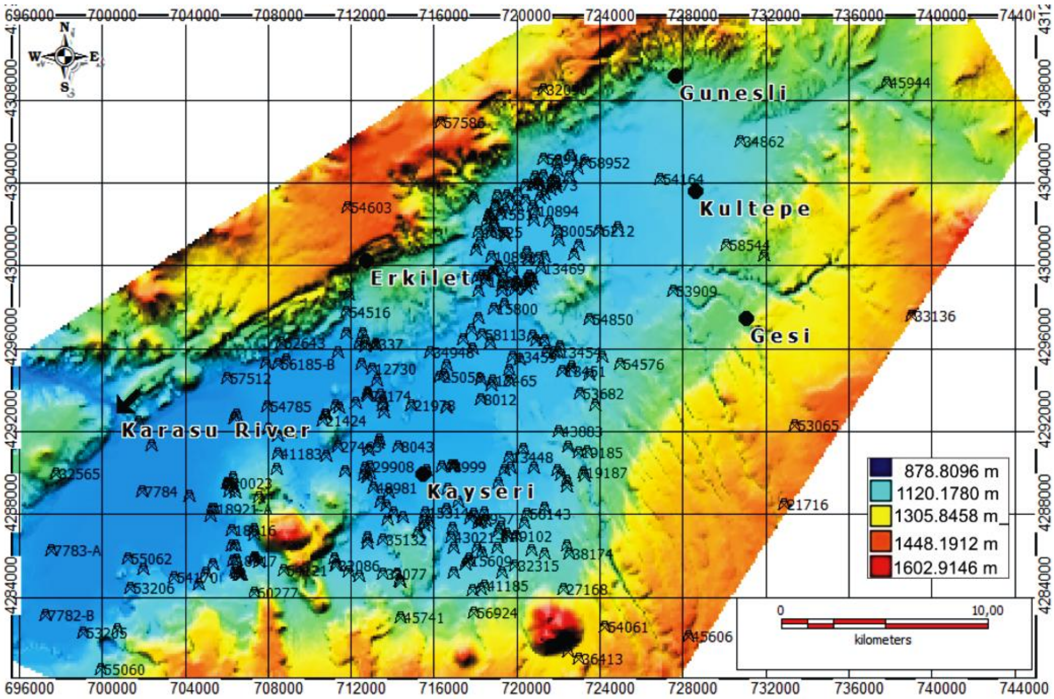


Figure 6.5. Location of 332 boreholes used in the study

6.3. Criteria for the Base of Quaternary Units

The main difficulty in the correlation of the units in the boreholes is to determine a key horizon. Individual layers that belong to Quaternary fill deposits can not be correlated because of intense lateral variations.

Some of the units in Ürgüp formation such as ignimbrites can be correlated; however, the clastic rocks overlying these ignimbrites might belong to Quaternary of two other units of the Ürgüp formation. The detail of the lithologic descriptions is not enough to differentiate these two clastic rocks. To simplify the problem and minimize the errors it is decided to consider the top of the first ignimbrite as the bottom of Quaternary sequence. An example of this case is shown in Figure 6.6 for the borehole no: 54164. The log data in this borehole consists of 50 m of clay-conglomerate intercalation overlying a tuff layer. The top of the tuff (ignimbrite) is considered to define the boundary of Quaternary fill deposits and the Ürgüp formation of Mio-Pliocene age.

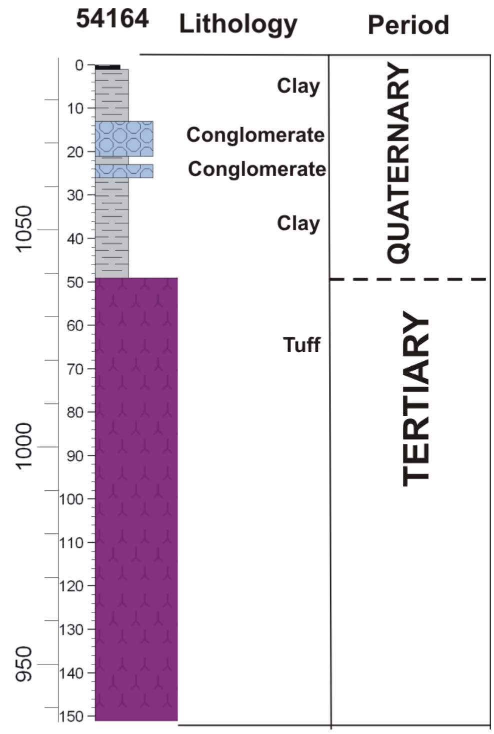


Figure 6.6. Determination of bottom of Quaternary sequence. Tuff is the key unit separating the Quaternary units from the older ones.

Another lithology is the lava flow that exists in 10 boreholes which might be interpreted in a wrong way because there are two sources for the lava flows in the area. The first one is the Erciyes volcanics which is relatively young and the flows erupted from this source can be intercalated with Quaternary sediments. These volcanics, therefore, are considered within the Quaternary sequence.

The second type is the lava flows that rarely occur in the Ürgüp formation. A lava flow of this origin is known around Erkilet area. Therefore if the lava flow in the borehole belongs to Ürgüp formation the base of Quaternary sequence should be above this unit. An example of this case is shown in Figure 6.7. Seven boreholes with lava flows in the whole data are close to Erciyes volcano (considered within Quaternary) and 3 boreholes are close to Erkilet area (considered below Quaternary).

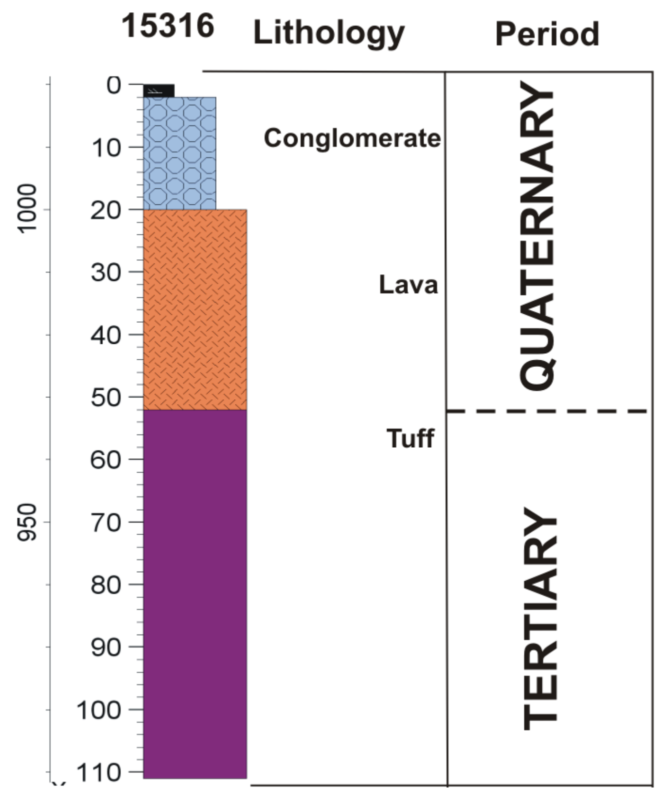


Figure 6.7. An example of lava flow in the borehole data. Since this borehole is close to Erciyes volcanics, the lava is considered in Quaternary sequence.

Other lithologies such as marble and schist are very distinct and can not be confused with Quaternary sequence. Therefore all lithologies other than tuff, lava, marble and schist are considered as Quaternary units. An example of this type borehole is shown in Figure 6.8. The "soil" in the boreholes is at the top of the borehole and corresponds to soil cover at the surface. The peat ("turba"), on the other hand, is usually at the upper parts of the boreholes below the soil and therefore is considered as a part of Quaternary.

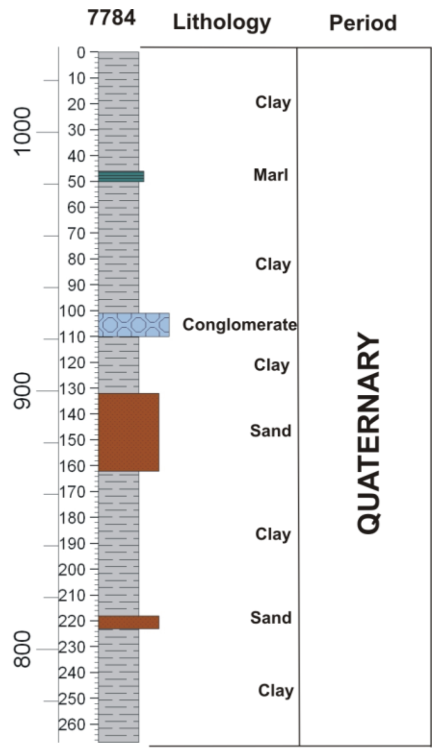


Figure 6.8. An example of borehole composed of Quaternary sequence.

6.4 Sections Prepared from Boreholes

By using the log values and columnar sections generated from borehole data files, borehole to borehole sections are prepared in six regions. The sections are illustrated in Figures 6.9 to 6.14. For each section a location map over the Sarımsaklı basin, a close up view of the section and attribute table of the lithologic units are given.

Region 1: The first section (Figure 6.9) is located between Erkilet and Kültepe oriented in E-W direction and comprises five boreholes (7304-B, 58111, 7309, 58114 and 7306). The first two boreholes in the western part, penetrated the tuff layer (ignimbrite) at depths of about 45 and 15 m which corresponds to the thickness of Quaternary sequence towards the margin of the basin in the west. The last three boreholes, on the other hand, which are located towards the middle part of the basin, are represented by Quaternary deposits to the bottom of the boreholes which are more than 150 m.

The sudden change in the thickness of Quaternary deposits between the boreholes 7309 and 58114 which is more than 125 m should correspond to vertical displacement of the fault. Accordingly the western part of the area is uplifted. The lithological variation in the Quaternary deposits in three eastern boreholes is a good indication of the intense lateral variation within Quaternary deposits.

Region 2: The second cross section is prepared from the western part of the area parallel to the margin of the basin (Figure 6.10). Six boreholes are used in this section which are 7307, 60189, 46895, 59252, 46825 and 60022 aligned from northeast to the southwest. Presence of tuff in four boreholes indicates the base of Quaternary deposits. Other two boreholes are located totally within the Quaternary deposits with more than 160 and 170 m. The thickness of Quaternary deposits range from 30 m to 100 m in other four boreholes.

The thickness of the Quaternary deposit is not systematically changing from north to south. The sudden changes in the thickness of the Quaternary deposits, for example, between boreholes 46825 and 60022 and between boreholes 59252 and 46825 should be an indication of the fault. Therefore, between boreholes 60189 and 46895, the existence of another fault can be also suggested. There is no information however on the orientation of these faults. The fault might be striking in NW-SE direction perpendicular to the long axis of the basin as suggested in the literature (Koçyiğit and Beyhan 1988; Dirik, 2001).

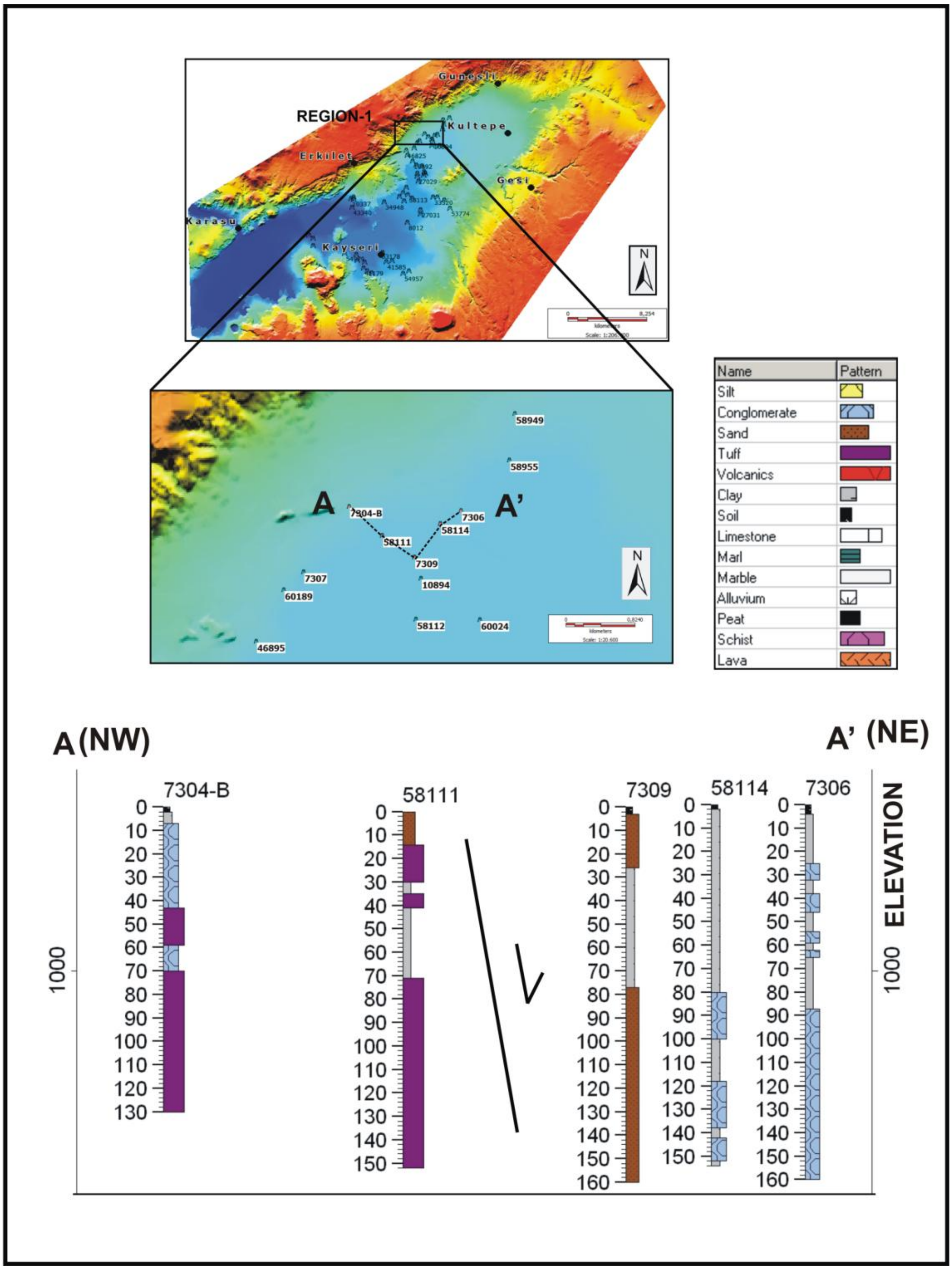


Figure 6.9. Borehole to borehole section of REGION-1 prepared from boreholes 7304-B, 58111, 7309, 58114 and 7306

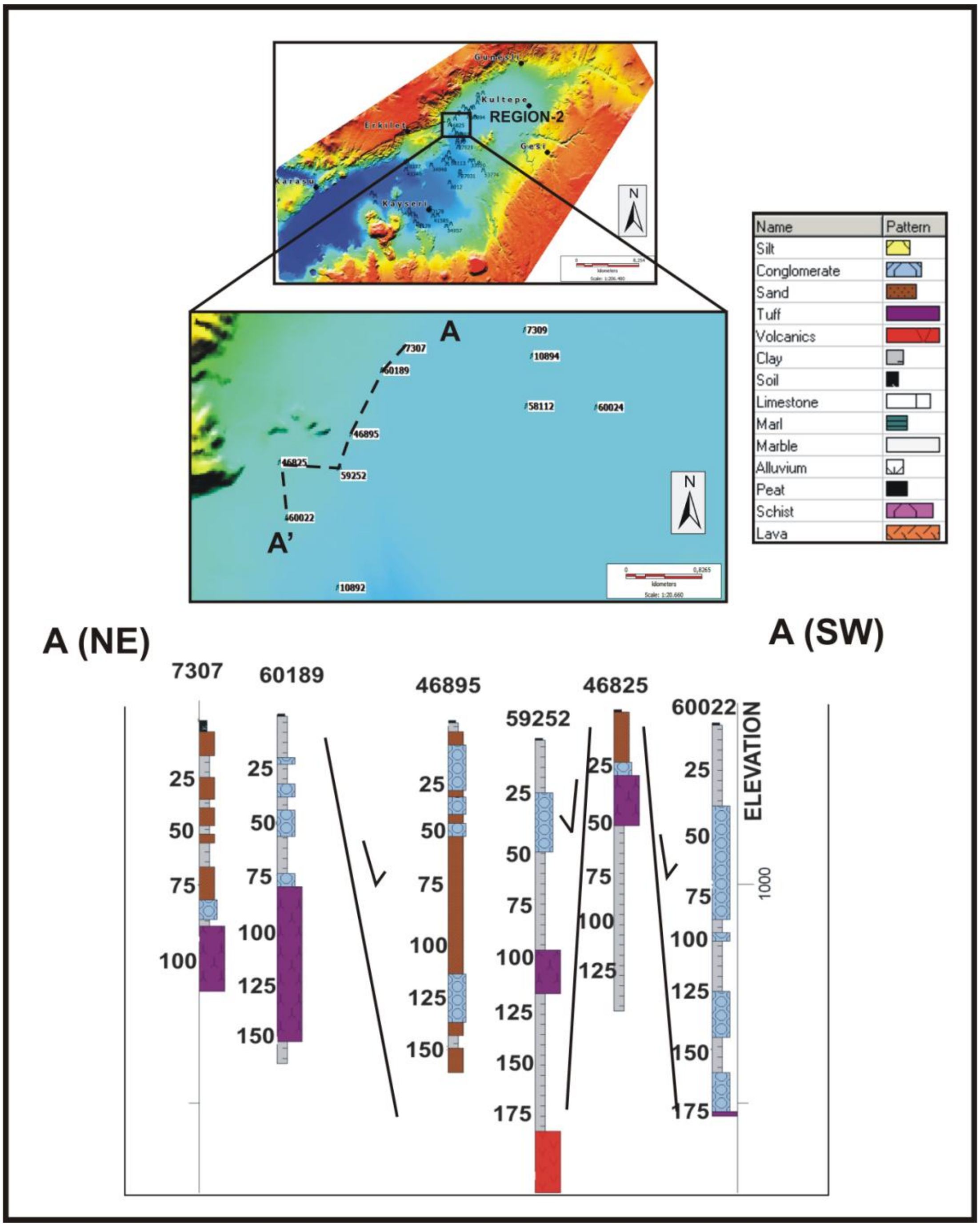


Figure 6.10. Borehole to borehole section of REGION-2 including the boreholes 7307, 60189, 46895, 59252, 46825 and 60022

Region 3: The third section is taken almost in the middle part of the area in NW-SE direction (Figure 6.11) and includes five boreholes (7309, 10894, 58112, 60024 and 8005). The most distinguished feature of this section is the depth to the bottom of Quaternary deposits consistently observed in all boreholes. The thickness is more than 180 m in borehole 8005 which is one of the highest values in the whole boreholes.

Accordingly, due to the lateral variation again commonly observed for the Quaternary deposits across the section given in Figure 6.11, indication of faults should be suggested between the boreholes 8005 and 60024; 7309 and 10894; 10894 and 58112; 58112 and 60024.

Region 4: The fourth section is located to the south of the previous section and almost parallel to it (Figure 6.12). This section, however, is close to the high areas located within the middle of the Sarımsaklı basin. Therefore, by this section it is aimed to test the effect of these high areas on the development of the Quaternary deposits. The section comprises five boreholes, namely, no: 10892, 59683, 7940, 60290 and 33319.

The thickness of the Quaternary deposits is about 195 m at the northeastern tip of the section (no: 10892) which is located in deeper parts of the basin. This value drops from northwest to southeast, to 75 m (no: 59683), 120 m (no: 7940), 32 m (no: 60290) and 22 m (no: 33319). Therefore, a fault can be located between the first and the second boreholes. Another fault might also be considered between the second and the third boreholes. Accordingly a horst is implied bounding the borehole no: 59683. Even if there is a horst in this area, amount of the vertical movement is higher for the eastern fault as indicated by gradual increase towards the east. Strong variation in the lithologies of the Quaternary deposits is emphasized in this section as well. Presence of two tuff layers in borehole no: 33319 is very important information to correlate the tuff with the layers exposed at the surface, however could not be utilized due to the lack of information.

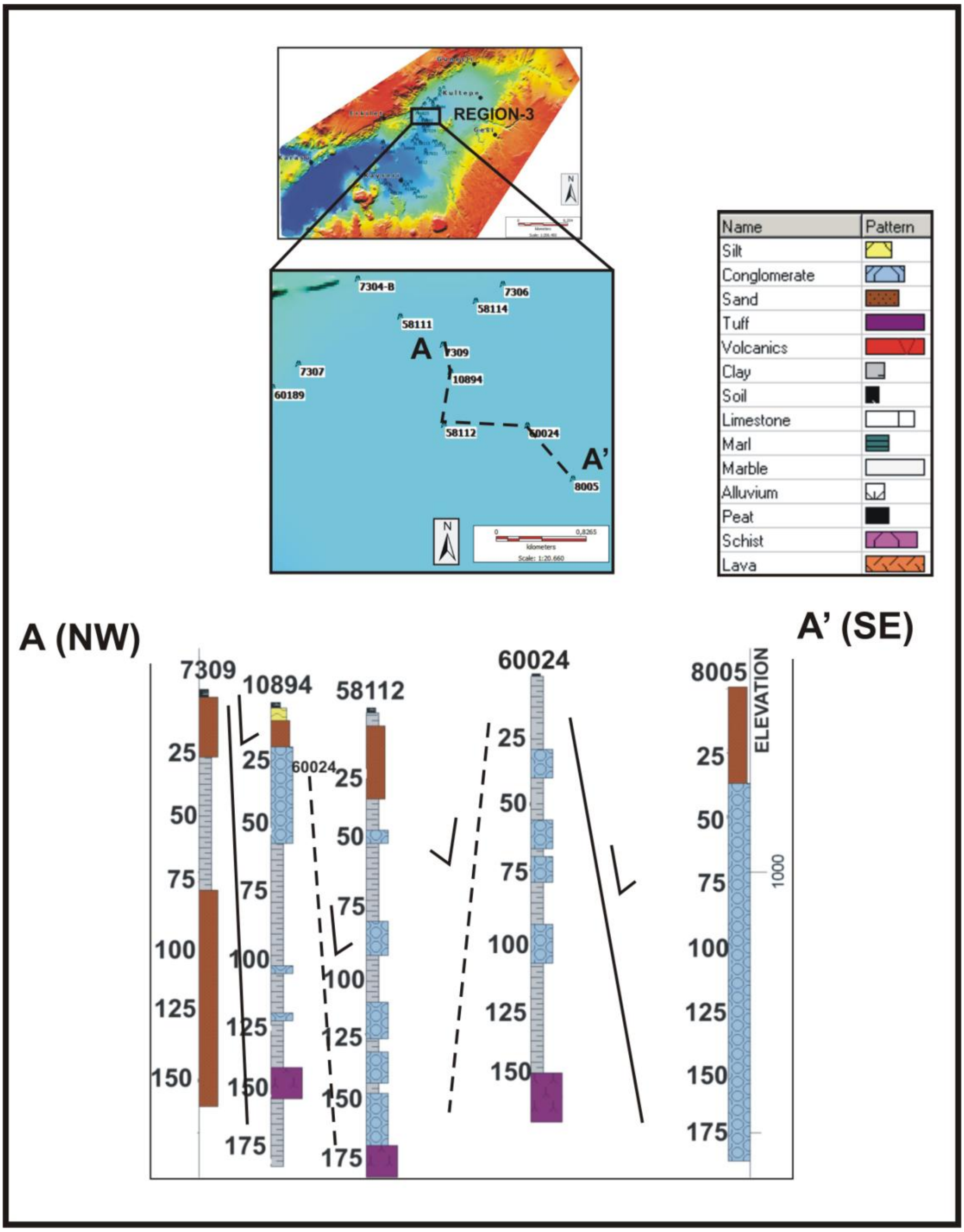


Figure 6.11. Borehole to borehole section of REGION-3 containing the boreholes 7309, 10894, 58112, 60024 and 8005

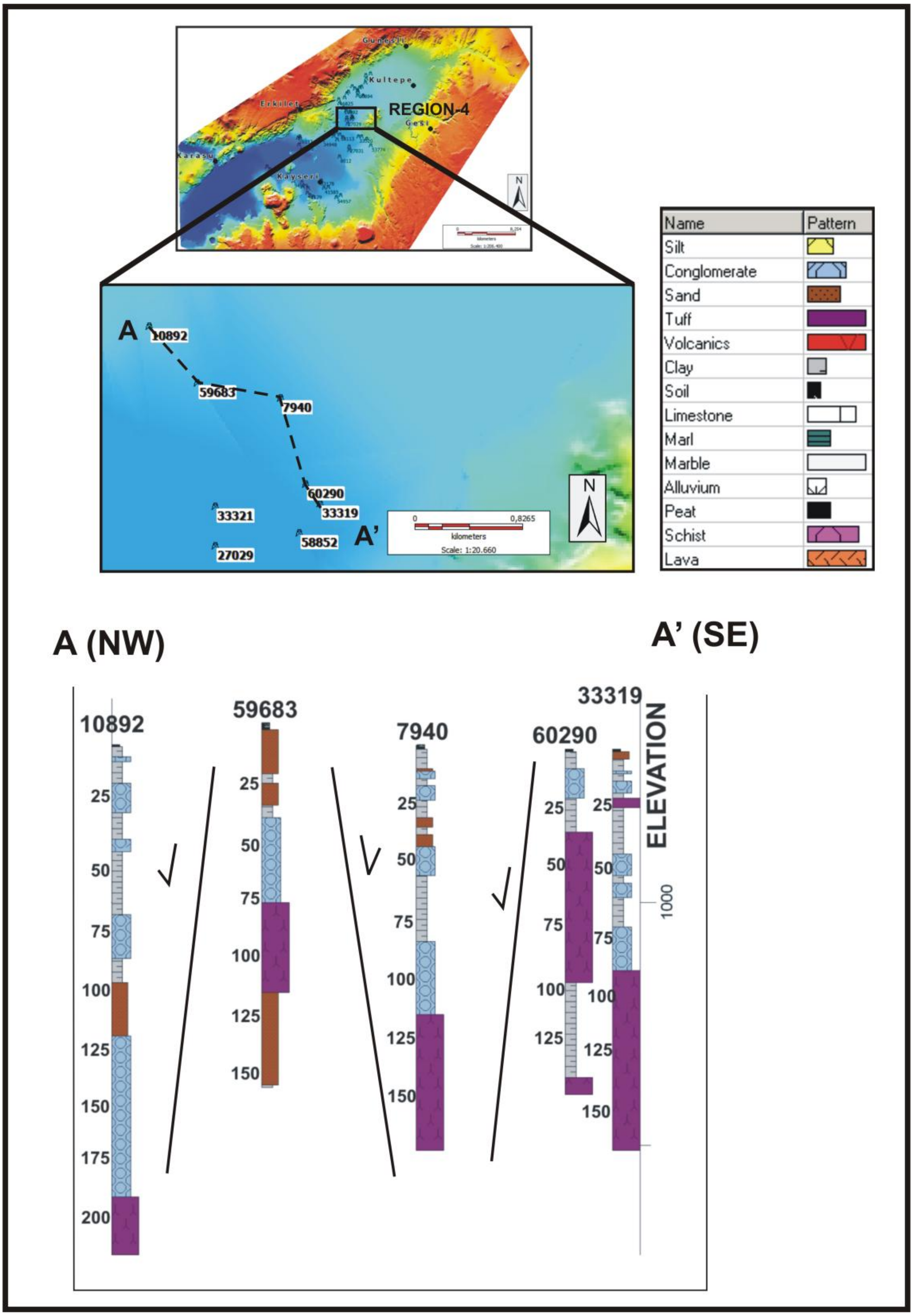


Figure 6.12. Borehole to borehole section of REGION-4 including the boreholes 10892, 59683, 7940, 60290 and 33319

Region 5: The fifth cross section is prepared at the close vicinity of Kayseri comprising five boreholes (58178, 41585, 44099, 54957 and 55924) in NW-SE direction (Figure 6.13). The line of section is very close to Erciyes volcanics which is confirmed by extensive lava flows in almost all boreholes. Some of the flows that exist both above and below ignimbrites might be a misinterpretation due to the description in the lithology log.

A clear observation in this section is the gradual decrease of the thickness of the Quaternary deposits towards the southeast. The thickness is a few m in the borehole no: 55924. The thickness compared with other sections is small except in the borehole next to Kayseri (no: 55178) which is about 125 m. This is because this borehole is located towards the middle of the basin.

A possible fault can be located between the first two boreholes where a sudden change in the thickness of the Quaternary deposits is observed. The gradual and consistent change observed in other four boreholes, on the other hand might be associated with faulting as well as to the regional tilting of the units.

Region 6: The last section is located in the central part for the area where Sarımsaklı basin has a minimum width to the hill exposed in this part (Figure 6.14). The section comprises four boreholes (58852, 33321, 27029 and 8007) aligned in E-W direction.

Following observations can be made in this section:

- There are three tuff layers in one borehole which is not a common case for other boreholes. These tuff layers could not be correlated with the units exposed in the area. However, such a correlation can contribute to the interpretation of the tectonic movements.

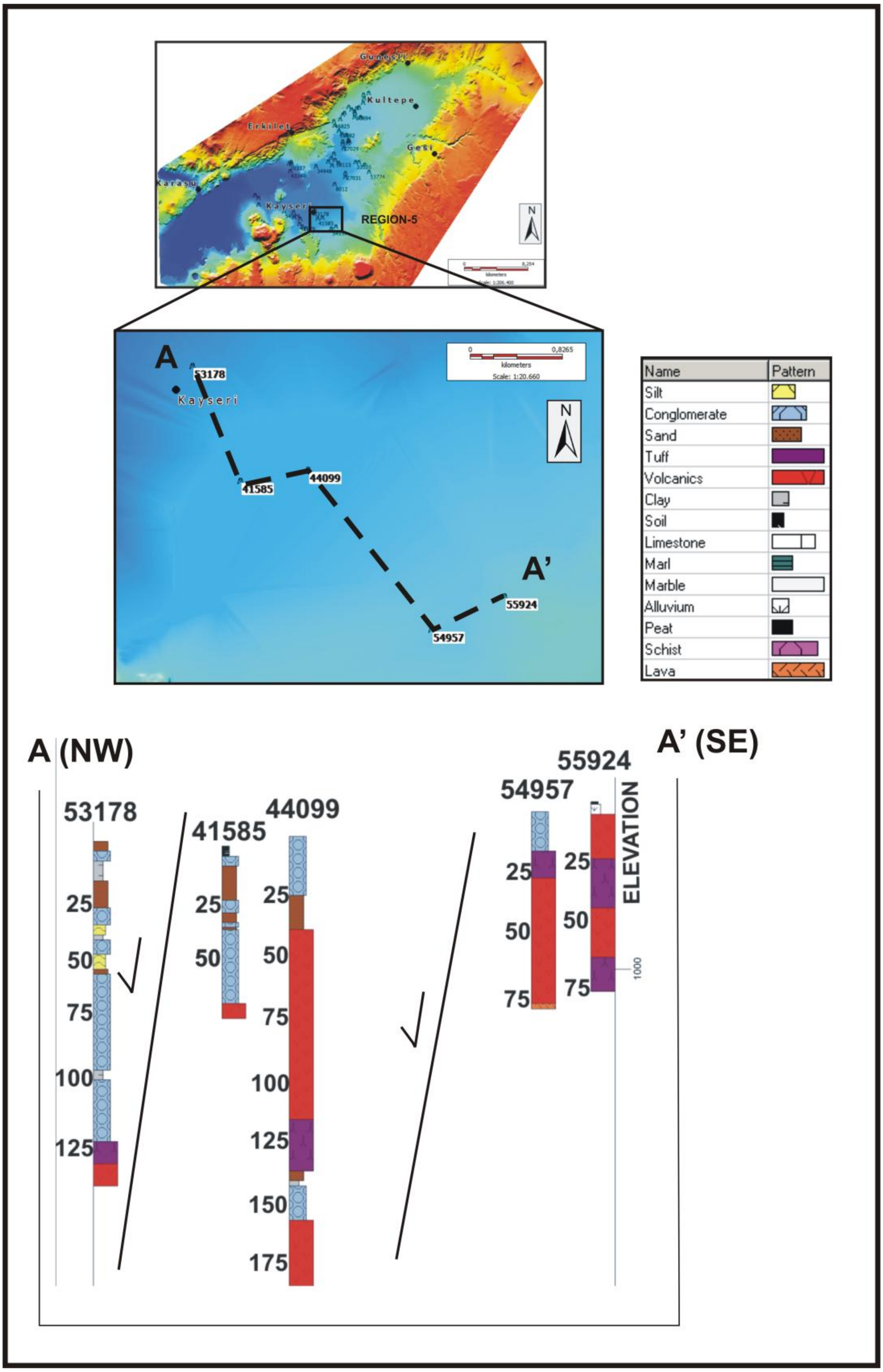


Figure 6.13. Borehole to borehole section of REGION-5 generated from the boreholes no: 58178, 41585, 44099, 54957 and 55924

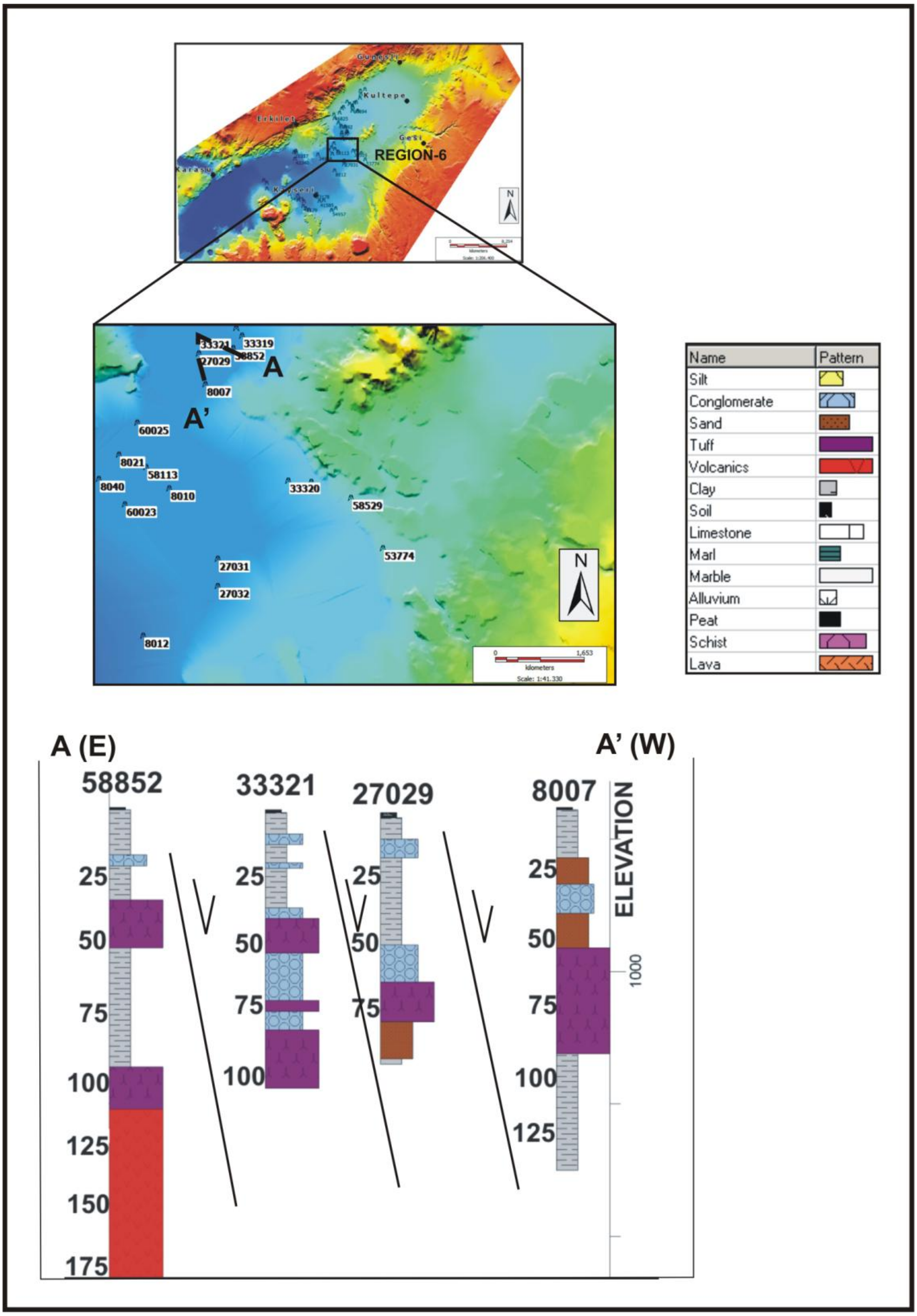


Figure 6.14. Borehole to borehole section of REGION-6 consisting of the boreholes numbered as 58852, 33321, 27029 and 8007

- The lava flow the tuff layer in borehole no: 58852 should belong to Erkilet valcanics since this borehole is the nearest one to Erkilet area and other boreholes do not have any lava flows.

- The maximum thickness of the Quaternary deposits does not exceed 65 m suggesting a shallow depth for this part of the basin. As indicated in the section to the south of this one (Region 5), the thickness of Quaternary deposits reaches almost to 125 m. Therefore there might be some faults striking in NW-SE direction parallel to the line of section further south of this region.

6.5. Quaternary Thickness Map

An attempt is made to estimate the thickness of the Quaternary deposits of the Sarımsaklı basin by using the borehole data. The boreholes very close to each other and the boreholes with very short depths ending in Quaternary units are omitted in this analysis. The total number of boreholes used is 229.

The thickness map is prepared by triangulation method using the MapInfo software. The resultant map is illustrated in Figure 6.15. The DEM showing the thickness values of Plio-Quaternary basin fill is generated by the means of triangulation method. The pink and red colors in the figure indicate the maximum thickness of in the area.

Based on the variation of the thickness, three parts in the basin can be suggested as deep which receive maximum accumulation of sediments. These are 1) vicinity of Karasu river; 2) the area between Erkilet and Kültepe, and 3) vicinity of Kayseri city. This pattern is controlled by the faults acting in the area.

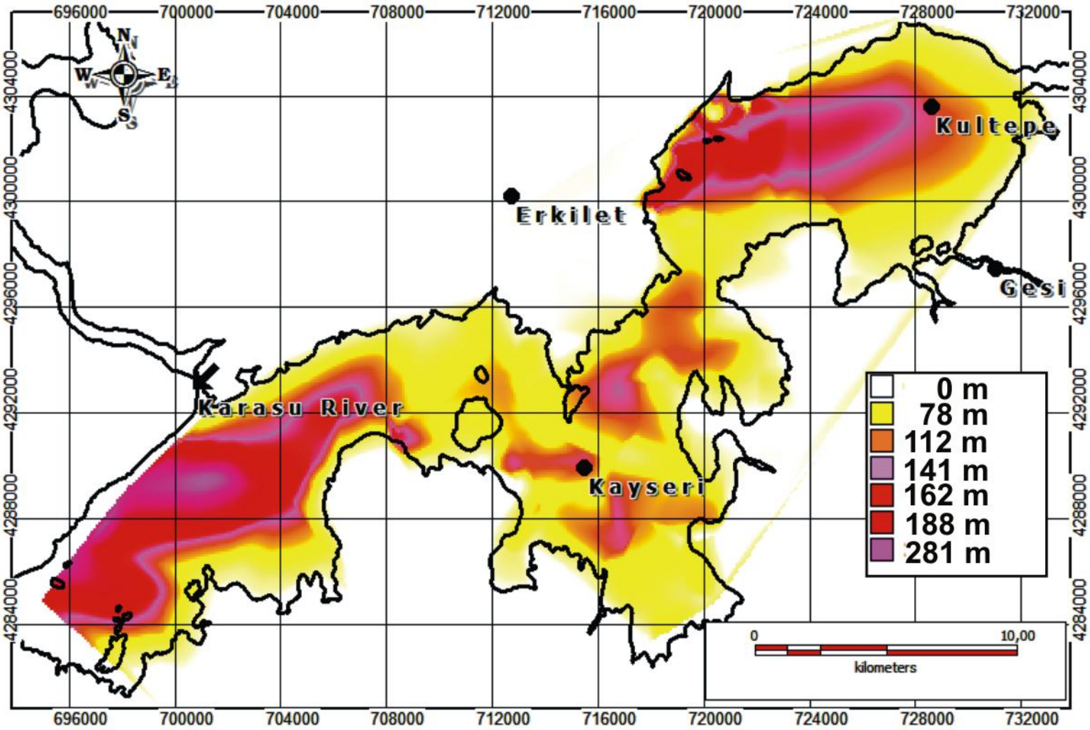


Figure 6.15. The DEM of Sarimsakli Basin showing the Quaternary thickness of the basin fill material generated from 229 boreholes.

CHAPTER 7

DISCUSSION AND CONCLUSIONS

7.1. Quality of Data

Two main data sources that affect the accuracy of the results are borehole data and geology map. In this section, the confronted flaws and issues affected the accuracy of results will be discussed.

Two main problems faced with the borehole data are 1) lack of information in some boreholes; and 2) insufficient lithologic description for all boreholes.

The lack of information, first of all, is observed in the location of the boreholes. Some of the boreholes contain coordinates consistent with the topographic maps used in this study. Therefore, there was no problem in locating these boreholes. Some boreholes miss the coordinate information but could be located with the help of “location map” provided in the data. These boreholes are also assigned coordinates successfully and are included in the database. Other boreholes, however, that miss both the coordinates and location map could not be used in this study.

The second reason for the lack of information is the invisibility of the information on PDF-files due to low quality of scanning of original files. These borehole data could not be used in this study.

A total of 170 boreholes are ignored due to these problems. The negative effect of this is an uneven distribution of the boreholes throughout the area. For example, the density of the boreholes is very high in some parts whereas there is no borehole in some other parts. The most important problem created by this distribution is the quality of the thickness map prepared for the basin fill deposits. The second problem is encountered during drawing borehole-to-borehole sections. Some sections that could be important to understand the nature of the basin could not be prepared because of the large distances between the boreholes.

Insufficient lithologic description which is the second flaw of borehole data refers to the description made for the rock units penetrated in the boreholes. Most of the units are described in a shortest way with minimum characteristic features. This affects the results negatively in two ways: 1) correlation between the boreholes can not be easily made; 2) of the units penetrated in the boreholes can not be integrated with the surface geological data. Therefore the actual throw along the faults can not be estimated. There are several stratigraphic units such as ignimbrites and limestone that could be used as key horizon, however, these units can not be effectively utilized for the understanding of the Sarımsaklı basin.

To overcome the problem caused by the lithologic descriptions two assumptions are made in this study:

1) Both Mio-Pliocene sequences (Ürgüp formation) and the Sarımsaklı basin Quaternary fill deposits are characterized by extensive clastic rocks. Descriptions in the borehole data are not enough to differentiate these two clastic levels. The boundary between these two sequences is distinguished by the appearance of the first ignimbrite (tuff) or lava flow. This is simply because of the fact that there is no ignimbrite in the Quaternary deposits. Therefore

the only way to differentiate the clastics rocks of two ages is the presence of ignimbrites.

2) There are lava flows both of Quaternary age (Erciyes volcanics) and Mio-Pliocene age (Erkilet volcanics). Therefore, one can easily be confused with the age of the sequence in the borehole if there is a lava flow. To overcome this problem it is assumed that if the borehole is close to Erciyes volcano, the lava flow should belong to Quaternary age; similarly if the borehole is close to Erkilet, the lava flow should belong to Mio-Pliocene period.

The problems associated with the geological map of the area are mostly due to stratigraphic nomenclature. Geological map of the area is included originally in two sheets at 1/100.000 scale, namely K34 and K35 (Dalkılıç, 2009; Dönmez et al., 2005). These maps are compiled most probably with different groups at different times. As a result, there are some inconsistencies in the boundaries and different names assigned in different sheets.

7.2. Evaluation of the Results

Geological results: Geological investigations made in this study are mostly based on the compiled geological maps. This compilation covers 1) the setting of the Sarımsaklı basin (together with the Sultansazlığı basin to the south) at regional scale; and 2) distribution of rock units originally mapped at 1/25.000 scale.

At regional scale it is clear that the Sarımsaklı basin is a pull-apart basin formed within the Central Anatolian Fault Zone during Plio-Quaternary period. This basin is bounded by two fault sets at the east and west. The eastern fault set in Sarımsaklı basin is named as Gesi fault and the western as Erkilet fault. Accordingly, the area between these two faults is subsiding with a certain rate resulting in the accumulation of sediments at the basin floor. Kültepe is located in this basin and is also gradually subsiding. Two data sets that confirm this observation are the slip data measured in the field and the seismic data compiled for the last century.

The slip data are measured along several fault scarps of Gesi and Erkilet faults. The most characteristic feature of these measurements is that the faults are dominantly of normal type indicating a vertical movement along the faults. This vertical movement is the main reason for the subsidence of the Sarımsaklı basin.

The seismic data compiled for the region indicates that most of the faults in the area are active. Therefore the vertical movements along the faults are still operating.

An accurate amount of vertical displacement can be estimated using the key horizons in the area. Although, the vertical movements are illustrated on two cross sections across the Sarımsaklı basin, amount of vertical throw can not be exactly calculated. This is because the key horizons can not be traced in the boreholes.

Morphological results: Morphological analysis of the basin contributed to important information particularly on the drainage characteristics of the area. First of all it is clear that the Sarımsaklı basin is drained only by one channel (Karasu river) which developed over the Erkilet fault at the western margin of the basin. The eastern segment of the Karasu river is V-shaped where it is connected to flat Sarımsaklı basin. It should be remembered that the fault line (Erkilet fault) is passing right along this boundary. Such a sharp change in the valley shape is an indication of elevated valley due to faulting. Therefore, as the fault is activated the channel will be elevated which, in turn; will block the drainage of the Sarımsaklı basin. As a result, the Sarımsaklı basin will be covered by a lake until the channel is re-dissected to a level that will start to drain the lake. This is a probable scenario for the development of a lake that will flood Kültepe.

Borehole data results: Two important outcomes of the borehole data are 1) thickness map of the Sarımsaklı basin fill deposits; and 2) borehole-to-borehole sections across the basin.

According to the thickness map, Quaternary fill deposits do not have a uniform distribution over the area. The pattern of the map suggests two observations that might be linked to the activity of the faults shaping the basin.

The first observation is the concentration of the maximum thickness along the western margin of the basin. Accordingly the vertical movements along the western margin should be more than the eastern one.

The second observation is that the fill deposits have certain breaks particularly in the central part of the basin. This is most probably due to the presence of faults striking oblique (NW-SE) to the elongation of the basin.

Based on the borehole-to-borehole sections, existence of several faults can be suggested. Ignimbrites and lava flows are the dominant lithologies used to identify the faults. The strike of these faults, however, can not be estimated from the borehole, because only one point on the line of section is known.

7.3. Conclusions

Conclusions reached in this thesis considering the research questions asked in the introduction are briefly as follows.

1) Kültepe is located in Sarımsaklı basin which is a tectonic depression (together with Sultansazlığı depression) formed during Plio-Quaternary. As a result of the activity of the two marginal faults (Gesi to the east and Erkilet to the west) the shoulders of the basin are uplifted while the basin is being subsided. Kültepe is located over this subsiding section.

2) The faults that shape the basin are still active suggesting that vertical movements can occur today as well as during the historical period.

3) The Sarımsaklı basin is drained by a single channel (Karasu river). The fault is located at the starting point of the river. As the fault activates, the channel is elevated resulting in the formation of a closed basin (lake) behind the channel.

4) Present morphological configuration suggests that a water level elevated for 70 m will totally bury Kültepe.

REFERENCES

Dalkılıç, H., 2009. Kayseri-K35 Paftası/ Türkiye Jeoloji Haritaları No:123, Maden Tetkik Arama Genel Müdürlüğü, Ankara

Dhont, D., Chorowicz, J., Yürür, T., Froger, J.-L., Köse, O., Gündoğdu, N., 1998., Emplacement of volcanic vents and geodynamics of Central Anatolia, Turkey/ Journal of Volcanology and Geothermal Research 85; 33-54

Dirik, K., 2001. Neotectonic Evolution of the Northwestward Arched Segment of the Central Anatolian Fault Zone, Central Anatolia, Turkey/ Geodinamica Acta 14; 147-158

Dönmez, M., Akçay, A., E., Türkecan, A., 2005. Kayseri-K34 Paftası/ Türkiye Jeoloji Haritaları No:49, Maden Tetkik Arama Genel Müdürlüğü, Ankara

Emre, K., 2010. The Discovery of Kanesh/ Anatolia's Prologue Kültepe Kanesh Karum Assyrians in Istanbul; 20-23

Froger, J.-L., Lenat, J.-L., Chorowicz, J., Le Pennec, J.-L., Bourdier, J.-L., Köse, O., Zimitoğlu, O., Gündoğdu, N., M., Gourgaud, A., 1998. Hidden calderas evidenced by multisource geophysical data; example of Cappadocian Calderas, Central Anatolia/ Journal of Volcanology and Geothermal Research 185; 99-128

Gans, C., R., Beck, S., L., Zandt, G., Biryol, C., B., Ozacar, A., A., 2009. Detecting the limit of slab break-off in central Turkey: new high-resolution *Pn* tomography results/ Geophysical Journal International 179; 1566-1572

Innocenti, F., Mazzuoli, G., Pasquare, F., Radicati Di Brozolo, F., Villari, L., 1975. The Neogene calcalkaline volcanism of Central Anatolia: geochronological data on Kayseri–Nigde area. Geol. Mag. 112 _4., 349–360.

Kocyigit, A., Beyhan, A., 1998. A new intracontinental transcurrent structure: the Central Anatolian Fault Zone, Turkey/ Tectonophysics 284; 317-336

Kulakoğlu, F., 2010. Kültepe Kanesh Karum: The Earliest International Trade Center in Anatolia/ Anatolia's Prologue Kültepe Kanesh Karum Assyrians in Istanbul; 40-51

Kuzucuoğlu, C., Pastre, J.-F., Black, S., Ercan, T., Fontugne, M., Guillou, H., Hatte, C., Karabıyıkoğlu, M., Orth, P., Türkecan, A., 1998. Identification and dating of tephra layers from Quaternary sedimentary sequences of Inner Anatolia, Turkey/ Journal of Volcanology and Geothermal Research 85; 153-172

Kürkçüoğlu, B., Sen, E., Aydar, E., Gourgaud, A., Gündoğdu, N., 1998. Geochemical approach to magmatic evolution of Mt. Erciyes stratovolcano Central Anatolia, Turkey/ Journal of Volcanology and Geothermal Research 85; 473-494

Kürkçüoğlu, B., Sen, E., Temel, A., Aydar, E., 2001. Trace-Element Modeling and Source Constraints for Tholeitic and Calc-alkaline Basalts from a Depleted Asthenospheric Mantle Source, Mt. Erciyes Stratovolcano, Turkey/ International Geology Review 43; 508-522

Pasquare, G., 1968. Geology of the Cenozoic volcanic area of Central Anatolia/ Atti Accad. Naz. Lincei 9; 53–204.

Temel, A., Gündoğdu, M., N., Gourgaud, A., Le Pennec, J.-L., 1998. Ignimbrites of Cappadocia _Central Anatolia, Turkey/: petrology and geochemistry/ Journal of Volcanology and Geothermal Research 85; 447-471

Topçuoğlu, O., 2010. Anitta Text/ Anatolia's Prologue Kültepe Kanesh Karum Assyrians in Istanbul; 24-29

Toprak, V., 1998. Vent distribution and its relation to regional tectonics, Cappadocian Volcanics, Turkey/ Journal of Volcanology and Geothermal Research 85; 55–67

APPENDIX A

GROUND TRUTH MEASUREMENTS

Table A-1. Slip-plane data measured from eight different locations in and from the edges of Sarimsakli Basin.

LOCATION	X (EASTING)	Y (NORTHING)	STRIKE	DIP	RAKE	SENSE of MOTION
1	731450	4297470	N55°E	75°NW	48°W	CN
			N55°E	72°NW	48°W	
			N73°E	81°NW	37°W	
			N65°E	81°NW	44°W	
2	729317	4294766	N55°E	44°NW	89°S	PS
			N30°E	89°NW	13°SW	CN
			N60°E	85°NW	13°SW	
			N70°E	86°NW	13°SW	
3	726430	4291252	N50°E	74°NW	85°SW	CN
			N68°E	64°NW	84°SW	
			N58°E	64°NW	89°SW	
			N76°E	69°NW	80°SW	
			N50°E	55°NW	78°SW	
			N50°E	60°NW	80°SW	
			N45°E	69°NW	89°SW	
4	726294	4287734	N56W	88°NE	89°N	CN
			N50°E	84°NW	89°S	
			N15°E	75°NW	89°S	
			N45°E	87°SE	89°N	
			N70°E	89° N	89°S	
			N33°W	66°NE	89°N	
			N35°W	67°NE	89°N	
			N53°W	69°NE	89°N	
			N35°W	89° N	89°N	
			N40°W	89° N	89°N	
			N35°W	89° N	89°N	
			N40°W	89° N	89°N	
			N30°W	60°SW	89°S	
5	721457	4296957	N45°E	85 NW°	85°S	CN
			N30°E	75°NW	85°W	
			N42°E	85°NW	85°W	
			N32°E	85°NW	88°W	
			N43°E	80°NW	80°W	
			N50°E	85°NW	85°W	
			N45°E	87°NW	88°W	
			N64°W	84°NE	89°W	
			N35°W	73°NE	86°W	

Table A-1 (continued). Slip-plane data measured from eight different locations in and from the edges of Sarimsakli Basin.

LOCATION	X (EASTING)	Y (NORTHING)	STRIKE	DIP	RAKE	SENSE of MOTION
5	721457	4296957	N28°E	72°NW	89° S	CN
			N31°E	80°NW	89° S	
			N55°E	55°SE	88° N	
			N28°E	85° W	60°S	CN
			N25°E	68°SE	70°E	
6	711887	4300067	N25°E	64°SE	85°SW	PN
			N27°E	60°SE	85°SW	
			N23°E	82°SE	85°SW	
			N25°E	71°SE	86°SW	
			N42°E	66°SE	82°SW	
			N26°E	70°SE	87°SW	
			N23°E	60°SE	86°SW	
			N32°E	70°SE	87°SW	
			N45°E	85°SE	88°SW	
			N45°E	75°SE	86°SW	
			N25°E	71°SE	85°SW	
			N20°E	82°SE	85°SW	
			N50°E	83°SE	78°S	CN
			N42°E	79°SE	88°S	
			N40°E	83°SE	89°S	
7	735062	4307729	N30°W	52°NE	58°S	CN
			N30°W	44°NE	78°S	
			N15°W	46°NE	80°S	
			N20°W	55°NE	77°S	
			N20°W	53°NE	82°S	
8	700625	4292464	N38°E	55°SE	86°S	CN
			N35°E	54°SE	85°S	
			N36°E	47°SE	87°S	
			N57°E	65°SE	84°S	