GEOARCHAEOLOGICAL INVESTIGATIONS IN ZEUGMA, TURKEY

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ABSTRACT

GEOARCHAEOLOGICAL INVESTIGATIONS IN ZEUGMA, TURKEY

Karaca, Ceren

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The purpose of this study is to investigate the geological and morphological features around ancient city of Zeugma. To achieve this, a geological map of Zeugma excavation site is prepared; an aerial photographic survey and morphological analyses are conducted on a broader area. Additionally, the biggest ancient quarry in the study area is investigated.

In the close vicinity of Zeugma, four lithologies which are, from bottom to top, clayey limestone, thick bedded limestone, chalky limestone and cherty limestone are identified. A major fault with a vertical throw of 80 m is mapped in the area. Geological survey reveals that the excavation site is located within the chalky limestone and the rock tombs are carved within the thick bedded limestone.

In the aerial photographic survey, Fırat River is classified into 4 morphological classes which are river, island, flood plain and basement. The change among these classes is investigated between 1953 and 1992. The results reveal that there is no considerable variation in the position of the river channel and margins of flood plain within 39 years. The major change is observed in the islands that are built within the flood plain.

Testing the elevation of Gaziantep and Fırat formations boundary using the relief map, investigating the visibility of selected points in the area, predicting the source area for the water supply, and evaluating the nature of the ancient route, constitute the morphological analysis carried out in this study. However, these analyses are not studied in detail and should be considered as the first attempts for more detailed morphological analyses.

Keywords: Geoarchaeology, GIS, Change Detection, Firat River, Zeugma

ÖZ

ZEUGMA'DA (TÜRKİYE) JEOARKEOLOJİK ARAŞTIRMALAR

Karaca, Ceren

Yüksek Lisans, Jeoloji Mühendisliği Bölümü
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Bu çalışmanın amacı Zeugma antik kenti dolayındaki jeolojik ve jeomorfolojik özellikleri araştırmaktır. Bu amaç doğrultusunda Zeugma kazı alanının jeolojik haritası hazırlanmış, daha geniş bir alanda ise hava fotoğrafı analizi ve dört adet morfolojik analiz yapılmıştır. Ayrıca çalışma alanındaki en büyük antik taş ocağı incelenmiştir.

Zeugma yakın dolayında dört birim tanımlanmıştır. Bunlar alttan üste doğru, killi kireçtaşı, kalın tabakalı kireçtaşı, tebeşirli kireçtaşı ve çörtlü kireçtaşıdır. Alanda, düşey atımı 80 m olan bir ana fay haritalanmıştır. Bu çalışmalar sonucunda elde edilen veriler kazı alanının tebeşirli kireçtaşında, kaya mezarlarının ise kalın tabakalı kireçtaşında açıldığını göstermiştir.

Hava fotoğrafı analizi kapsamında, Fırat Nehri şu dört morfolojik sınıfa ayrılmıştır: nehir, ada, taşkın ovası ve temel birimi. 1953'ten 1992'ye kadar süren zaman aralığında, bu birimler arasındaki değişim araştırılmıştır. Hava fotoğrafı araştırması sonucunda nehir yatağında ve taşkın havzasının sınırlarında önemli bir değişim olmadığı, en önemli değişimin taşkın ovası içinde oluşan adalarda olduğu sonucu çıkmıştır.

Yükseklik haritası kullanarak Gaziantep ve Fırat Formasyonlarının yükseklik verilerini test etmek, arazideki belirli noktalardan görülebilen alanları araştırmak, su kaynaklarının yerlerini tahmin etmek ve antik yolun yapısını değerlendirmek bu çalışmada yapılan morfolojik analizleri oluşturmaktadır. Ancak, bu analizler detaylı bir şekilde çalışılmamıştır, ileride yapılacak daha detaylı morfolojik çalışmalar için başlangıç analizleri olarak kabul edilmelidir.

Anahtar kelimeler: Jeoarkeoloji, CBS, Değişim Analizi, Fırat Nehri, Zeugma

To my beloved family

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TABLE OF CONTENTS

ABSTRACT IV
ÖZ VI
ACKNOWLEDGEMENT IX
TABLE OF CONTENTS XI
LIST OF TABLES XIII
LIST OF FIGURES XIV
CHAPTER
1. INTRODUCTION 1
1.1. Purpose and Scope 1
1.2. Study Area 2
1.3. Zeugma 4
1.3.1. Historical Background 4
1.3.2. Geoarchaeological Studies 5
1.4 Method of Study 6
2. REGIONAL GEOLOGY 8
2.1. Gaziantep Formation 8
2.2. Fırat Formation 12
2.3. Yavuzeli Basalt 13
2.4. Old Alluvium 14
2.5. Alluvium 15
3. GEOLOGY OF THE STUDY AERA 16
3.1. Stratigraphy 16
3.2. Structural Geology 30
4. AERIAL PHOTO ANALYSIS 33
4.1. Step 1: Selection of input data 35
4.2. Step 2: Registration and Mosaicing 35
4.3. Step 3: Digitization 38
4.4. Step 4:Change Detection Analysis 40
4.5. Step 5: Evaluation and Interpretation of Results 45
5. MORPHOLOGICAL ANALYSES 47
5.1. Digital Elevation Model (DEM) and its Derivatives 47
5.2. Firat River Flood Plain 55
5.3. Analyses 59
5.3.1. Elevation of Gaziantep and Fırat formations 59
5.3.2. Visibility Analysis 61

5.3.3. Possible Sources for Water Supply 65
5.3.4. Evaluation of Ancient Route 67

6. ANCIENT QUARRY 70

7. DISCUSSION AND CONCLUSIONS...74

7.1. Geology of The Area...74
7.2. Fırat River Flood Plain..75
7.3. Aerial Photo Analysis 76
7.4. Morphological Analysis 77
7.5. Rock Quarries of Zeugma 79

REFERENCES...81

LIST OF TABLES

Table 4.1. Aerial photographs provided for the analysis 35

Table 4.2. Theoretical sixteen change classes and quantity of the change occurred 42

Table 4.3. Change matrix of subtraction analysis of 1953 and 1992 aerial photographs 45

LIST OF FIGURES

Figure 1.1. Location Map of the Study Area 3
Figure 1.2. Location Map of Seleucia and Apamea (from Kennedy, 1998)... 4
Figure 2.1. Regional geological map of the area (from Ulu, 1996) 9
Figure 2.2. Generalized stratigraphic section of the area (simplified from Ulu, 1996).. 10
Figure 2.3. A.Boundary between Fırat (upper) and Gaziantep (lower) formations B.General view of Fırat formation C.General view of Gaziantep formation... 11
Figure 2.4. A view of Yavuzeli basalt.. 14
Figure 2.5. A general view of old alluvium.. 15
Figure 2.6. A view of the Birecik Dam reservoir under which Firat River flood plain is buried.. 15
Figure 3.1 Geological Map of The Study Area (A) and cross section along A-B line (B)... 17
Figure 3.2. Stratigraphic columnar section of the study area 18
Figure 3.3. A view of eastern slope of Belkıs Hill where four units are recognized 19
Figure 3.4. Field and microscopic views of clayey limestone................ 21
Figure 3.5. Field and microscopic views of thick bedded limestone 22
Figure 3.6 External (A, B) and internal (C) views of tombs carved within thick bedded limestone.. 24
Figure 3.7. Field and microscopic views of chalky limestone 25
Figure 3.8. An example of carved room supported against failure in the excavation site 26
Figure 3.9. Field and microscopic views of cherty limestone 27
Figure 3.10. General views of talus deposits formed by natural processes (A) and those that have a human impact (B) 29
Figure 3.11. Sketch cross sections showing two types of talus deposits identified in the field 30
Figure 3.12. A general view of the major fault showing the vertical throw measured using the bottom boundary of cherty limestone 31

Figure 3.13. Example of mesoscopic faults observed in the area............ 32
Figure 4.1. Topographic map of the area used for the change detection analysis for Firat River 33
Figure 4.2. Flowchart of aerial photo analysis 34
Figure 4.3. An example of aerial photo with ground control points selected for registration 36
Figure 4.4. An example of GCP data showing pixel locations, earth coordinates and residual errors for each GCP...................... 37
Figure 4.5. Map digitized from 1953 aerial photographs....................... 39
Figure 4.6. Map digitized from 1992 aerial photographs....................... 39
Figure 4.7. Transparent overlay of 1953 and 1992 digitized maps 41
Figure 4.8. Change map for all 14 “change” classes 44
Figure 4.9. Change map in which the “no change” classes are masked.. 44
Figure 5.1. Contour map of the area with selected spot elevations......... 48
Figure 5.2. Digital Elevation Model of the study area. 49
Figure 5.3 Color coded relief map of the area....................................... 51
Figure 5.4. Slope map of the area given in degrees................................ 52
Figure 5.5. Histogram of the slope values of slope map 53
Figure 5.6. Aspect map of the area.. 54
Figure 5.7 Histogram of the aspect values of aspect map 55
Figure 5.8. Profiles across Firat River flood plain from north to south .. 56
Figure 5.9. General view of meander between Halfeti and Gümüşgün .. 57
Figure 5.10. A view of the section of meanders between Birecik and Zeugma.. 58
Figure 5.11. Map of three elevation intervals and the boundary between Gaziantep and Fırat Formations............................. 60
Figure 5.12. Viewshed maps prepared for four points............................. 64
Figure 5.13. Map showing potential areas of water sources (>571) to provide water to Zeugma 66
Figure 5.14. Ancient and modern routes in the vicinity of Zeugma......... 67
Figure 5.15. Histograms of the slope values along the route of ancient road (A) and the modern road (B)... 68
Figure 5.16. Wrong calculation of a horizontal road (dashed) on a sloping surface indicated by topographic contours (solid)... 69

Figure 6.1. General view of ancient quarry 17 km north of Zeugma 70
Figure 6.2. A close up view of the quarry 71
Figure 6.3. A view of the quarry showing the Roman marks on the wall of excavated blocks 72
Figure 6.4. Microscopic Views of the Lower (A) and the Upper (B) Levels of the Quarry... 73

CHAPTER 1

INTRODUCTION

1.1. Purpose and Scope

Zeugma is a historical settlement which is considered among the four most important settlement areas under the reign of the kingdom of Commagene. The word itself means “bridge-passage” or “bridge of boats” which reflects the city’s importance in the antiquity.

Being one of the most attractive ancient settlements in Turkey, the inundation of the city by the Birecik Dam reservoir has taken a strong public attention. In 2000, the construction of Birecik Dam had finished and the city of Zeugma began to be inundated by the water of reservoir. In the last three years, the recent excavations are carried out in the non-flooded areas and expected to last hundred years or more due to the city’s archaeological potential.

A main goal of archaeology is to comprehend and evaluate past human behavior, however, it also aims to comprehend the processes that shape the final landscape and this is where the geology and archaeology act together. In the content of archaeological research, utilization of geological principles in the evaluation of archaeological problems forms the geoarchaeological aspect of the archaeological studies.

In the previous researches in Zeugma, geoarchaeological studies were not conducted in detail, however, in the modern archaeology; geoarchaeology is an indispensible method to attain substantial results. Therefore, this study aims to investigate the geological features of the region that shaped the archaeological landscape.

The purpose of this thesis is to investigate the geology and geomorphology of the city of Zeugma and its vicinity. These investigations include detailed mapping of the lithologies in the excavation site, the aerial photography survey on a broader area, study of the morphology of the landscape, particularly the flood plain of Fırat River, analysis of certain morphological features, and a reconnaissance survey in the ancient quarries.

1.2. Study area

Zeugma is located in the east of Nizip (Gaziantep) on the western bank of Fırat River (Figure 1.1). Two study areas are considered (as regional and local) considering the scope of this study.

The study area at regional scale covers four 1/25000 scale topographic maps, namely N39-c1, c2, c3 and c4. This area is bounded by Nizip (SW), Birecik (SE) and Halfeti (N). Fırat River is the most significant geomorphological element included in the study area. The river flows towards south to southeast and forms the boundary of Gaziantep and Urfa provinces in the vicinity of the area. This regional scale study area is discussed in three chapters: Chapters 2, 4 and 5 for regional geological setting, for change detection in Fırat River flood plain and for morphological analysis, respectively.

The local scale study area which is located in the close vicinity Zeugma included within the N39-c4 topographic map at 1/25.000 scale. Eastern part of the area is covered by the reservoir of Birecik Dam. In this area, a geological map is prepared that includes the distribution and stratigraphic positions of four distinct levels within Gaziantep Formation which is the dominant rock unit exposed within the area. This map and its details will be given in Chapter 3.

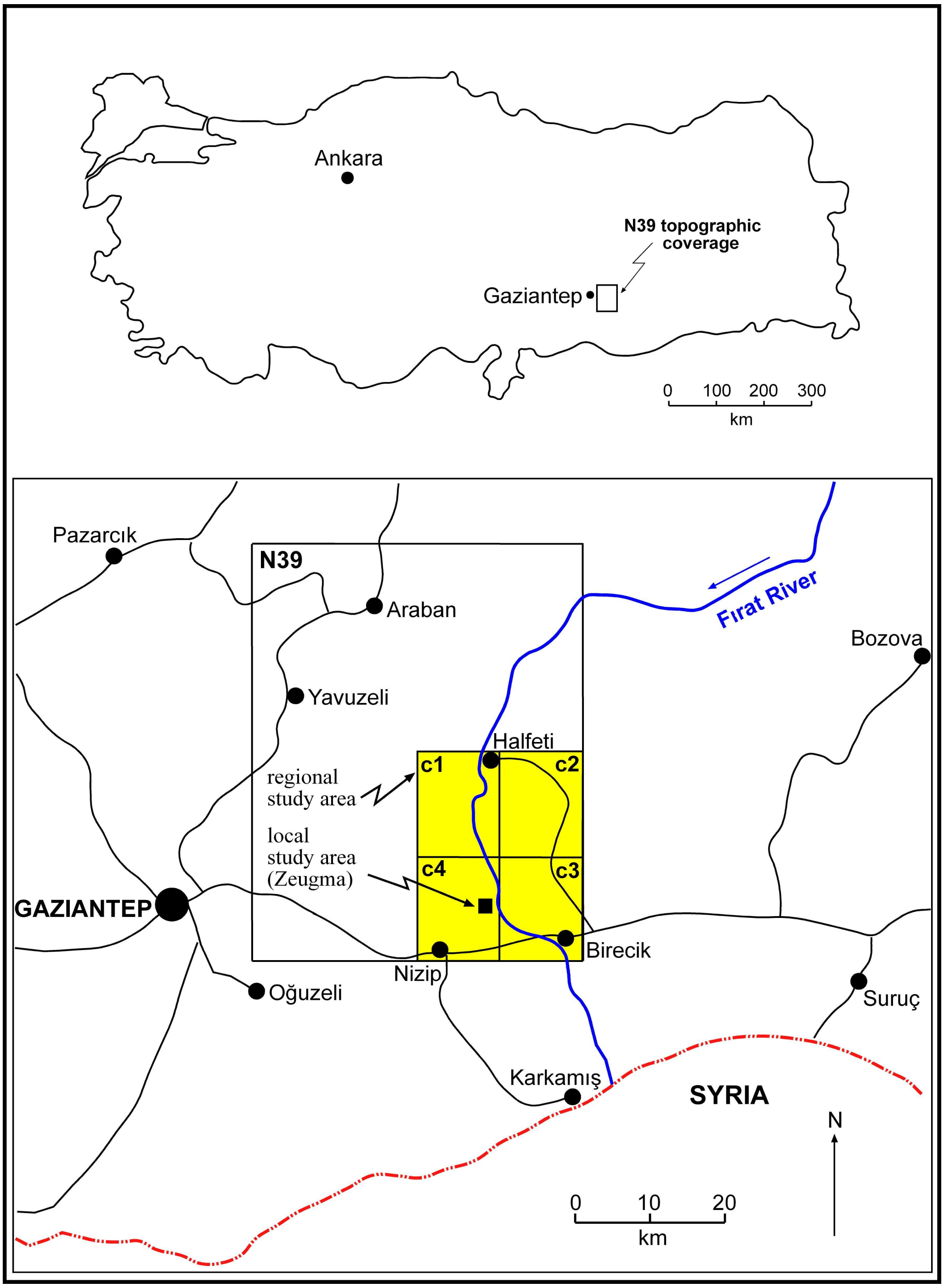


Figure 1.1. Location map of the study area. The large box indicated in yellow is regional study area where morphological analyses are carried out. The small black box corresponds to the local study area where geological map is prepared.

1.3. Zeugma

1.3.1. Historical Background

The earliest significant settlement is marked by the tells of the Bronze Age (Kennedy, 1998). After Syria fell to Alexander, in 300 c. B.C., the new Macedonian ruler of Syria, Seleucus I Nicador, founded twin towns; on the west bank of Fırat River he founded Seleucia; named for himself, and opposite it Apamea, named for his Iranian queen, Apama (Kennedy, 1998). In Figure 1.2., locations and extents of the twin towns of Zeugma are presented. At that time the population in the city was approximately 80 000 (Summak, 2008). In 64 B.C. Zeugma was conquered and ruled by Roman Empire and with this shift the name of the city was changed into Zeugma to mean “bridge-passage” (Summak, 2008).

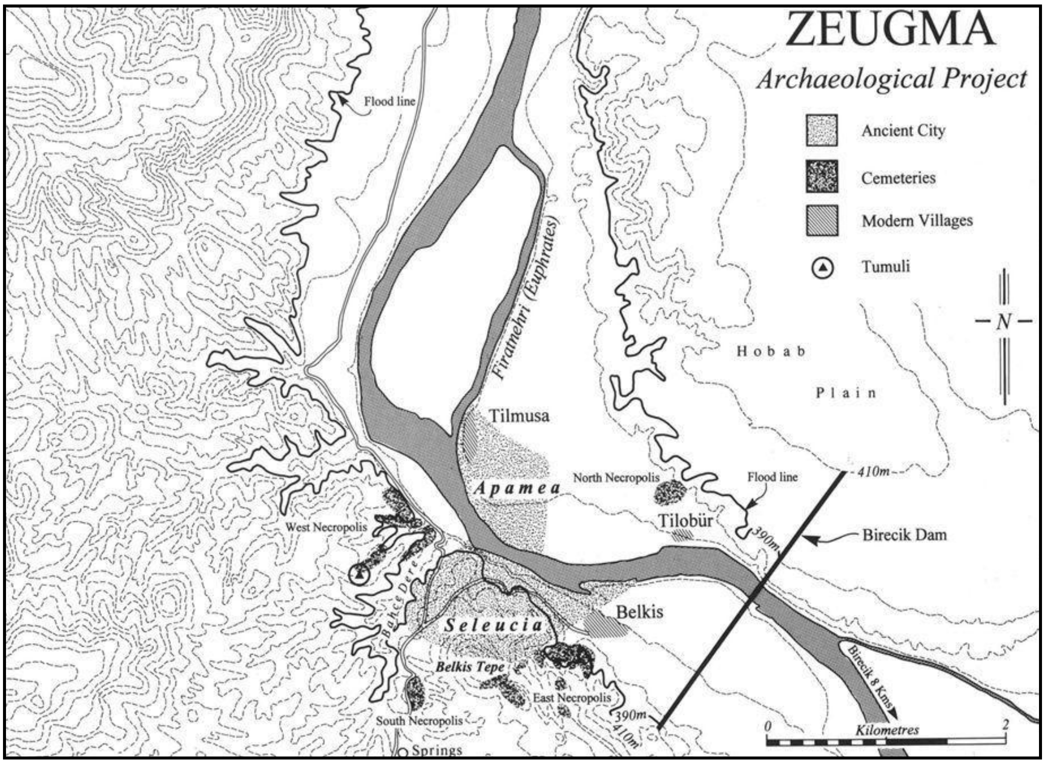


Figure 1.2. Location Map of Seleucia and Apamea (from Kennedy, 1998)

During the Roman rule, the city became one of the attractions in the region, due to its commercial potential originating from geostrategic location because; the Zeugma city was on the silk-road connecting Antiach to China with a quay on the river Euphrates. In 256 A.D. Zeugma experienced an invasion and it was fully destroyed by the Sassanian King, Sapur I. The city never gained the prosperity once achieved during the Roman rule. In 4th Century A.D. Zeugma settlement became a Late Roman territory. During the 5th and 6th Centuries the city was ruled over by the Early Byzantine domination. As a result of the ongoing Arab raids the city was abandoned once again. Later on, in the 10th and 12th centuries a small Abbassid residence settled in Zeugma. Finally a village called “Belkis” was founded in the 17th century (Summak, 2008).

During the Roman Era, troops called “Schythian Legion” consisting of Anatolian soldiers were positioned around Zeugma. For about two centuries the city was home to high ranking officials and officers of the Roman Empire. Zeugma became considerably rich, owing to the liveliness created by Legion formation. At that time, there was a wooden bridge connecting Zeugma to the city of Apamea on the other side of Euphrates, and current excavations revealed that there was a big customs and a considerable amount of border trade in the city (Summak, 2008).

1.3.2. Geoarchaeological Studies

In Zeugma, there has not been performed a detailed geoarchaeological study in the previous excavation periods. Kennedy and Bunbury (1998) studied geography of the Zeugma and its vicinity, Comfort et al. (2000) and Comfort and Ergeç (2001) studied the trend of ancient routes passing through Zeugma.

Kennedy and Bunbury (1998) describe the morphology of Fırat River and the valley. They observe that the settlements in the upstream were confined to a narrow zone within the valley. In their study, they briefly examine the morphology of the region which is bounded by Nizip River in the west, Birecik in the east using satellite images in their study.

Kennedy and Bunbury (1998) also make observations on the geological formations classifying them as marly limestone. They identified existence of talus on the slopes of Belkis Hill and referred to them as slope wash.

Kennedy and Kennedy (1998) suggest the source of building stones as the prominent limestone beds on the hilltops of northeast of Zeugma. Quarries and the ancient roads are identified, and they also interpret visually the statue pieces resembling the stone in the quarry.

The study of Comfort et al. (2000) aimed to identify the ancient routes in the east-west direction leading to Zeugma. They utilized satellite images in the identification of the archaeological features such as walls, piers of bridges etc. They stated that in the antiquity, Zeugma was an important crossing point over the Fırat River but not the only one in the middle course of Fırat River. Birecik in the south and Rumkale (north of Halfeti) in the north are the other crossing points across the river.

Comfort and Ergec (2001) discussed sites located in the vicinity of Zeugma on the east and west banks of Fırat River and searched for the ancient routes in the north-south direction. They utilized the information on ancient settlements, ancient routes that was gathered from satellite images. Accordingly, they prepared maps showing ancient routes that lead to Zeugma in east-west and north-south directions.

1.4. Method of Study

The methods used in this study are “field study” and “office work”. In the field study, the first step was conducting a reconnaissance survey in the field to decide the purpose and scope of this study. Two fieldworks in two successive years (from 2006 to 2007) are organized to the site to prepare geological map of the area and collect rock samples for petrographic studies.

The first step in the office work is the literature survey on the ancient city of Zeugma, the geoarchaeological studies, and archaeological GIS applications. Literature survey is followed by acquisition of data (1/100000 scaled geological map from MTA, 1/250000 scaled topographical maps of the study area and 4 sets of stereographic aerial photo from General Command of Mapping). TNTMips software (version 6.9) is used in the registration of aerial photographs, digitization of geological map and aerial photographs, conducting change detection analysis, performing GIS analysis and production of output maps. Microsoft Excel 2003 is used in the organization of data, preparation of diagrams and histograms. Macromedia Freehand 8.0 and AutoCAD 2007 are used in the preparation of some figures and maps.

CHAPTER 2

REGIONAL GEOLOGY

Regional geological map and the description of rock units are compiled from literature. Geological map includes for sheets at 1:25.000 scale (N39-c1, c2, c3 and c4). This map redrawn from Ulu (1996) is illustrated in Figure 2.1. Five rock units are exposed in the region which are, from bottom to top, Gaziantep Formation, Fırat Formation, Yavuzeli Basalt, old alluvium, and alluvium (Figure 2.2). All unit names are adopted from the literature, considered as formal names and therefore are capitalized. These units are briefly explained below.

2.1. Gaziantep Formation

The name is first given by Wilson and Krummenacher (1957) due to its type section in the vicinity of the Gaziantep. It is represented by dominantly limestone of Middle Eocene-Middle Oligocene age (Ulu et al. 1991). The base of the formation is not exposed in the area. It covers Hoya Formation of Middle Eocene age conformably out of the study area. Fırat Formation of Middle Oligocene-Early Miocene age (Figure 2.3-A) conformably overlies the Gaziantep Formation. The formation covers large areas in the central and southern parts of the area.

Gaziantep Formation in general is composed of limestone. The lower parts of the formation include white to beige, soft to hard, thin to medium bedded, chalky, silty limestone with chert nodules. The upper levels are formed of white to beige, thin to thick bedded, partly massive algal limestones and thin to medium bedded chalky limestones with marl intercalations. The formation transitionally passes to Fırat Formation at the uppermost level to clayey, cherty limestone. Total thickness of the formation is suggested to vary between 200 and 600 m (Ulu et al. 1991).

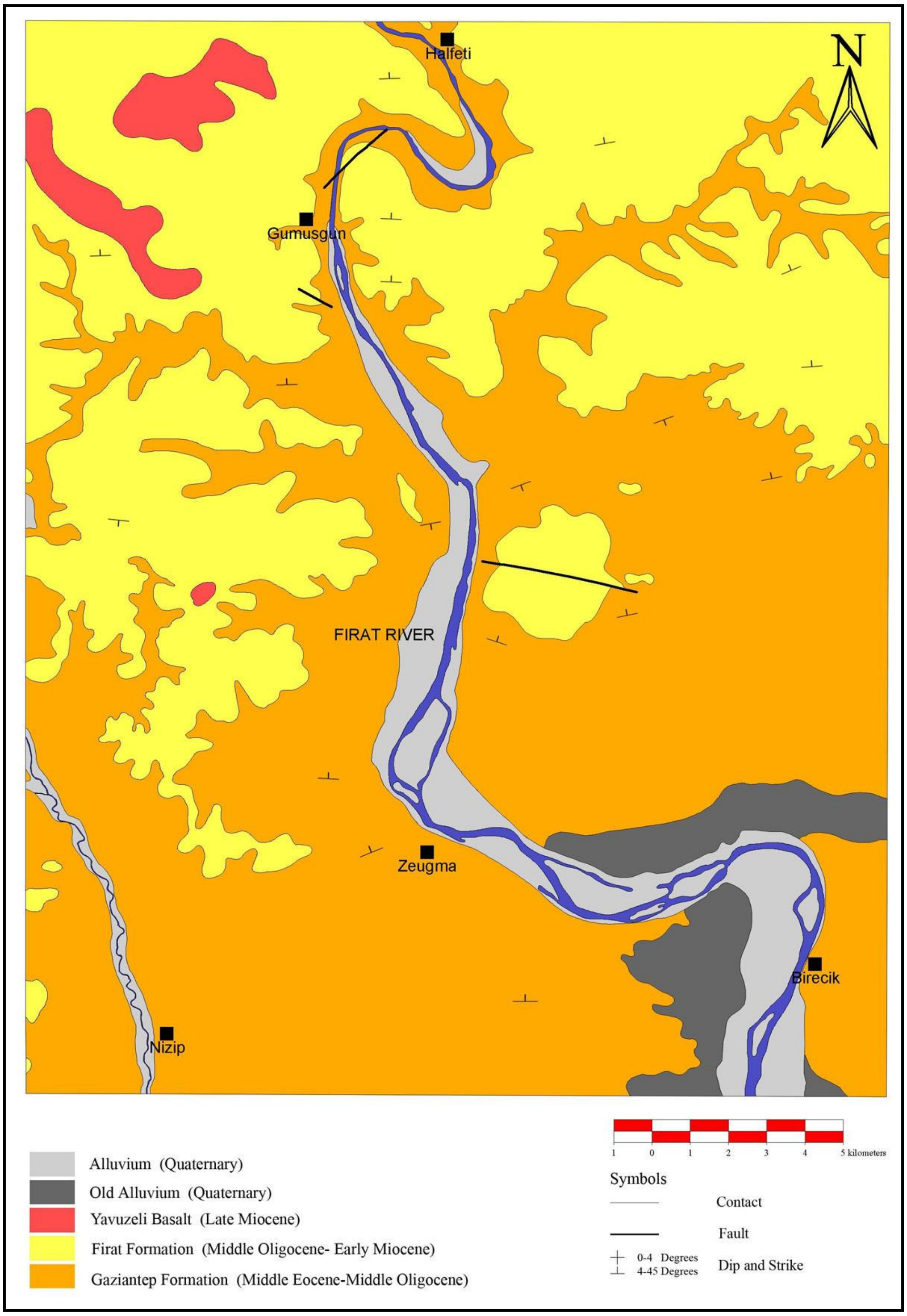


Figure 2.1. Regional geological map of the area (from Ulu, 1996).

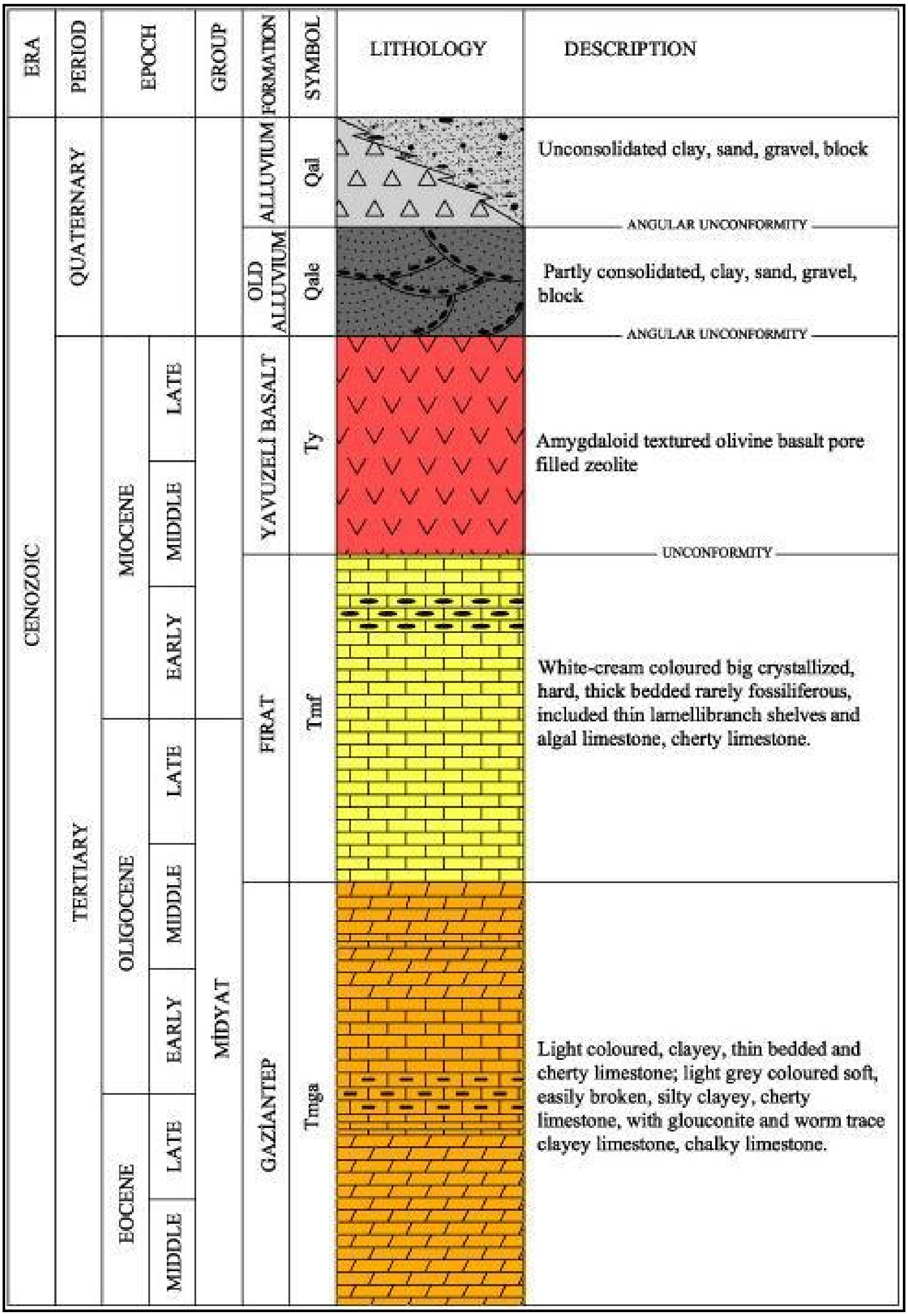


Figure 2.2. Generalized stratigraphic section of the area (simplified from Ulu, 1996).

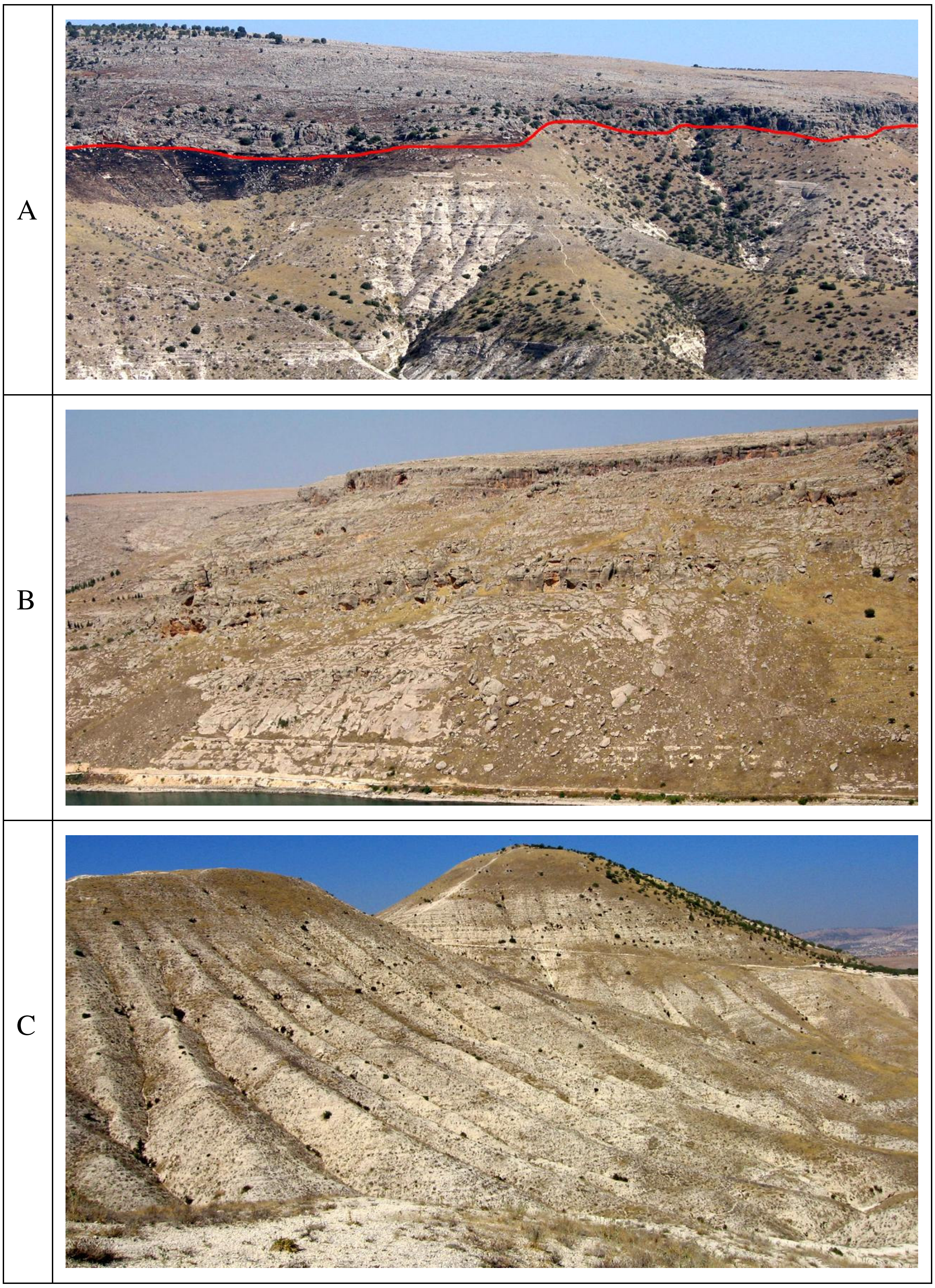


Figure 2.3. A. Boundary (red) between Fırat (upper) and Gaziantep (lower) formations
B. General view of Fırat Formation (5 km S of Halfeti)
C. General view of Gaziantep Formation (Close vicinity of Zeugma)

Following fossils are identified within the Gaziantep Formation (Ulu et al., 1991 and Ulu, 1996), from bottom to top: *Nummulites aturicus* Joly and Leymerie, *Nummulites beaumonti* d'Archiac and Haime, *Nummulites praefabiani* Varentsof and Manner, *Nummulites millecaput* Boube'e, *Linderina brugesii* Schlumberger, *Sphaerogypsina globules* Reus, *Orbitolites complanatus* Lamarck, *Eorupertia magna* Le Calvez, *Alveoloina* sp., *Lockhartia* sp., *Lithothamnium* sp., *Discocyclina* cf. *sella* d'Archiac, *Nummulites* cf. *fabianii* (Prever), *Halkyardia minima* Liebus, *Chapmanina gassinensis*, *Nummulites fichteli* Michelotti, *Nummulites vascus* Joly and Leymerie, *Lepidocyclina dilatata* Michelotti, *Amphistegina* sp. and *Gypsina* sp. Some fossils such as *Globigerina* sp., *Alveolina* sp. and *Operculina* sp. are observed at different levels of the formation. Accordingly an age of Late Lutetian to Stampien (Middle Eocene to Middle Oligocene) is assigned to the Gaziantep Formation. The depositional environment of Gaziantep Formation is suggested as outer shelf and hemi-pelagic environment.

2.2. Fırat Formation

This formation is first named as "Karadağ Formation" by Wilson and Krummenacher (1957) based on the outcrops around Karadağ, and "Pirin Formation" by Krausert (1958 in Ulu et al., 1991) around Midyat. Later, however, Ulu et al. (1991) claimed that the type section is best exposed along the course of Fırat River north of Birecik and suggested the name of "Fırat Formation" for this unit. The unit is represented dominantly by limestone of Middle Oligocene to Early Miocene age.

Fırat Formation conformably overlies Gaziantep Formation (Figure 2.1, 2.2., 2.3-A). Upper boundary of the unit, on the other hand, is unconformable with Fırat Formation. Within the area it is overlain by Yavuzeli Basalt of Late Miocene age. Out of the area, however, it is overlain by Çatalaltı Basalt of Middle Miocene (Ulu et al., 1991). The formation is exposed in the northern and central parts of the area as continuous outcrops at higher elevations.

Fırat Formation is composed of cream to beige, hard, brittle, thin to very thick bedded fossiliferous limestone. The total thickness of the formation is about 600 m. (Ulu et al., 1991). In general, the unit is thin bedded in the lower and upper levels and thick bedded in the middle levels. Towards the top, the dominant lithology becomes cherty limestone (Ulu et al., 1991).

Following fossils are identified within the formation by Ulu et al. (1991) and Ulu (1996), from bottom to top: *Lepidocyclina* sp., *Austrotrillina* sp., *Archaias* sp., *Operculina* sp., *Amphistegina* sp., *Globigerina* sp., *Globorotalia* sp., *Pararotalia* sp., *Heterostegina* sp., *Miogypsinoides* cf. *complanatus* Schlumberger. Based on this fossil assemblage an age of Middle Oligocene-Early Miocene is assigned to Fırat Formation. The unit was deposited in the shallowest part of the carbonate platform.

2.3. Yavuzeli Basalt

This unit is first named by Yoldemir (1987) based on its type locality around Yavuzeli district of Gaziantep. The unit is represented by basaltic rocks of Late Miocene age. Both upper and lower boundaries of Yavuzeli Basalt are unconformable. Within the study area it overlies Fırat Formation (Middle Oligocene-Early Miocene) whereas out of the area it overlies volcanic conglomerates (Şelmo Formation) of Middle-Late Miocene. It is overlain by old alluvium of Quaternary age although there is not a direct contact between these two units.

Yavuzeli Basalt is exposed in the area as three outcrops as caps at the tops of the hills (Figure 2.1, 2.4). Two larger outcrops are observed in the NW part of the area whereas the other smaller one is located in the central west of the area. It covers approximately 12 km^2 in the regional study area. The lithology of the Yavuzeli Basalt is described as dark gray olivine-augite basalt with zeolite or calcite filled pores. The matrix is composed of microliths of andesine and labrodorite.

Total thickness of the formation is about 250 m out of study area (Ulu et al., 1991). The age of the basalt is identified as 10.6 ± 0.2 Ma based on K/Ar age determination. Therefore, the age of the unit is Late Miocene. The formation of the basalts is attributed to the collision between Arabian and Anatolian plates (Ulu et al., 1991).

Figure 2.4. A view of Yavuzeli basalt (5 km west of Gümüşgün village, facing north)

2.4. Old Alluvium

Old alluvium (Ulu et al., 1991) is exposed around Birecik (SE part of the area) as two outcrops on both sides of Euphrates (Figure 2.1). The unit is represented by semi-consolidated fluvial clastics composed of alternation of siltstone, sandstone and conglomerate. The outcrop pattern suggests that these units might be deposited along the abandoned old channels of Fırat River or by old alluvial fans (Figure 2.5). Although there is not any evidence on the age of the unit, an age of Quaternary is suggested by Ulu et al. (1991)

2.5. Alluvium

Alluvium is represented by recent deposits forming along the actual channels of the Fırat River and its tributaries (Figure 2.1). It is composed of unconsolidated clay, silt, sand, gravel. The flood plain where this unit is deposited is buried today under the reservoir of the Birecik Dam (Figure 2.6).

Figure 2.5. A general view of old alluvium (5 km NW of Birecik, facing east)

Figure 2.6. A view of the Birecik Dam reservoir under which Fırat River flood plain is buried (from Belkis Hill towards southeast).

CHAPTER 3

GEOLOGY OF THE STUDY AREA

In this chapter, the geology of the area in the vicinity of Zeugma is investigated. The aim of this local geological investigation is to examine the geology of the study area in detail, classify and correlate geological units within the excavation site. The chapter is divided into two sections. The first section describes stratigraphy of the area and the second section deals with the geological structures of the area with a main emphasis given to the fault identified within the area.

3.1. Stratigraphy

The boundary of the mapped area includes close vicinity of Zeugma and covers an area of approximately 2 by 2 km. The geological map and a cross section are shown in Figure 3.1. Stratigraphic columnar section of the units exposed in this area is given in Figure 3.2.

Rock units exposed in the study area belong to a certain section of Gaziantep Formation. Based on the field evidences such as grain size, thickness, impurities etc, four lithologies are recognized in the area with the limestone being the common and the dominant one. Although all units are mapped separately, they are not recognized as members in the Gaziantep Formation since the whole formation could not be investigated. For this reason, the units are named informally on the lithological basis as, from bottom to top, clayey limestone, thick bedded limestone, chalky limestone and cherty limestone (Figures 3.1, 3.2). A talus deposit which is not mappable and, therefore, is not shown in the map, covers these four units.

Stratigraphic section is best exposed on the eastern slope of Belkis Hill which is located to the western margin of Zeugma. Description of these units is made below based on the field data observed along the slopes of Belkis Hill and petrographic determinations. Figure 3.3 shows a general field view of these units and their boundaries at Belkis Hill.

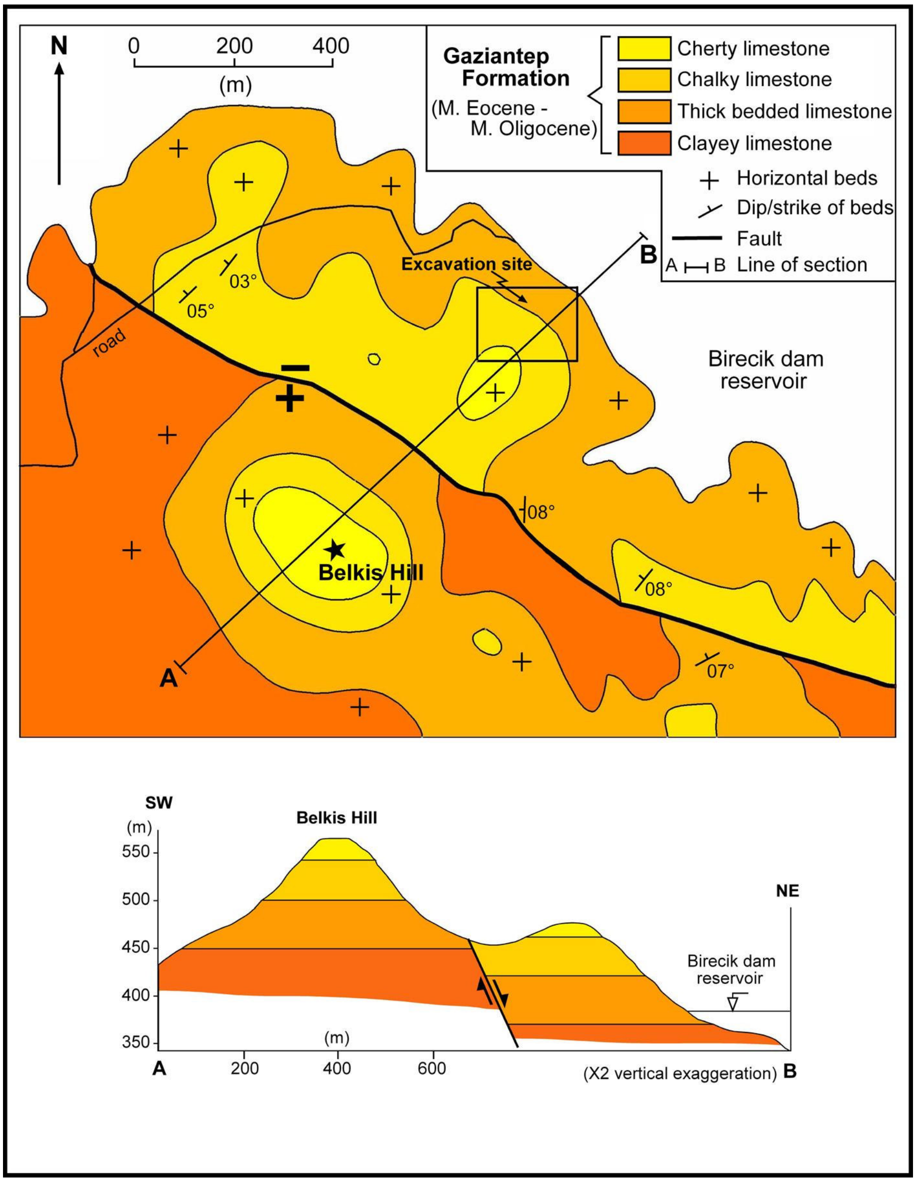


Figure 3.1. Geological map of the study area (A) and cross section along A-B line (B)

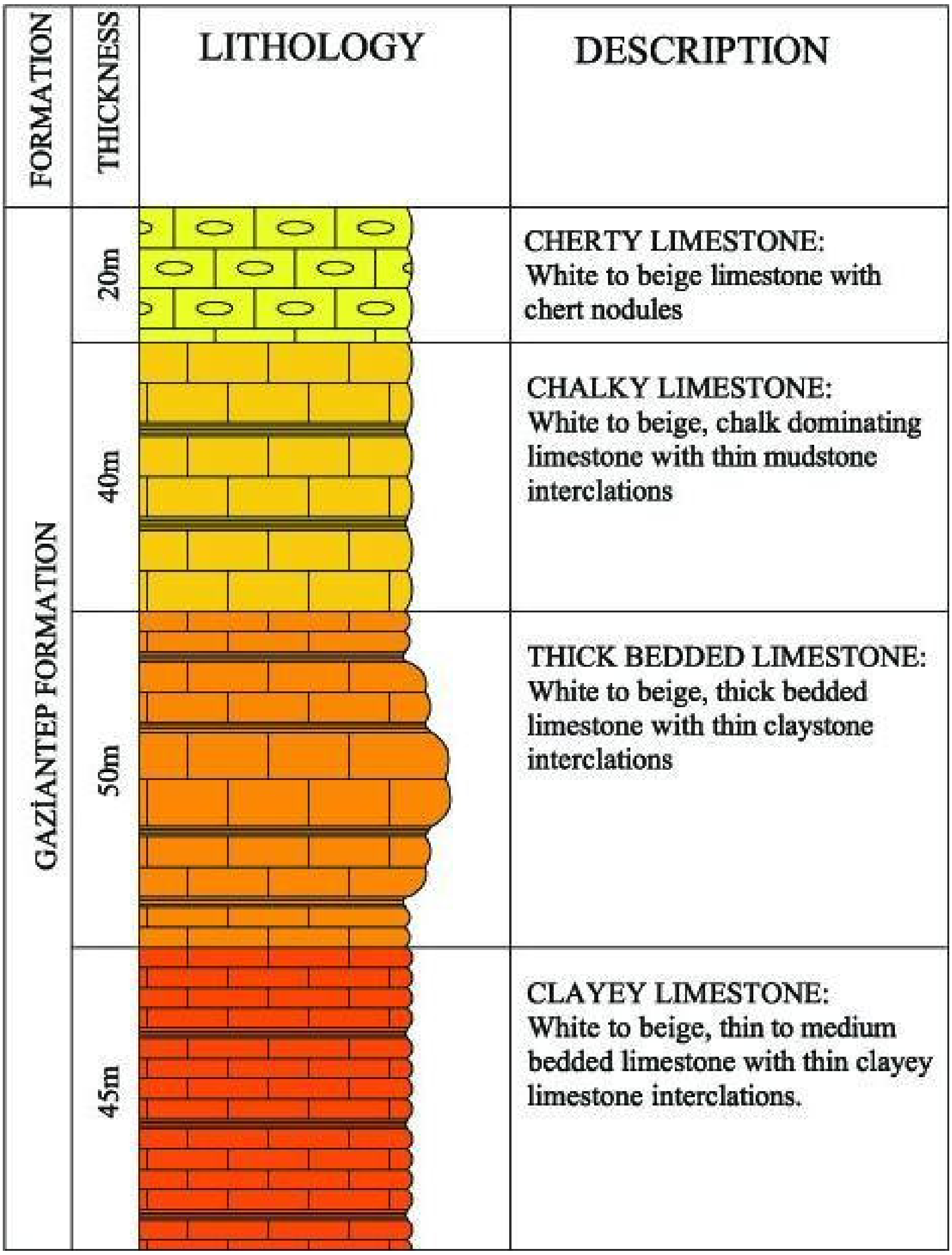


Figure 3.2. Stratigraphic columnar section of the study area.

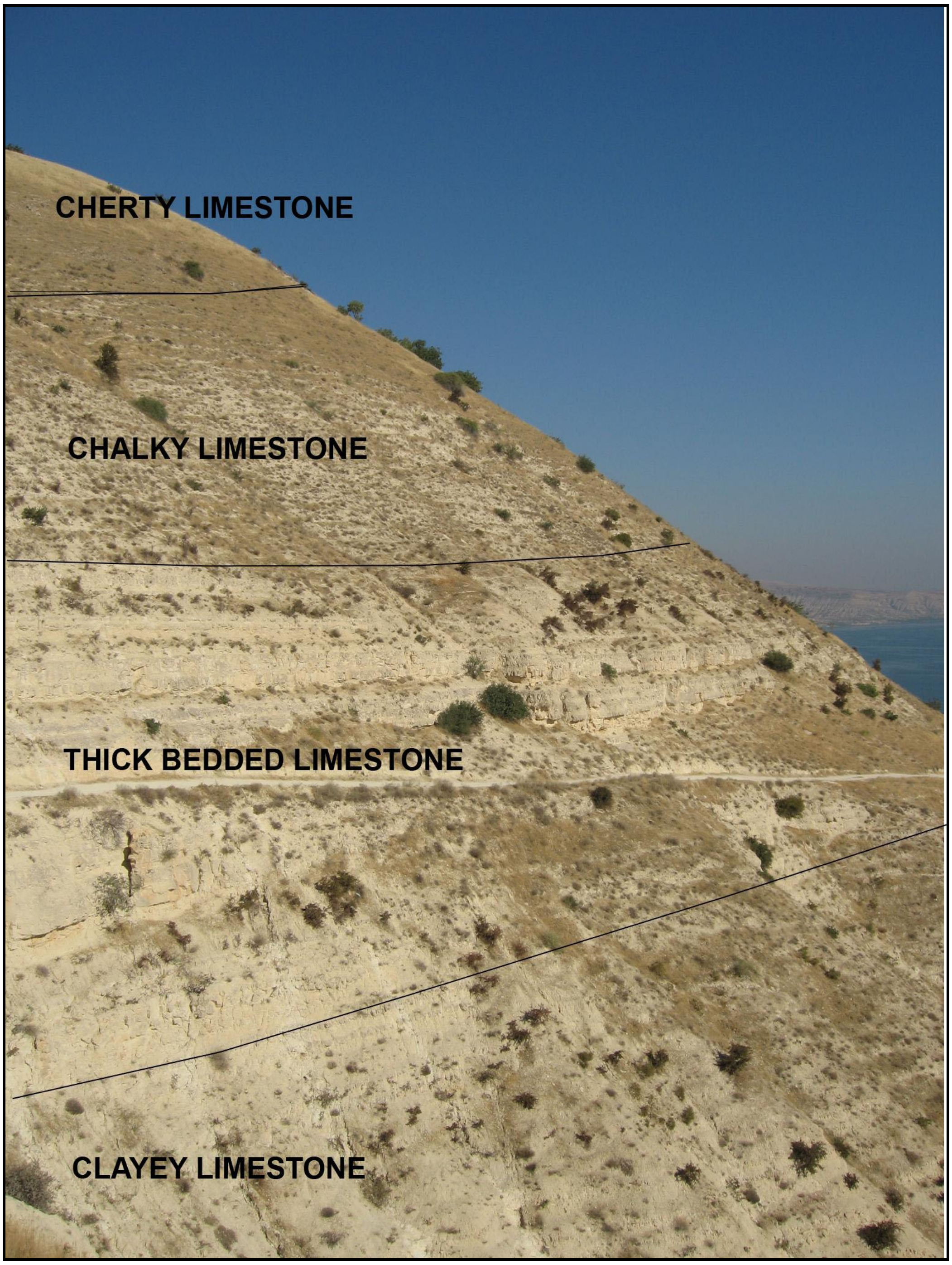


Figure 3.3. A view of eastern slope of Belkis Hill where four units are recognized.

Clayey limestone

This is the oldest unit recognized in the section (Figure 3.4). The base of this unit is not exposed in the area. However, out of the area it is observed to overlay conformably other units of Gaziantep Formation.

Clayey limestone is observed at the lower elevation of Belkis Hill and mostly confined to the west of the major fault. To the east of the fault which is the downthrown block, the unit is not exposed because it is buried under the reservoir of the Birecik Dam (Figure 3.1).

The unit is composed of an alternation of thin to medium bedded clayey limestone beds. The thickness of each cycle is about 4 to 5 m. Minimum observable thickness of the unit is estimated as 45 m. Microscopic determinations of the unit are made in the thin section laboratory of the Geological Engineering Department (METU). Accordingly, the rocks can be classified as pelagic wackestone to mudstone with large foraminiferas.

Thick bedded limestone

Thick bedded limestone is conformable with underlying and overlying units. It is exposed as two outcrops in the area separated by the major fault (Figure 3.1). The first outcrop is to the east of the fault where the lower part of the unit is buried under the Birecik Dam reservoir. The second outcrop is located to the west of the fault at middle altitudes of Belkis Hill.

The unit is composed of thick bedded limestone layers intercalated with thin siltstone and claystone layers (Figure 3.5). Total thickness of this unit is about 50 m. Seven distinct thick layers can be recognized within the unit. The thickest layer, with more than 5 m thickness, is located at the middle part of the unit. The thickness gradually decreases towards both lower and upper sections of the unit to 1-1.5 m. The microscopic analysis reveals that the unit contains planktonic foraminifera and is relatively micritic and consolidated with no porosity resulting in thicker limestone layers.

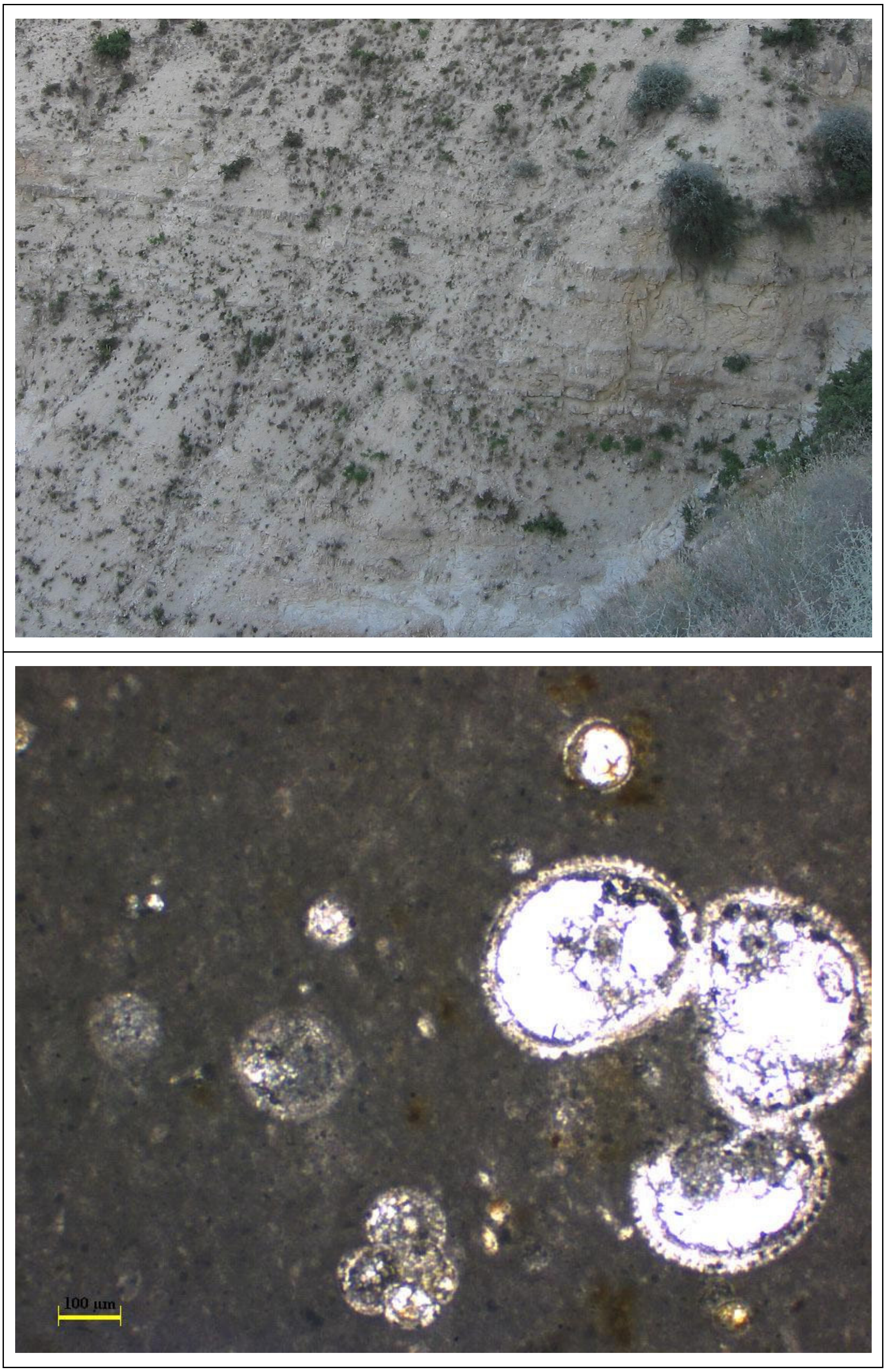


Figure 3.4. Field and microscopic views of clayey limestone

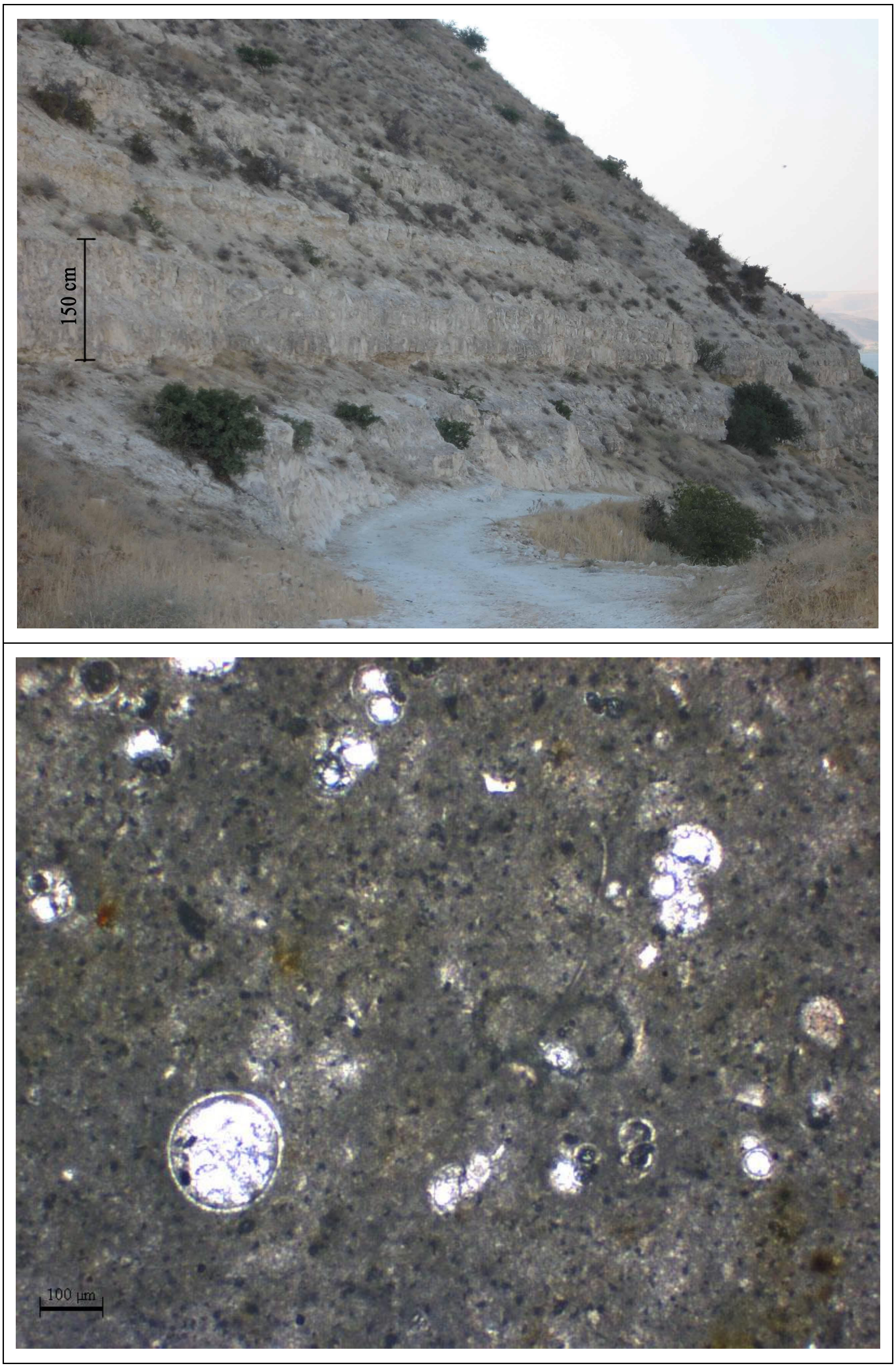


Figure 3.5. Field and microscopic views of thick bedded limestone

An important feature of this unit is that, the tombs of Zeugma are carved within this unit. These tombs are commonly observed at the SE slope of Belkis Hill, in the eastern part of the area and out of the area further west of Belkis Hill (Figure 3.6). Joints are common characteristics of these tombs as seen in Figure 3.6-C. In the earlier stages of this study, a joint survey was planned in these tombs to investigate the effect(s) of the fractures on the carving these tombs. This plan failed, however, due to accessibility problems to most of the tombs. The fractures only in a few tombs could be measured which is not enough to evaluate for statistical purposes.

Chalky limestone

The third unit from the bottom is the chalky limestone. The unit is exposed as three outcrops, towards the top of Belkis Hill, in the central parts of the area around the excavation site, and in the SE corner of the area (Figure 3.1). The last two outcrops are truncated by the major fault along their western margins.

The unit is composed of alternation of limestones and mudstones (Figure 3.7). Limestone layers have an average thickness of 30-35 cm. These layers are characterized by considerable amount of chalk content. The thickness of individual mudstone layers is about 10-15 cm. Total thickness of the unit is approximately 40 m. According to microscopic analysis the rock can be defined as pelagic, pelloidal wackestone with abundant planktonic foraminifera (Figure 3.7).

Current excavation site of Zeugma is located within this unit. As the carved spaces are exposed to the surface they tend o collapse or disintegrate which is one of the major problems faced during the excavation. Intensity of the expansion increases as the clay content increases. An example of such problematic spaces is shown in Figure 3.8. There are two main reasons for this problem. The first reason is that the limestone layers are fractured by closely spaced joints and the mudstone layers are sheared, and therefore, weakened during the later tectonic movements. The second reason is the lithological nature (clay content) of the rocks in this unit that expands as exposed to the atmosphere.

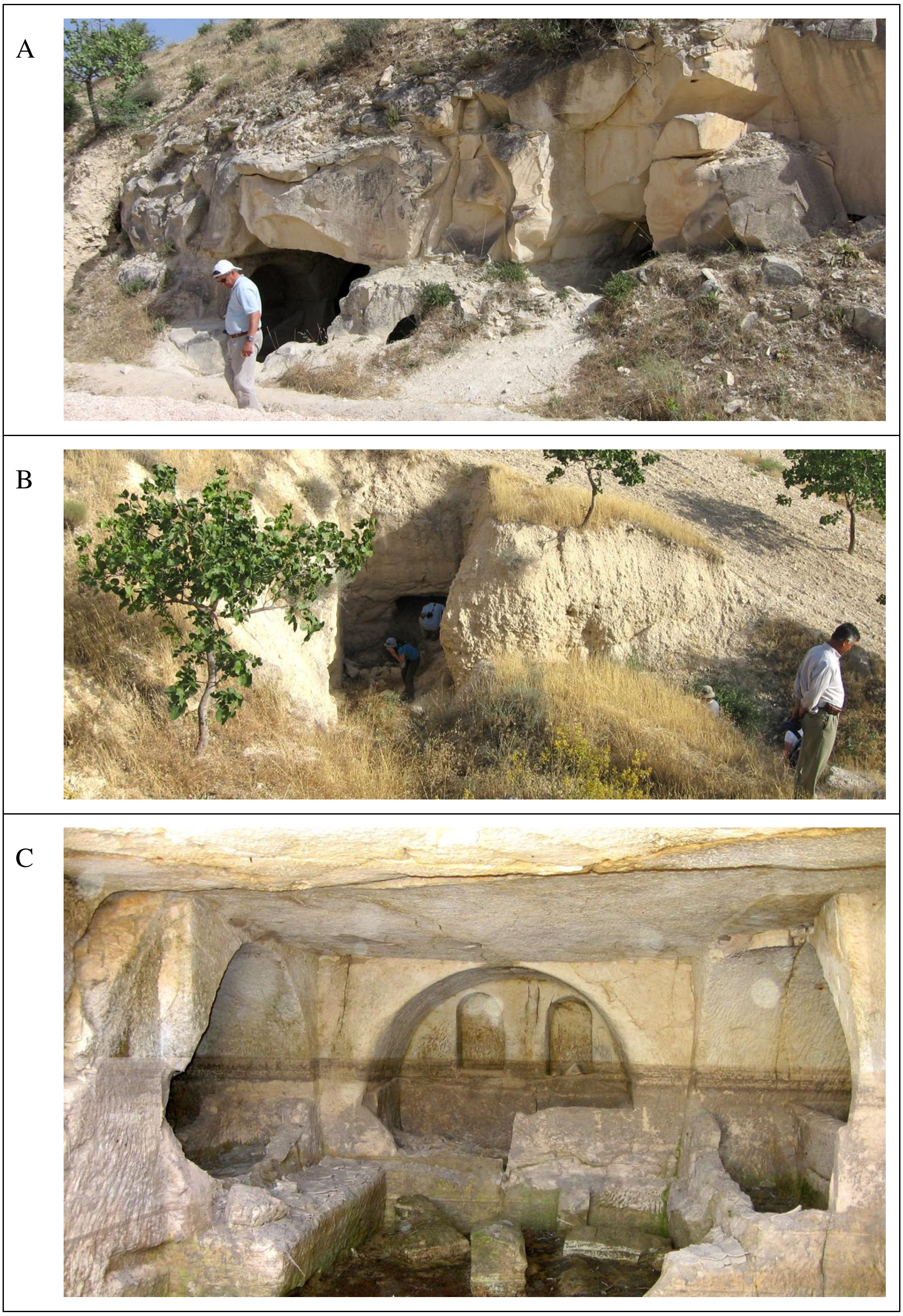


Figure 3.6. External (A, B) and internal (C) views of tombs carved within thick bedded limestone . A and C are from 500 m west of Belkis Hill, B from southern slope of Belkis Hill

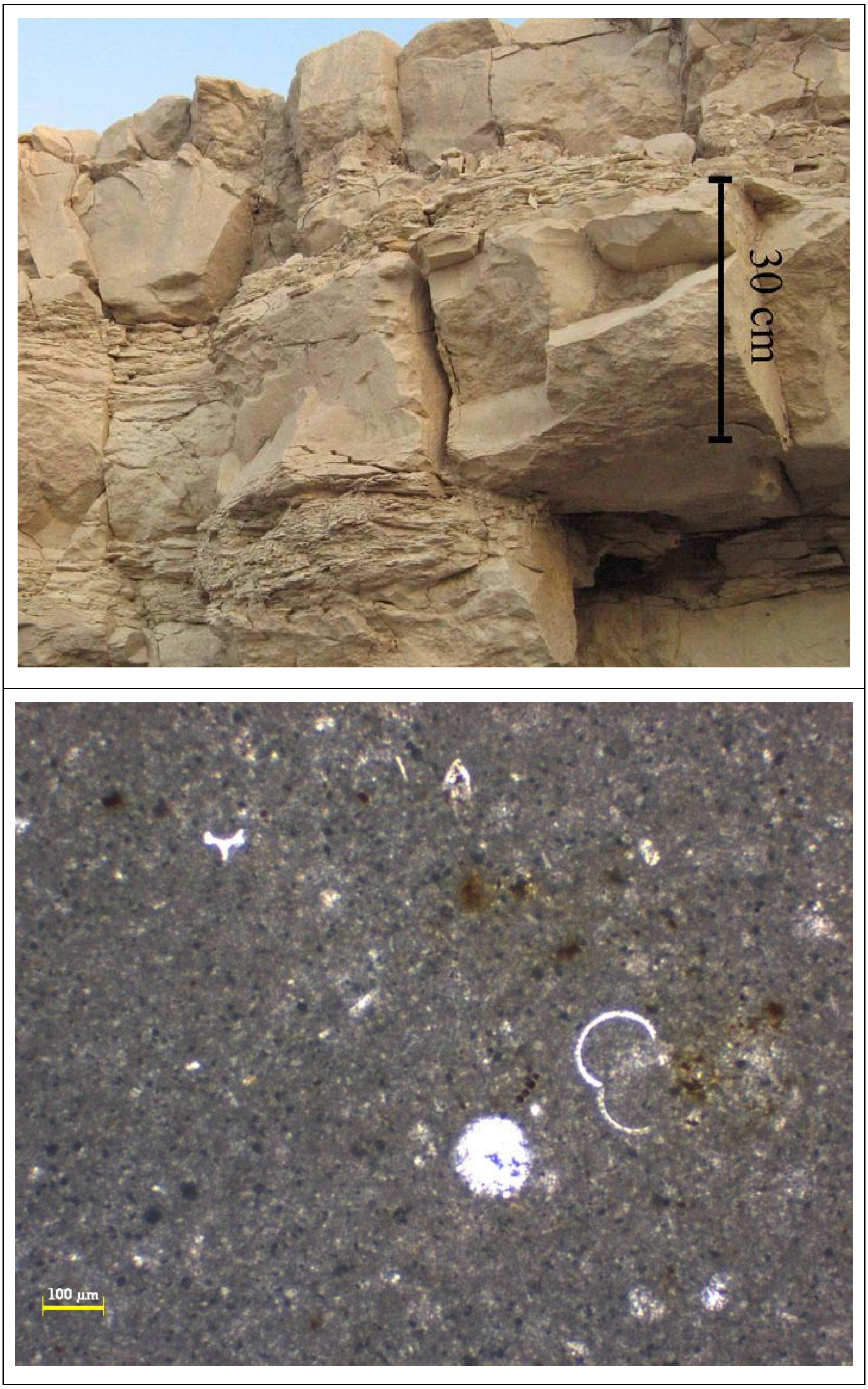


Figure 3.7. Field and microscopic views of chalky limestone

Figure 3.8. An example of carved room supported against failure in the excavation site.

Cherty limestone:

The youngest unit of the Gaziantep Formation exposed in the area is cherty limestone. This unit is exposed as three circular outcrops at the top of hills, the largest one being over Belkis Hill (Figure 3.1). The unit is distinct from other units by the presence of abundant chert nodules (Figure 3.9). Dimensions of these nodules range from 10 to 30 cm.

Limestone layers are thick to massive. Total thickness of the unit is about 20 m. Replacement of calcite by silica is commonly observed under the microscope (Figure 3.9). According to microscopic analysis this unit can be also classified as pelagic, pelloidal packstone.

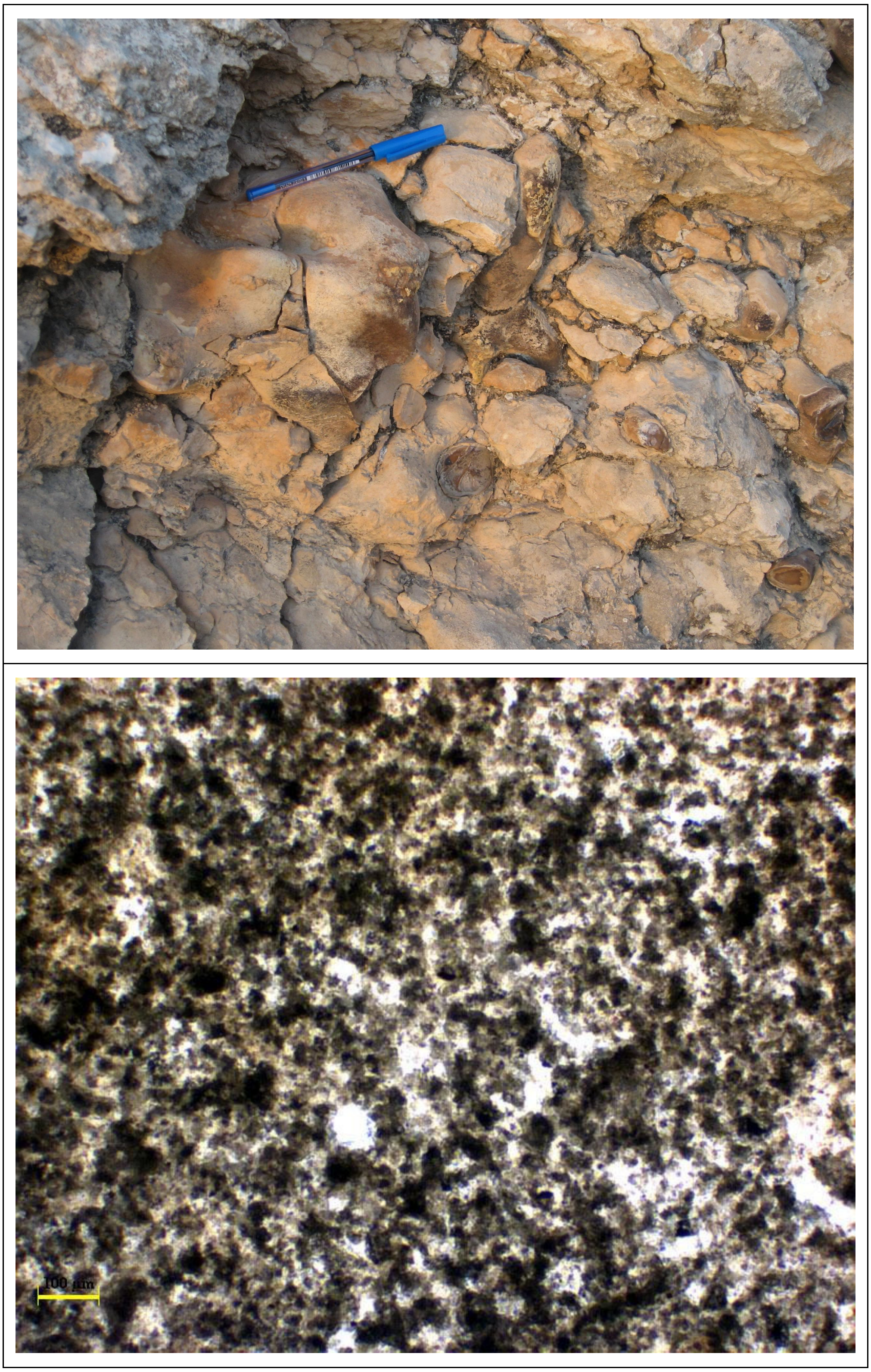


Figure 3.9. Field and microscopic views of cherty limestone

Talus deposits

Talus deposits are not shown in the geological map and the columnar section of the area because they form a thin layer at the surface and cannot be mapped at that scale. They are, however, important in terms of excavation and their understanding might contribute to the design of the excavation. Therefore, these talus deposits will be explained here briefly.

Two types of talus deposits are recognized in the study area. The first type is formed by natural processes through the erosion, transportation and deposition of material from high to low elevations (Figure 3.10-A). Bedding and initial dips are visible in some deposits. The deposits are composed of angular fragments ranging in size from a few mm to a few tens of cm. They are observed commonly in the northern and southern slopes of Belkis Hill.

The second type talus deposits are exposed within the excavation site and bury archaeological structures (Figure 3.10-B). The pattern and internal structure of these deposits are more complicated because there might be a human impact on the formation of this type talus deposits.

Two hypothetical cross-sections are drawn to show the differences in these two types of talus deposits (Figure 3.11). The first section (A) shows the development of talus deposit on a natural surface. In general the slope has a wedge shape with a minimum thickness at higher elevation that gradually increases towards the bottom of the slope.

In the second section (B), however, the talus is deposited on a surface where the landscape is shaped artificially. Therefore the thickness of the talus deposits can change from place to place.

A

B

Figure 3.10. General views of talus deposits formed by natural processes (A) and those that have a human impact (B). The upper figure is from 800 m north of Belkis Hill, the lower one is from excavation site.

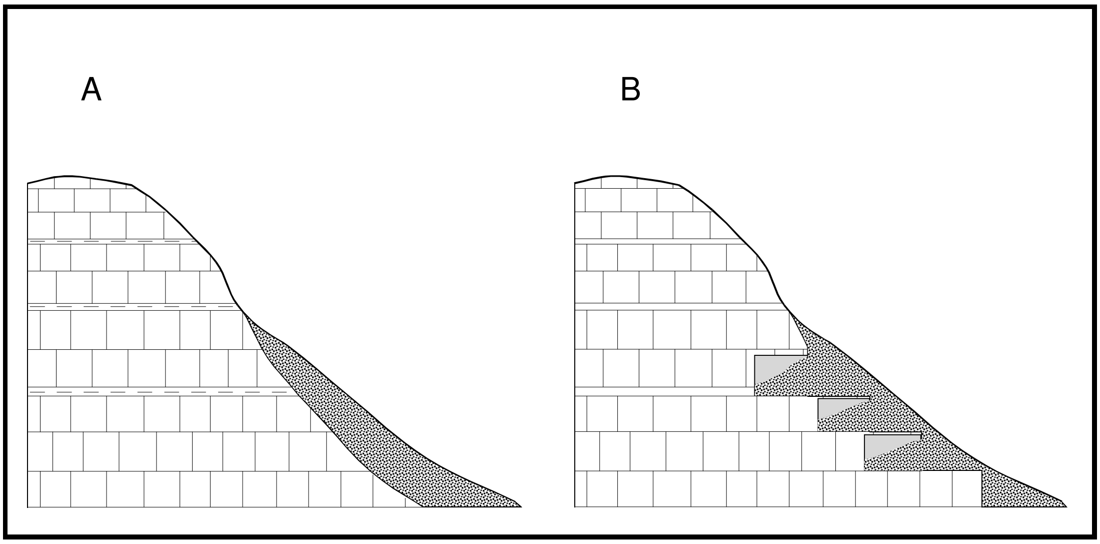


Figure 3.11. Sketch cross sections showing two types of talus deposits identified in the field.

3.2. Structural geology

Two structural elements existing in the study area are faults and joints. Observations made about these structures are explained below.

Faults

A major fault is identified in the area (Figure 3.1) that strikes in NW-SE direction passing through eastern slope of Belkis Hill. Total length of the fault is about 1700 m and extends further out of the area towards southeast.

Eastern block of the fault is downthrown as indicated by the younger adjacent units in eastern block. Position of cherty limestone which is exposed at the tops of the hills on both sides is the best indication of that movement. Amount of vertical throw is determined using the bottom elevations of cherty limestone on both sides (Figure 3.12). Accordingly the amount is measured as approximately 80 m. The fault plane makes a "V" at the stream located to the east of Belkis Hill indicating the dip direction towards the east. Therefore, type of the fault is normal.

There is not, however, any information on the lateral component of the fault. No slip data could be measured on the fault plane.

Several other small (mesoscopic) faults are observed in the area that has similar characteristics of the major fault. They are normal faults with eastern downthrown blocks. An example of such faults is illustrated in Figure 3.13. These faults strike almost parallel to the major fault and dip in the same direction. Therefore, these small faults can be considered as synthetic faults.

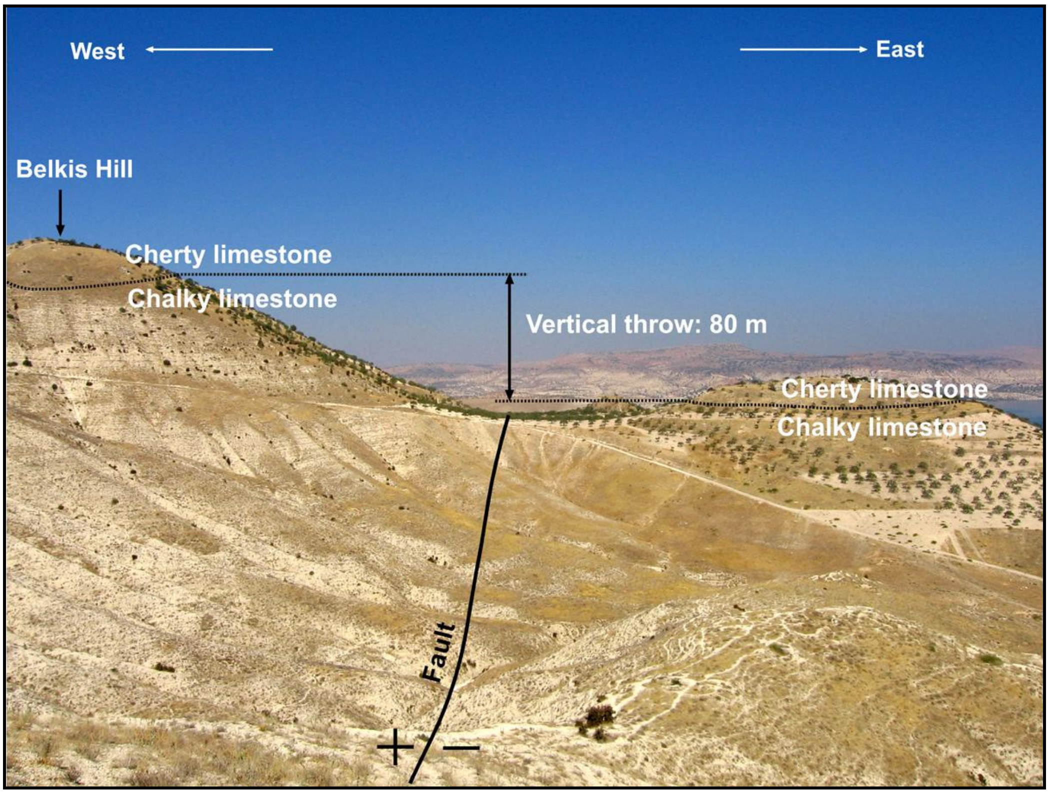


Figure.3.12. A general view of the major fault showing the vertical throw measured using the bottom boundary of cherty limestone (view to NW)

Figure 3.13. Example of mesoscopic faults observed in the area (1200 m east of Belkis Hill, view to NW)

Joints

Joints are extensively developed within the units exposed in the area. Most of the joints are confined to the layers and do not cut across (Figures 3.7-A, 3.8). Therefore, these joints do not have a tectonic origin but rather formed due to the release of overburden pressure. In the vicinity of the faults, however, closely spaced tectonic joints are also locally observed. Presence of joints in the excavation site (within clayey limestone unit) is sometimes the main reason for the collapse of the roof. A joint survey is not conducted in the area because there is no chance to compare the joints exposed in the area with the joints that exist in ancient site due to limited number of accessible excavated spaces.

CHAPTER 4

AERIAL PHOTO ANALYSIS

In this chapter the morphological behavior of the Fırat River in the vicinity of Zeugma is investigated for the period 1953 to 1992. The purpose of this analysis is to detect the change in this period that might imply for the changes during ancient times. Area of investigation is the flood plain of Fırat River between Zeugma and Birecik. This is the area where the river makes two meanders and the flood plain has a maximum width (Figure 4.1). Flood plain characteristics for the rest of Fırat River will be discussed in the next chapter.

The flowchart of the change detection analysis is shown in Figure 4.2. The procedure is composed of five steps which are explained below in detail.

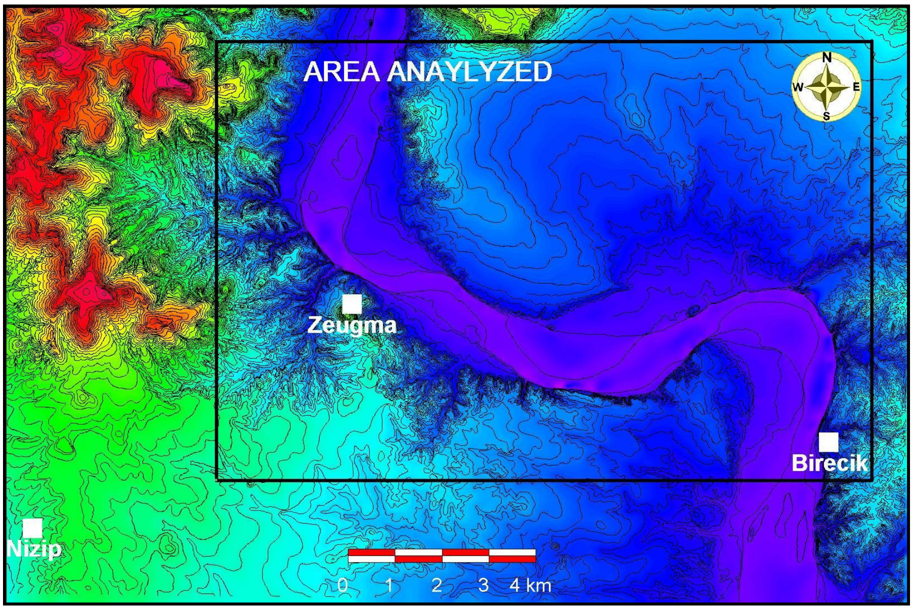


Figure 4.1. Topographic map of the area used in the change detection analysis of Fırat River.

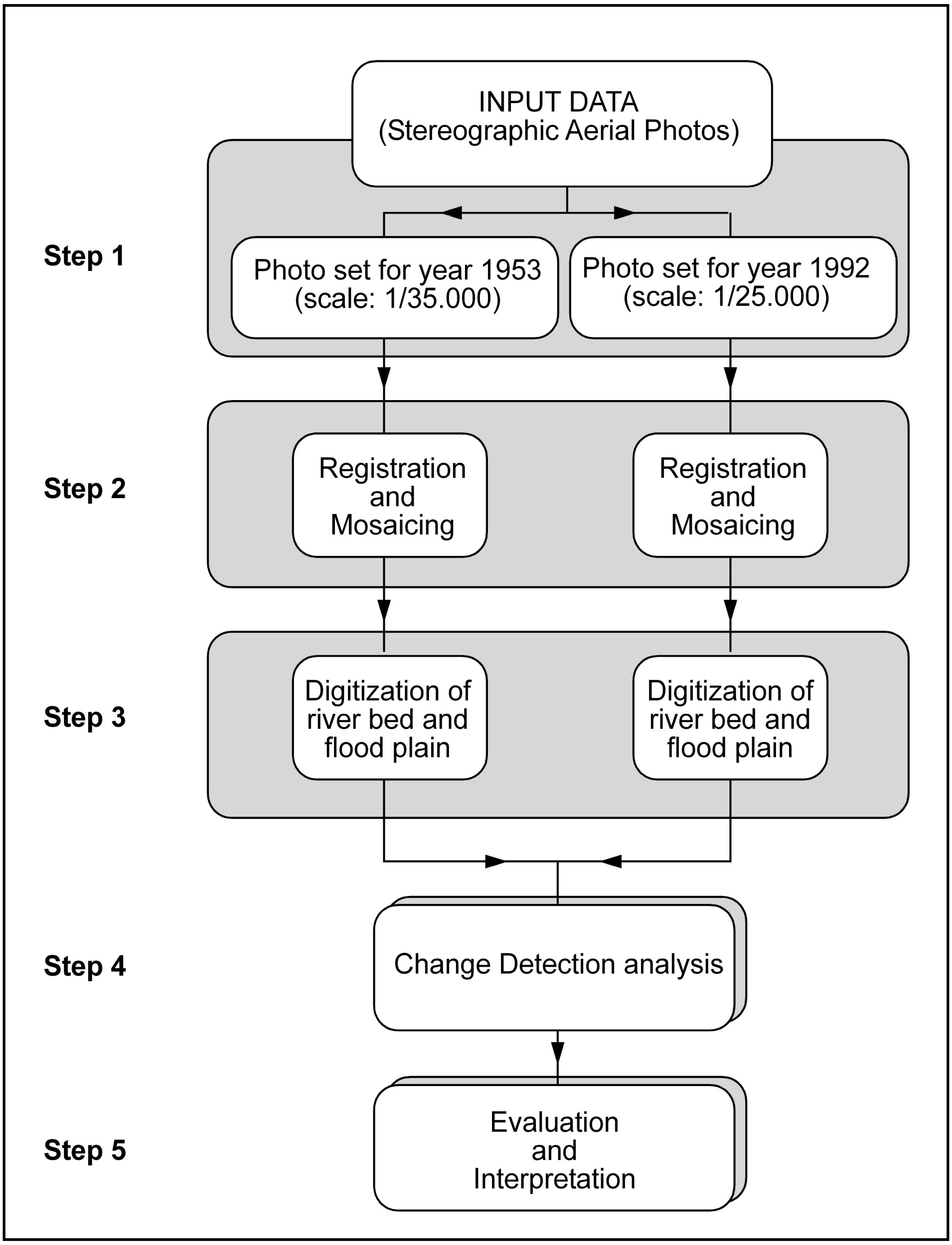


Figure 4.2. Flowchart of aerial photo analysis

4.1. Step 1: Selection of input data

The first step is the selection of aerial photographs to be used in the analysis. All available photographs are asked from the General Command of Mapping that covers this part of Fırat River flood plain. Aerial photograph sets purchased for this purpose are shown in Table 4.1. A total of four sets are available for the area at the scale range of 1/25.000 to 1/35.000. Production years of these photographs are 1953, 1956, 1992 and 1999.

The oldest set (1953) covers the area of interest and therefore is decided to be used in the analysis. The set that belong to year 1956 is excluded because it does not include that section of the flood plain. Both of other two sets (1992 and 1999) cover the interested area. However, it is decided to use only one of them in order not to complicate the process. 1992 photographs are selected for the second set since the scale is 1/25.000. The time span, therefore, investigated in this change detection corresponds to 39 years.

Table 4.1. Aerial photographs provided for the analysis. Two sets (1953 and 1992) are used in this study.

Set	Year	Scale	Number	Flight	Area covered
1	1953	1/35.000	21	E-W	N39-c3, c4
2	1956	1/35.000	30	N-S	N39-c1, c2
3	1992	1/25.000	41	E-W	N39-c3, c4
4	1999	1/35.000	35	E-W	N39-c1, c2, c3, c4

4.2. Step 2: Registration and Mosaicing

The aerial photographs are obtained initially in the hard copy format. These photographs are scanned at 600 dpi and transferred into soft copy format. Accordingly, the cell size is 2.41 m for 1/25.000, and 2.35 m for 1/35.000 aerial photographs. The photographs are registered using TNT Mips software. During the selection of ground control points (GCP) topographic map at 1/25.000 scale is used. Registration is performed using at least 30 GCPs for each single photograph. A sample aerial photograph with GCPs is shown in Figure 4.3. Selection of GCP within the flood plain is problematic because this area is dynamic and can change in time. For this reason all the GCPs are selected out of flood plain. Common features used as GCP are road-junctions, stream intersections, hill-tops etc which are visible both in the photograph and the topographic map.

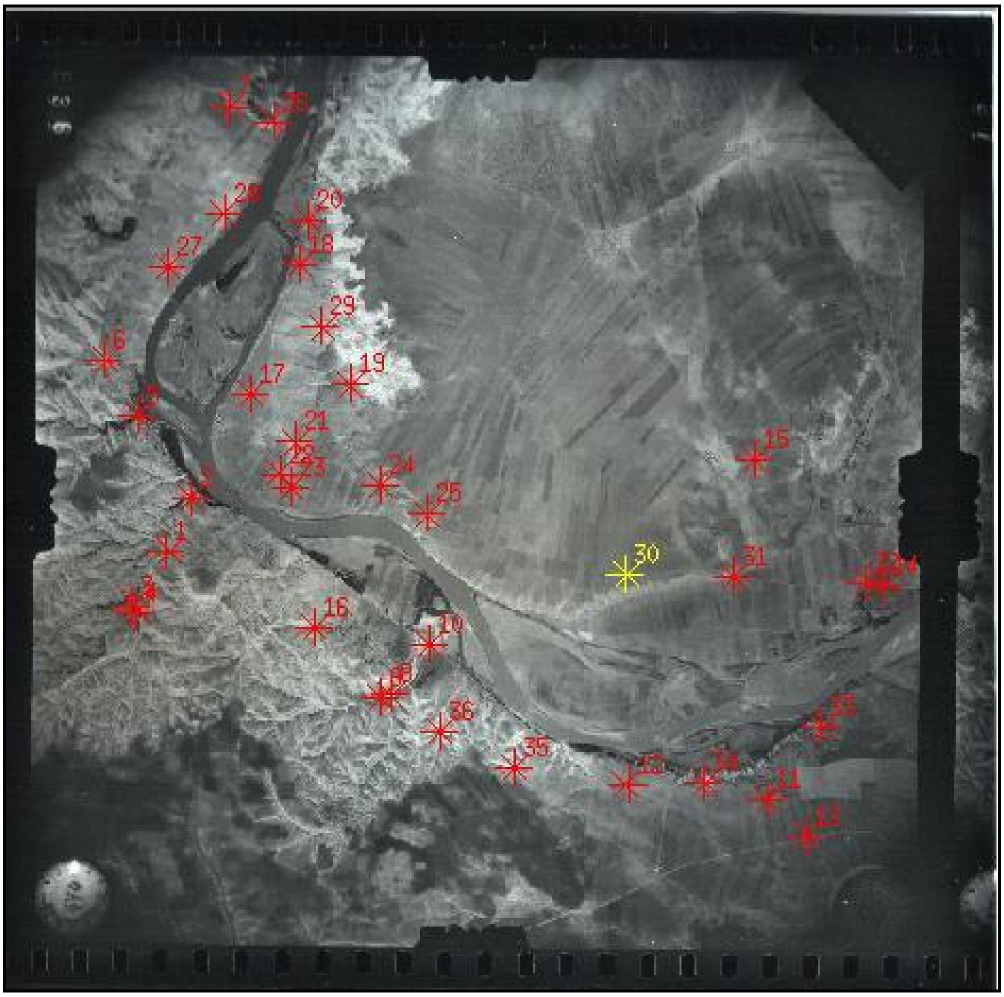
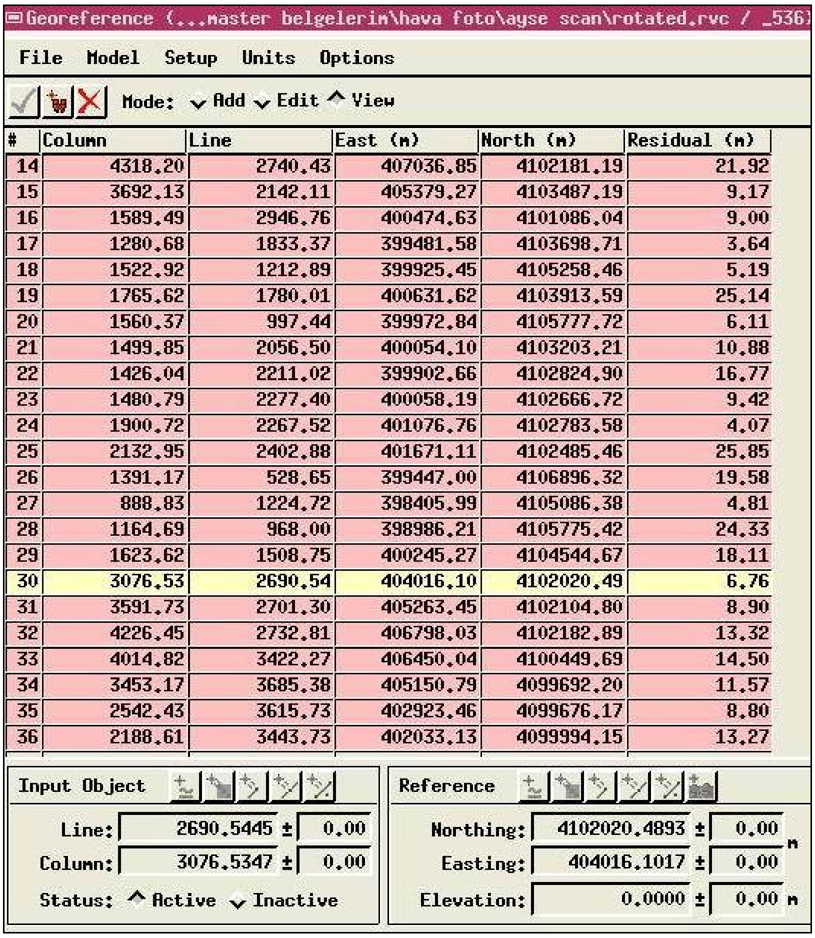


Figure 4.3. An example of aerial photo with ground control points selected for registration.

After selection of all GCPs the RMS error (Root Mean Square error of residual) is calculated for each photograph. An example of the table that includes the error amount for each GC is illustrated in Figure 4.4. A special attention is given for the amount of error not being greater than 30 m. Therefore, the erratic GCPs are either edited (re-measured) or replaced by new points. This process is repeated until the satisfactory results are obtained. The errors for the GCPs in Figure 4.4, for example, range between 3.64 to 25.85 m.

After registration (geo-referencing) of all aerial photographs they are assembled to generate the mosaic of this set. Two resultant mosaics are obtained separately for 1953 and 1992 photographs.



#	Column	Line	East (m)	North (m)	Residual (m)
14	4318.20	2740.43	407036.85	4102181.19	21.92
15	3692.13	2142.11	405379.27	4103487.19	9.17
16	1589.49	2946.76	400474.63	4101086.04	9.00
17	1280.68	1833.37	399481.58	4103698.71	3.64
18	1522.92	1212.89	399925.45	4105258.46	5.19
19	1765.62	1780.01	400631.62	4103913.59	25.14
20	1560.37	997.44	399972.84	4105777.72	6.11
21	1499.85	2056.50	400054.10	4103203.21	10.88
22	1426.04	2211.02	399902.66	4102824.90	16.77
23	1480.79	2277.40	400058.19	4102666.72	9.42
24	1900.72	2267.52	401076.76	4102783.58	4.07
25	2132.95	2402.88	401671.11	4102485.46	25.85
26	1391.17	528.65	399447.00	4106896.32	19.58
27	888.83	1224.72	398405.99	4105086.38	4.81
28	1164.69	968.00	398986.21	4105775.42	24.33
29	1623.62	1508.75	400245.27	4104544.67	18.11
30	3076.53	2690.54	404016.10	4102020.49	6.76
31	3591.73	2701.30	405263.45	4102104.80	8.90
32	4226.45	2732.81	406798.03	4102182.89	13.32
33	4014.82	3422.27	406450.04	4100449.69	14.50
34	3453.17	3685.38	405150.79	4099692.20	11.57
35	2542.43	3615.73	402923.46	4099676.17	8.80
36	2188.61	3443.73	402033.13	4099994.15	13.27

Figure 4.4. An example of GCP data showing pixel locations, earth coordinates and residual errors for each GCP.

4.3. Step 3: Digitization

The next step in the change detection analysis is the digitization of photo-units on both mosaics. Four units digitized are 1) river channel, 2) flood plain, 3) basement, and 4) island.

River channel: River channel is the actual bed of river through which the Fırat River water is drained. In most flood plains position of river channel is expected to change laterally.

Flood plain: Flood plain is the smooth valley floor built of sediments deposited during times of flooding. The river channel is located in a certain section of flood plain.

Basement: Basement here refers to the shoulders of flood plain. Therefore importance of the basement is that it defines the margin of the flood plain.

Island: Within the flood plain of Fırat River there are some islands formed by bifurcation and joining of river channel. These islands correspond to sand bars frequently developed in meandering and/or braided rivers.

"On screen digitization" is performed to generate the resultant maps. The boundaries are drawn manually directly over the aerial photo mosaics. Although the scales of two sets of photographs are different (1/35.000 for year 1953, 1/25.000 for the year 1992) this will not negatively affect the accuracy of resultant change map because both digitized maps are transferred to raster maps of the same resolution. The cell size during this process is selected as 10 m.

Results of the digitization for 1953 and 1992 aerial photographs are shown in Figures 4.5 and 4.6, respectively. As seen in the figures the basement unit is mapped on both sides of the flood plain in order to define the boundaries of the plain. That is why this unit is mapped as a thin strip during the digitization.

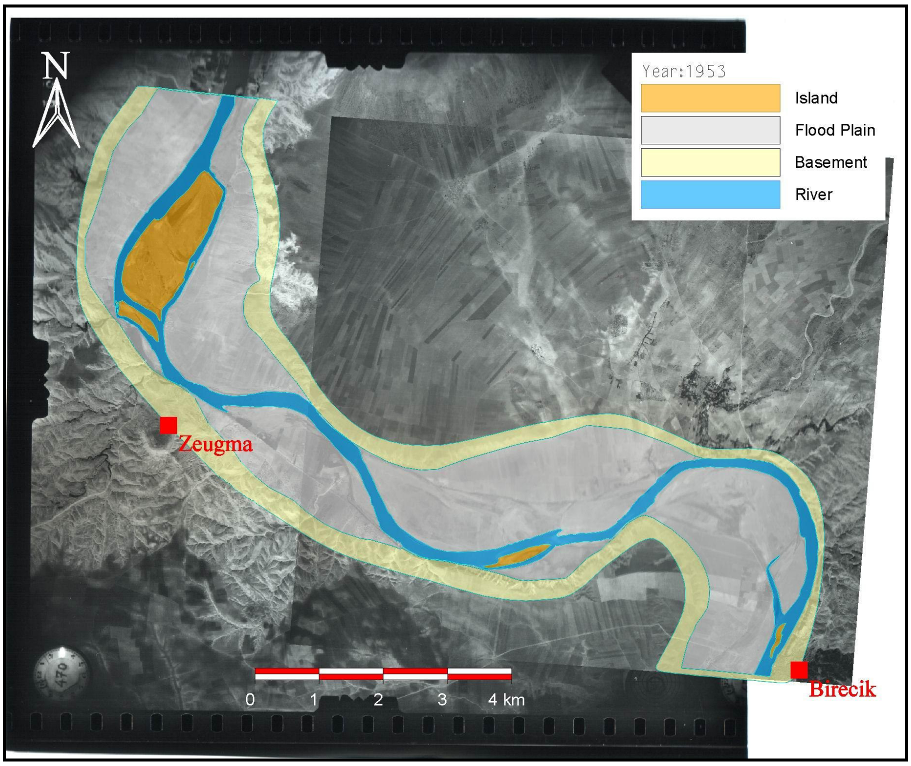


Figure 4.5. Map digitized from 1953 aerial photographs.

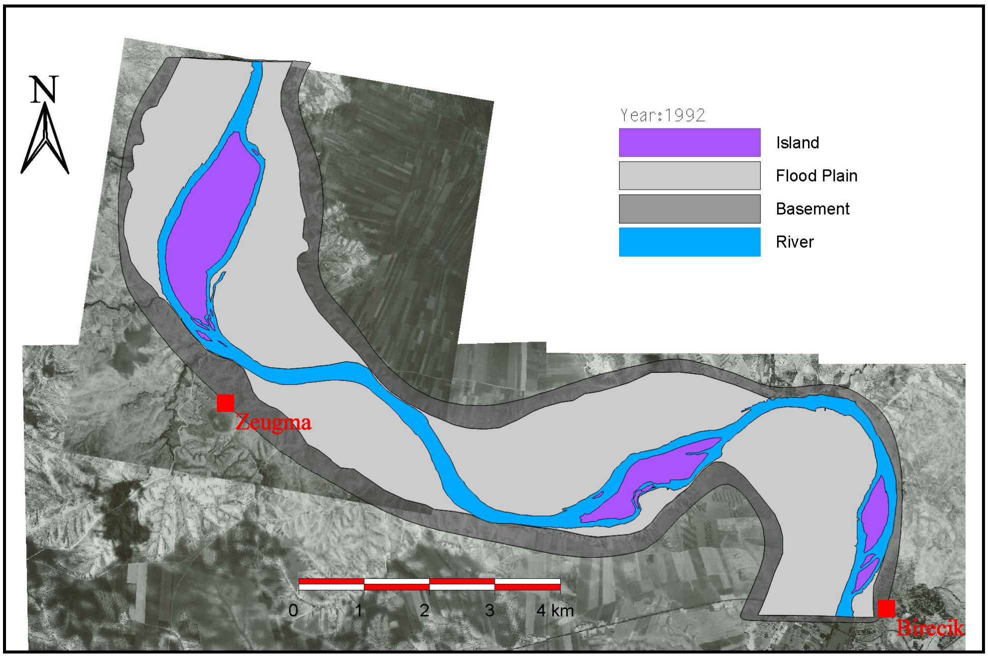


Figure 4.6. Map digitized from 1992 aerial photographs.

4.4. Step 4: Change Detection Analysis

The definition of change detection is, according to Singh (1989), the process of identifying differences in the state of an object or phenomenon by observing it at different times. Change detection using remotely sensed data provides a valuable research and monitoring tool on land-cover related subjects such as changes in forestation (Guild et al., 2004), fluvial systems (Munyati, 2000) , coast lines (Fulat, 2005), urban areas (Jensen and Im, 2007) and landslide investigations (Nichol and Wong, 2005).

There are many techniques searching the changes on Earth's surface developed in recent decades. Lu et al. (2004) reviewed, discussed and compared these techniques. Accordingly, image differencing, principal component analysis and post-classification comparison are the most common methods used for change detection in the literature. Satellite images are common sources of these change detection techniques.

In this study stereoscopic aerial photographs are used to detect the change of Fırat River. Most of change detection techniques use satellite images as input data and are not applicable in studies utilizing aerial photographs. In this thesis, post classification technique is used in the detection of changes of Fırat River by using aerial photographs as input data source.

Two methods are performed in this study; the first method is visual change detection which is basically the comparison of two multitemporal images and obsevation of changes visually and the second one is the digital change detection which compares two images by digital values of the pixels. Digital change detection analysis is an important feature of this study since it aims to detect the change systematically rather than visually and obtain quantified, statistical results.

Visual Change Detection:

Two maps that are prepared in step 3 are overlaid (Figure 4.7) to produce a composite figure for visual purposes to have a rough idea on the intensity of the change. A quick look at the composite figure suggests that:

1. There is no considerable variation in the river channel position in 39 years. Almost all the meanders and in general the route of the channel keep their nature except minor variations in the southeastern part of the area.

2. The margins of the flood plain are almost the same in time. Thin strips suggesting a change between flood plain and the basement are visible in most parts of the area.

3. The most prominent change is observed in the islands that develop within the flood plain. In both years there are three islands in the plain, however, two of these islands located in the eastern part of the area are enlarged considerable in time while the western one keeping its shape and size.

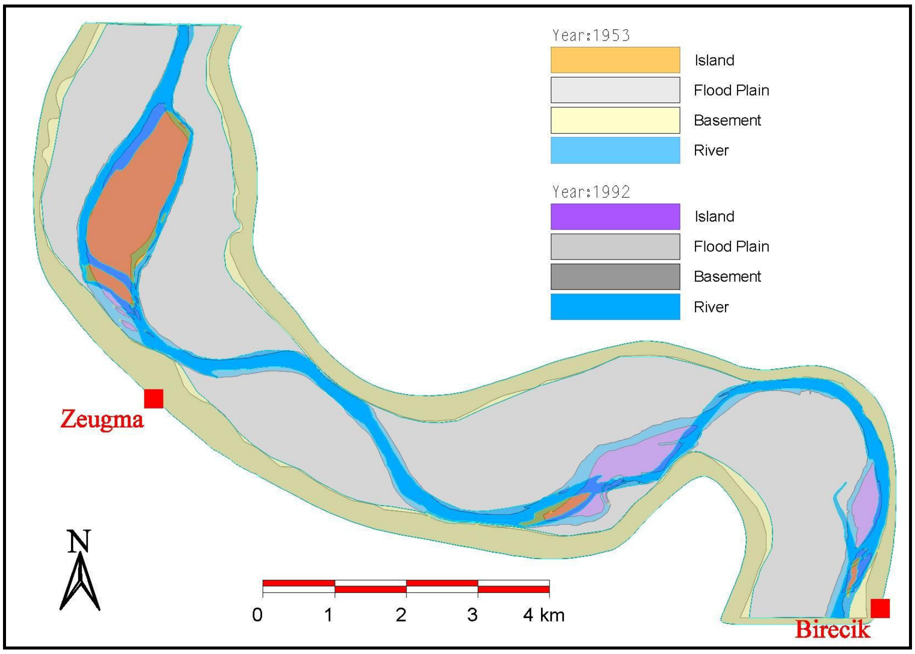


Figure 4.7. Transparent overlay of 1953 and 1992 digitized maps.

Digital Change Detection:

Two maps are subtracted from each other. To do this, first the vector data are converted into raster with a cell size of 10 m. The difference of the image is recoded so that each pixel will correspond to a particular change. 16 theoretical change classes (e.g. four classes for each unit including itself) are tabulated in the first column of Table 4.2. The first term in each class indicates the unit in year 1953 and the second term the unit in 1992. The units in four of these classes are identical in both years. These are river to river, island to island, flood plain to flood plain and basement to basement. These classes represent the pixels that are identical in both years. Therefore these four classes collectively can be classified as "no change" classes. All others, on the other hand will correspond to a "change".

Table 4.2. Theoretical sixteen change classes and quantity of the change occurred.

Change Classes (1953 to 1992)	**Number of Pixels**	**Area (km²)**
River To Island	5785	0.6
River To Flood Plain	3646	0.4
River To Basement	198	0.0
Island To River	2018	0.2
Island To Flood Plain	101	0.0
Island to Basement	0	0.0
Flood Plain To River	12106	1.2
Flood Plain To Island	8400	0.8
Flood Plain To Basement	443	0.0
Basement To River	804	0.1
Basement To Island	0	0.0
Basement To Flood Plain	10852	1.1
TOTAL:	**44353**	**4.4**
No Change	**Number of Pixels**	**Area (km²)**
River To River	28657	2.9
Island To Island	17974	1.8
Flood Plain To Flood Plain	198420	19.8
Basement To Basement	81075	8.1
TOTAL:	**326126**	**32.6**

The results of the subtraction of two maps are given in the second and the third columns in Table 4.2 (as number of pixels and area). As seen in the table 4.2, only in two classes a change is not detected. These are island to basement and basement to island classes. Therefore, in other 14 classes a change is identified although the nature of change can vary from one class to another. The map showing the distribution of these 14 change classes is shown in Figure 4.8.

The expected classes for the change from 1953 to 1992, as results of image subtraction are; flood plain to river, island to river, basement to river, river to island, flood plain to island, river to flood plain, island to flood plain, basement to flood plain, and no change classes which are island to island, flood plain to flood plain, river to river and basement to basement. However the operation resulted in two unexpected classes which are flood plain to basement and river to basement. These changes can not take place under natural conditions and might be products of erratic digitization or other similar reasons. However, the amount of the change in these two classes is negligible and they are kept untouched.

In order to get a numerical representation of all the units the "change matrix" is used which is illustrated in Table 4.3. The matrix is a cross-tabulation of four units for 1953 and 1992 years. This table is designed to show the "loss" and "gain" by each individual class. The loss in the table is illustrated by the rows and the gain by the columns. Therefore, each cell in the table shows: 1) amount of loss or gain, and 2) to which unit it is lost or from which unit it is gained. For example the first row of the table suggests that the river class has lost 3633 pixels to flood plain, 5785 pixels to island and 80 pixels to basement. Similarly, from the first column it can be concluded that the river gained 12106 pixels from flood plain, 2018 from island and 804 from basement. The total pixels of river class for 1953 and 1992 years are 38165 and 43595, respectively. Therefore, the gain for the river is greater than the loss. In terms of percentages amount of gain for river is equal (11.6 minus 10.1) to 1.5 percent.

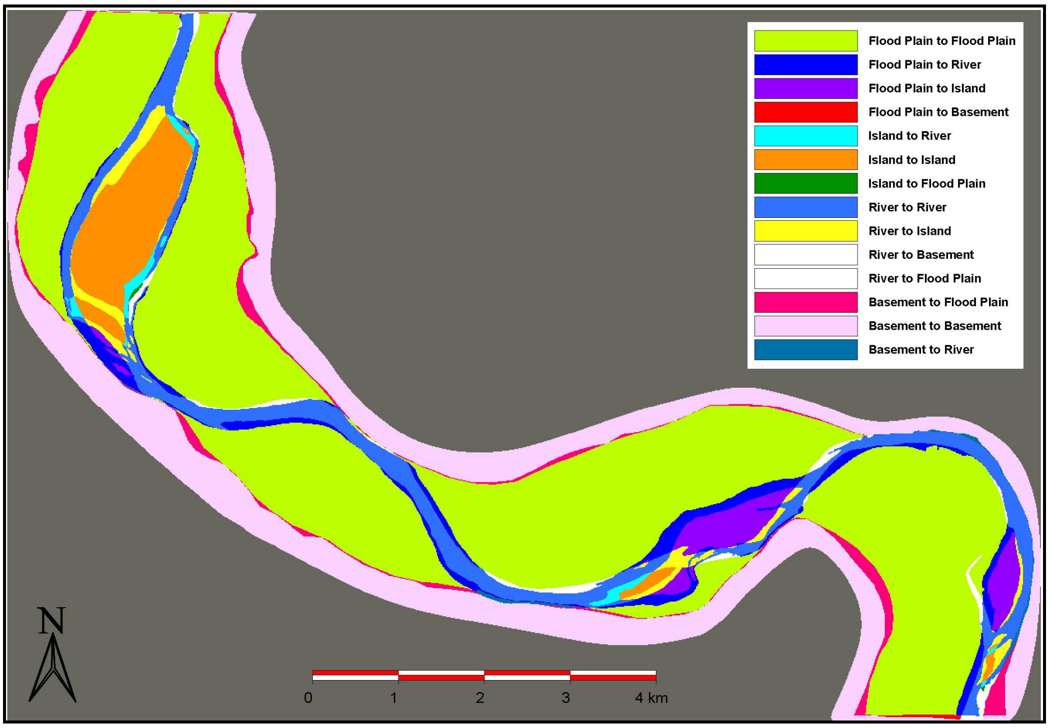


Figure 4.8. Change map for all 14 “change” classes

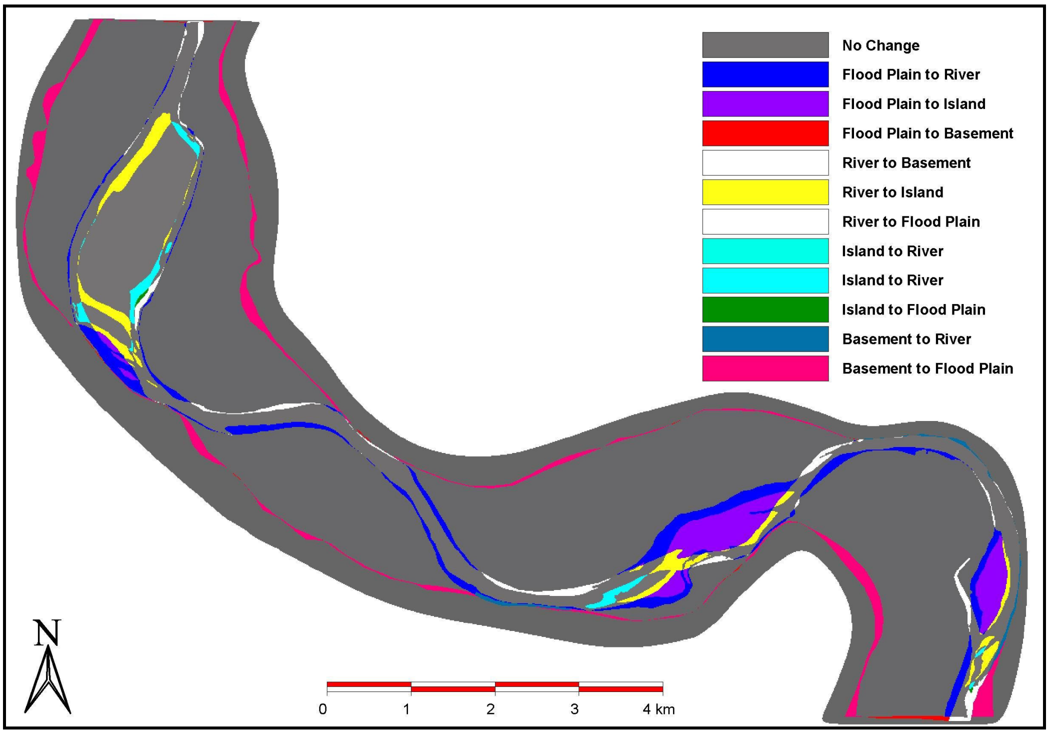


Figure 4.9. Change map in which the “no change” classes are masked.

Table 4.3. Change matrix of subtraction analysis of 1953 and 1992 aerial photographs. Numbers indicate pixel frequencies. (1 pixel is 10x10 m)

		1992					
		River	**F. Plain**	**Island**	**Basement**	**TOTAL**	**%**
1953	**River**	28667	3633	5785	80	38165	10.1
	F. Plain	12106	198443	8400	140	219089	58.1
	Island	2018	101	17974	0	20093	5.3
	Basement	804	10888	0	88219	99911	26.5
	TOTAL	43595	213065	32159	88439	**377258**	
	%	11.6	56.5	8.5	23.4		**100.0**

4.5. Step 5: Evaluation and Interpretation of results

Following observations can be made based on the numbers given in Table 4.3:

1) In 1992 the total number of river pixels is 43595 which constitute 11.6 % of the total area. Whereas the total number of river pixels is 38165 in 1953 which constitute 10.1% of the total. . Hence there is an increase of 1.5 % from 1953 to 1992. 28667 pixels of the total number of river class in 1992 also belong to river class in 1953, that is to say the 28667 of the pixels of the river did not change through 39 years. 12106, 2018 and 804 pixels represented by flood plain, island, basement in 1953 respectively are transformed to river in 1992.

2) In 1992 the total number of flood plain pixels is 213065 which correspond to 56.5 % of the total area; this number is 219089 in 1953 with a percentage of 58.1. That reveals a 1.6 % decrease in the cumulative area of flood plain from 1953 to 1992. The number of pixel with no change, i.e. the number of pixels which are flood plain in both years, is 198443. The

numbers of pixels that change from river, island and basement classes of 1953 to flood plain class of 1992 are 3633,101 and 10888 respectively.

3) In 1992 the number of pixels constituting island class is 32159; in 1953 this number is 20093. Therefore, the percentage of the island pixels is raised from 5.3% to 8.1% indicating a 2.3% increase in 39 years. From 1953 to 1992; 17974 of 32159 pixels show no change, 5785 and 8400 pixels are changed from river and flood plain to island respectively. There is no pixel transfer between basement and island classes.

4) The number of basement pixels in 1992 is 88439, in 1953 it is 99911. The ratios of basement to the total area are 23.4 % and 26.5 % in 1992 and 1953 respectively. This indicates a decrease of 3.1 % for the basement class. According to the change matrix, there are changes of river to basement and flood plain to basement of 80 and 140 pixels respectively. But this should not be a real case and can be attributed to errors during digitization.

According to Table 4.2, total number of pixels that belong to “no change” area is 326126 and the number pixels which subjected to change is 44353. The highest change occurred from flood plain to river with the amount of 12106 pixels. The following largest change is basement to flood plain with the amount of 10852 pixels. It is possible to say that there is a significant amount of transformation of areas from flood plain and river to island with the number of pixels 8400 and 5785 respectively. On the other hand, 2018 of the island pixels is transformed into river pixels. The transformation of the other classes to basement which is 641 pixels is insignificant with compared to other transformations.

Evaluation of these results will be made in the DISCUSSION chapter considering effect of season (or month) the photographs are acquired and the dams built over Fırat River in the upstream direction.

CHAPTER 5

MORPHOLOGICAL ANALYSES

In this chapter, the features associated with the morphology will be introduced. The area of morphological investigation covers four 1/25.000 scale topographic maps (N39c1, c2, c3, c4, Figure 1.1). The chapter is divided into three sections. In the first section production of digital elevation model and its derivatives will be explained. Second section deals the main course and flood plain characteristics of Fırat River. In the last section certain morphological analyses carried out will be presented.

5.1. Digital Elevation Model (DEM) and its Derivatives

The digital elevation model (DEM) of the area is generated from the digital topographic maps at 1/25.000 scale obtained from the General Command of Mapping. The contours provided by these digital data are illustrated in Figure 5.1.

The maps are first merged to have one single layer and ready to produce a digital elevation model (DEM). In the process of DEM production "Surface Fitting by Minimum Curvature" operation is utilized in the interpolation of the contour data. The size of the raster cell is 10 by 10 m. The shape of the search area is chosen as circle and its size is decided as 160 cells. The size of the search distance is controlled by the maximum spacing between two adjacent contour lines in the digital elevation data. The shaded DEM of the area in grayscale is given in Figure 5.2. Source of illumination is N45E with an angle of sun of 45 degrees. This image can be used to analyze the drainage texture. Accordingly, in the southern and northern parts of the area the texture is coarse that correspond to low flat and high mesa-like morphology.In the middle parts of the area, on the other hand, particularly to the west of Fırat River, the texture is fine. This area is represented by deeply dissected rivers, therefore, by steep slopes.

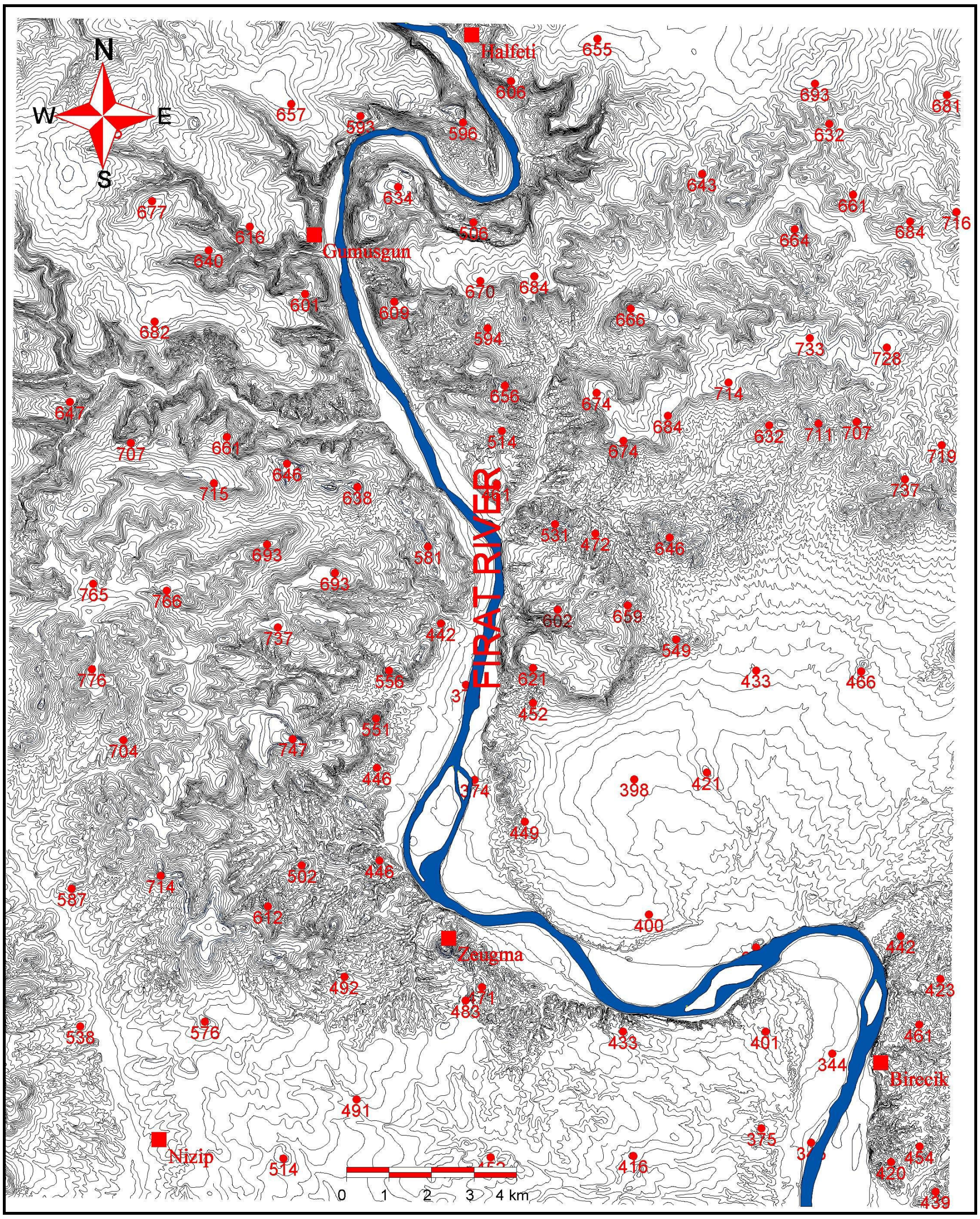


Figure 5.1. Contour map of the area with selected spot elevations (red numbers).

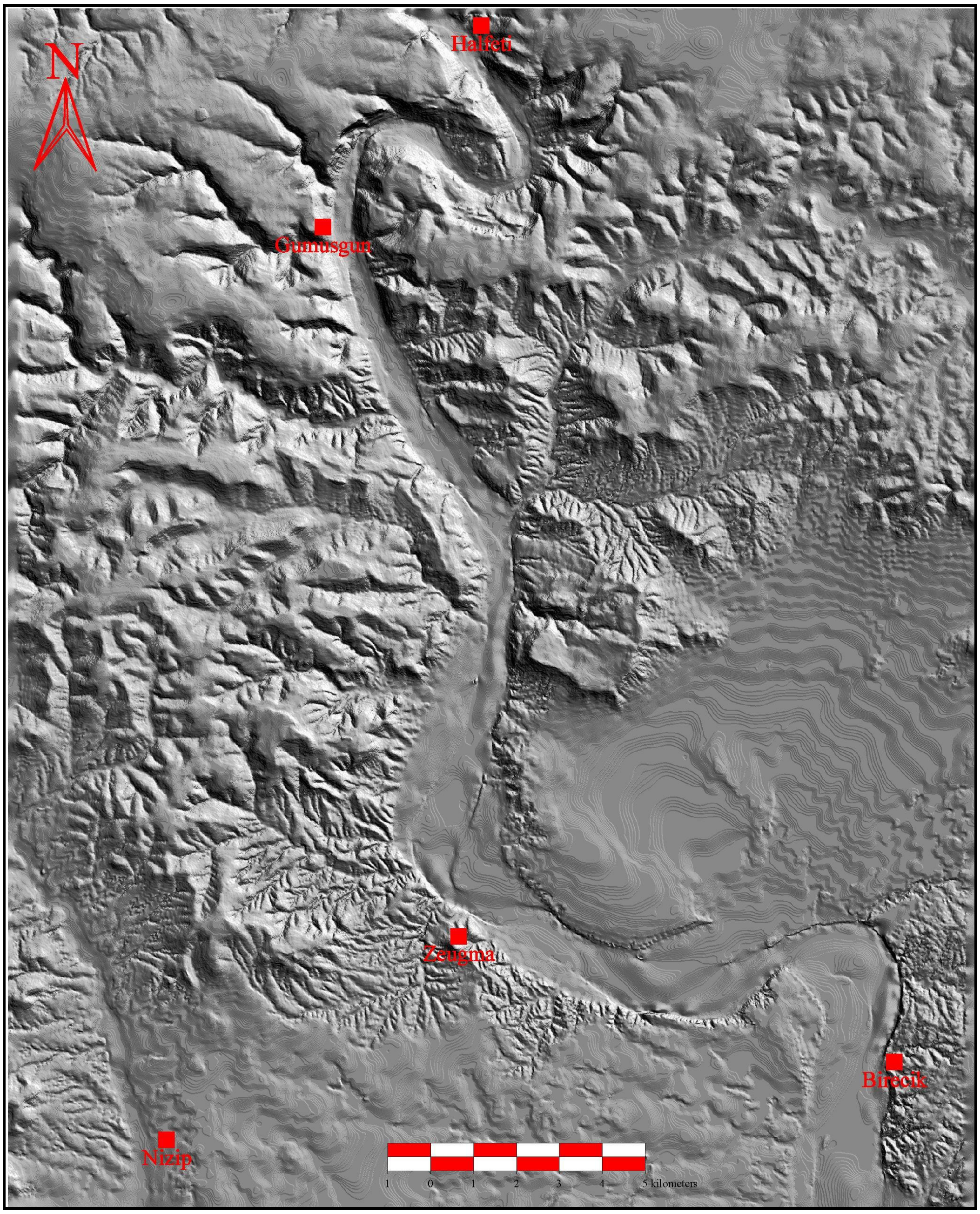


Figure 5.2. Digital Elevation Model of the study area.

All other morphological products (relief map, aspect map and slope map) are derived from the DEM. Color coded relief map of the area is illustrated in Figure 5.3. Elevation in the area ranges from a minimum of 313 to a maximum of 783 m that ranges in color from blue to red, respectively. Elevation, in general, decreases from northwest of the area towards the southeast.

Drainage pattern of the area can be easily investigated from the relief map. In the southeastern quarter of the area, there is no well developed drainage pattern. This area is partly covered by “old alluvium” as explained in Chapter 3 and is represented by a flat surface. The rest of the area, however, is dominated by dentritic drainage pattern on both sides of the Fırat River flood plain. The reasons for the development of this pattern are: 1) This is a sedimentary terrain with more or less horizontal strata, and 2) The area is free of intense structural features such as faults as indicated by regional geological map (Figure 2.1).

Slope map of the area is shown in Figure 5.4. The slope values are computed by comparing the elevation values in the adjacent eight cells and the output slope map gives the steepness of the surface. Slope amount theoretically ranges between 0 and 90 degrees. In the area, however, this range is 0 to 78. The histogram of slope values at 5 degree interval is shown in Figure 5.5. According to the histogram, almost half of the pixels (about 48 %) fall in the interval of 0 to 4 degrees. Most of these pixels are located to the southern half of the area (Figure 5.4). Some pixels observed at high elevations are due to the mesa-like morphological units developed in the horizontal sequences. The slope amount, as seen in the histogram (Figure 5.5), dramatically decreases after 4 degrees and have frequencies of 0.1 percent around 50 degrees. Slope values greater than 50 degrees are almost negligible.

According to the slope map (Figure 5.4) the values greater than 5 degrees are dominantly observed around Gümüşgün and Halfeti where the area is deeply dissected by the tributaries of Fırat River. The pattern of these steep slopes indicates thin strips parallel to the topography representing the steep slopes of the valleys.

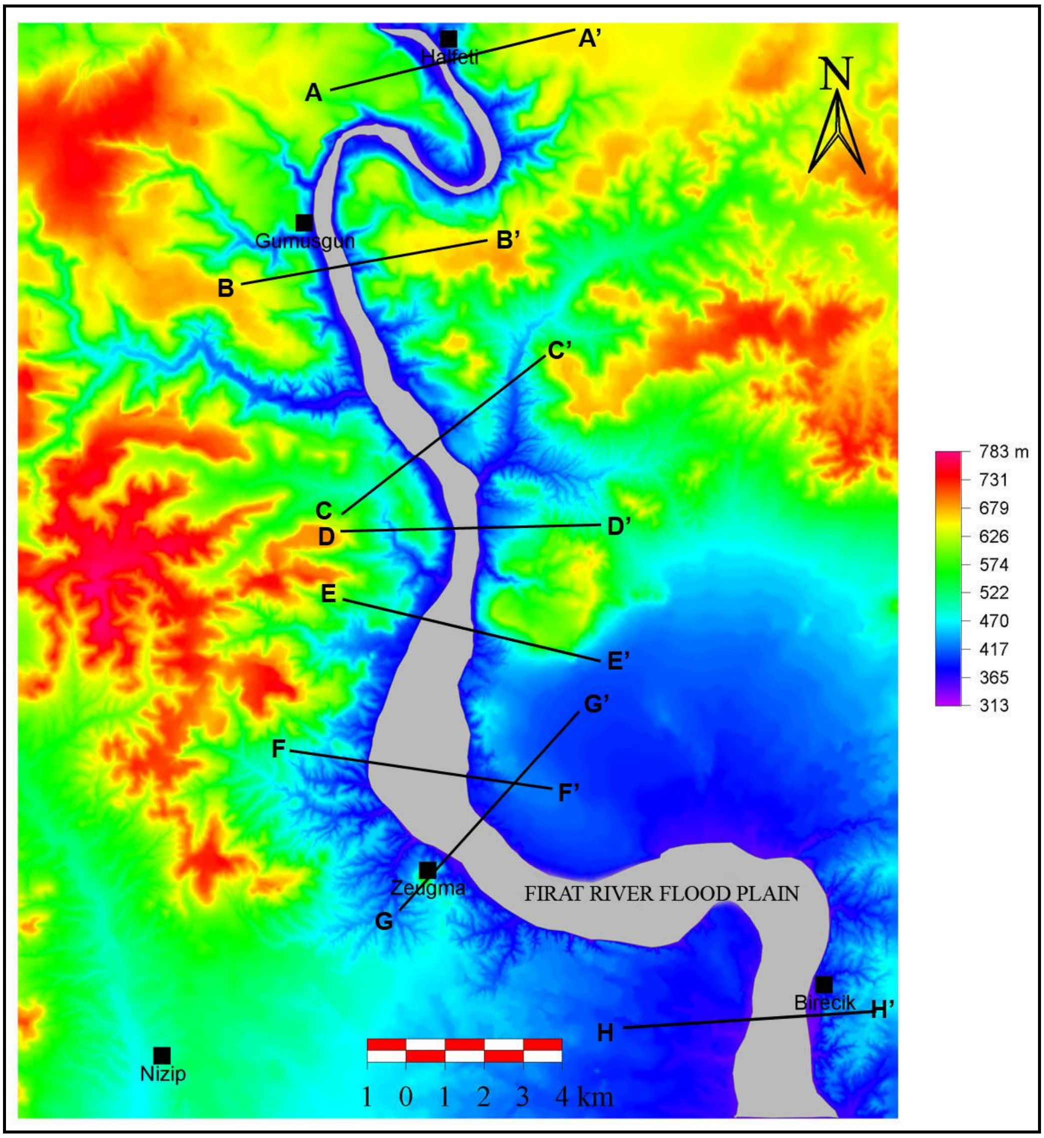


Figure 5.3. Color coded relief map of the area. Solid lines along the Fırat River are "lines of profiles" that will be used in the next section.

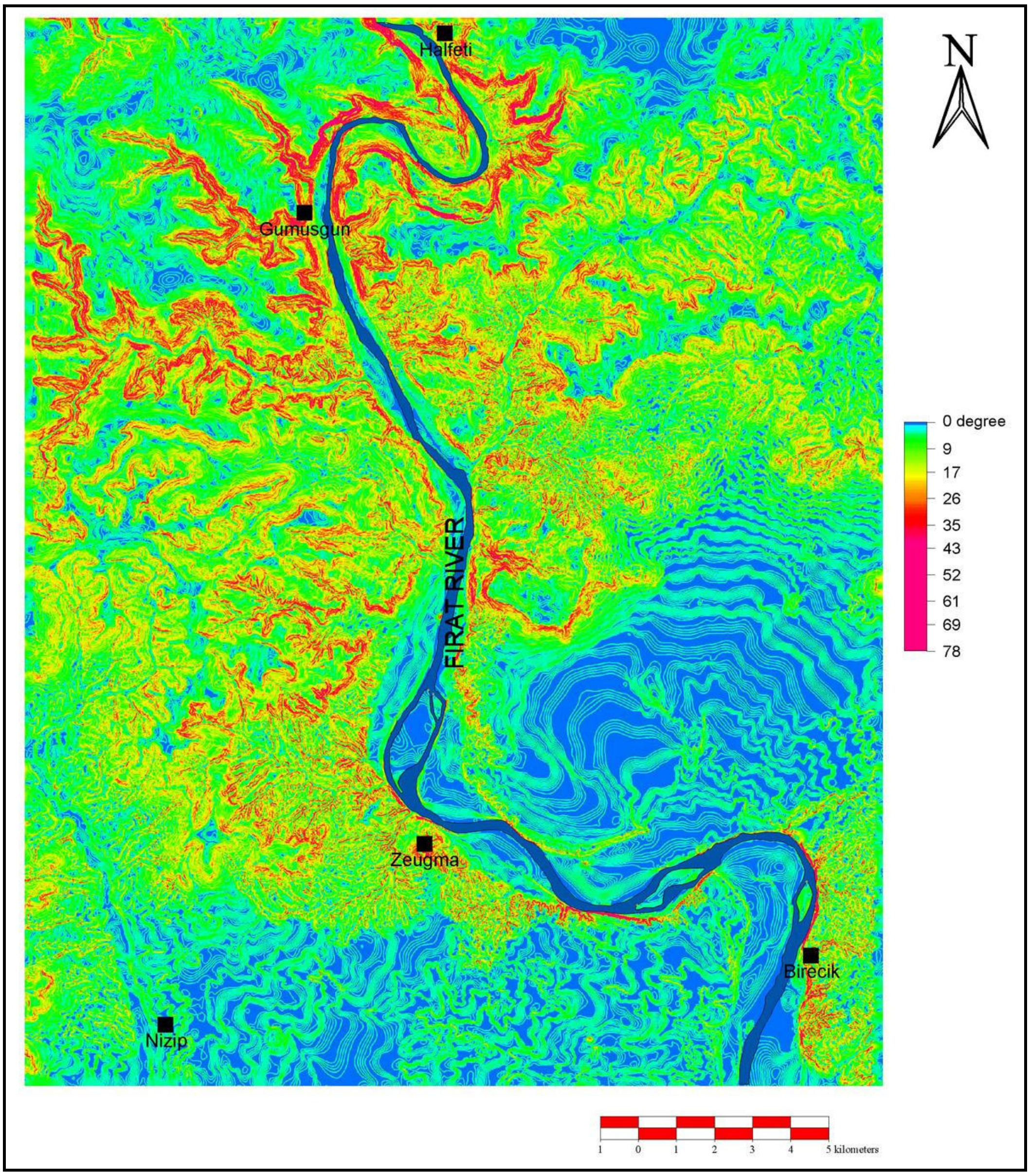


Figure 5.4. Slope map of the area given in degrees.

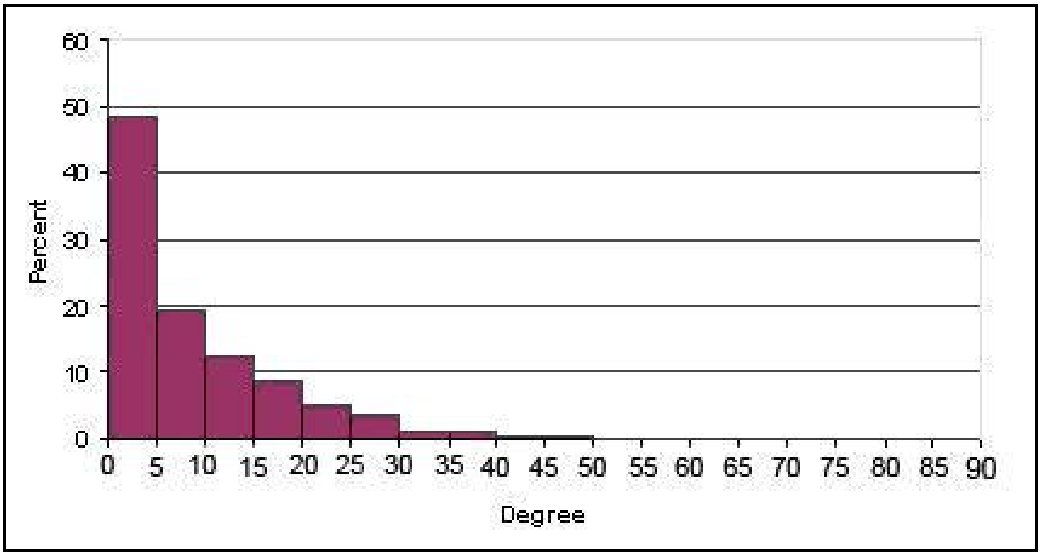


Figure 5.5. Histogram of the slope values of slope map shown in Figure5.4.

Aspect map of the area is illustrated in Figure 5.6. Similar to slope values, the aspect values are computed by comparing the elevation values in the adjacent eight cells. The output aspect map gives the slope direction of the surface in the range of 0 to 360 degrees. The value -1 corresponds to the flat surface where the slope amount is zero. Therefore, there is no aspect value for such pixels. Aspect values in the map show the whole range of colors from blue to red. In this range north facing slopes is indicated by red, east by blue, south by green, and west by yellow.

The histogram of the aspect values is given in Figure 5.7 at a range of 10 degrees. The maximum concentration with 16 % is observed for flat areas which are indicated by -1 value in Figure 5.6. Rest of the values ranges between 2 and 8 % with the dominant percentages in four principal directions (north, east, south and west). This is due to the directions of the Fırat River and tributaries flowing in these basic directions.

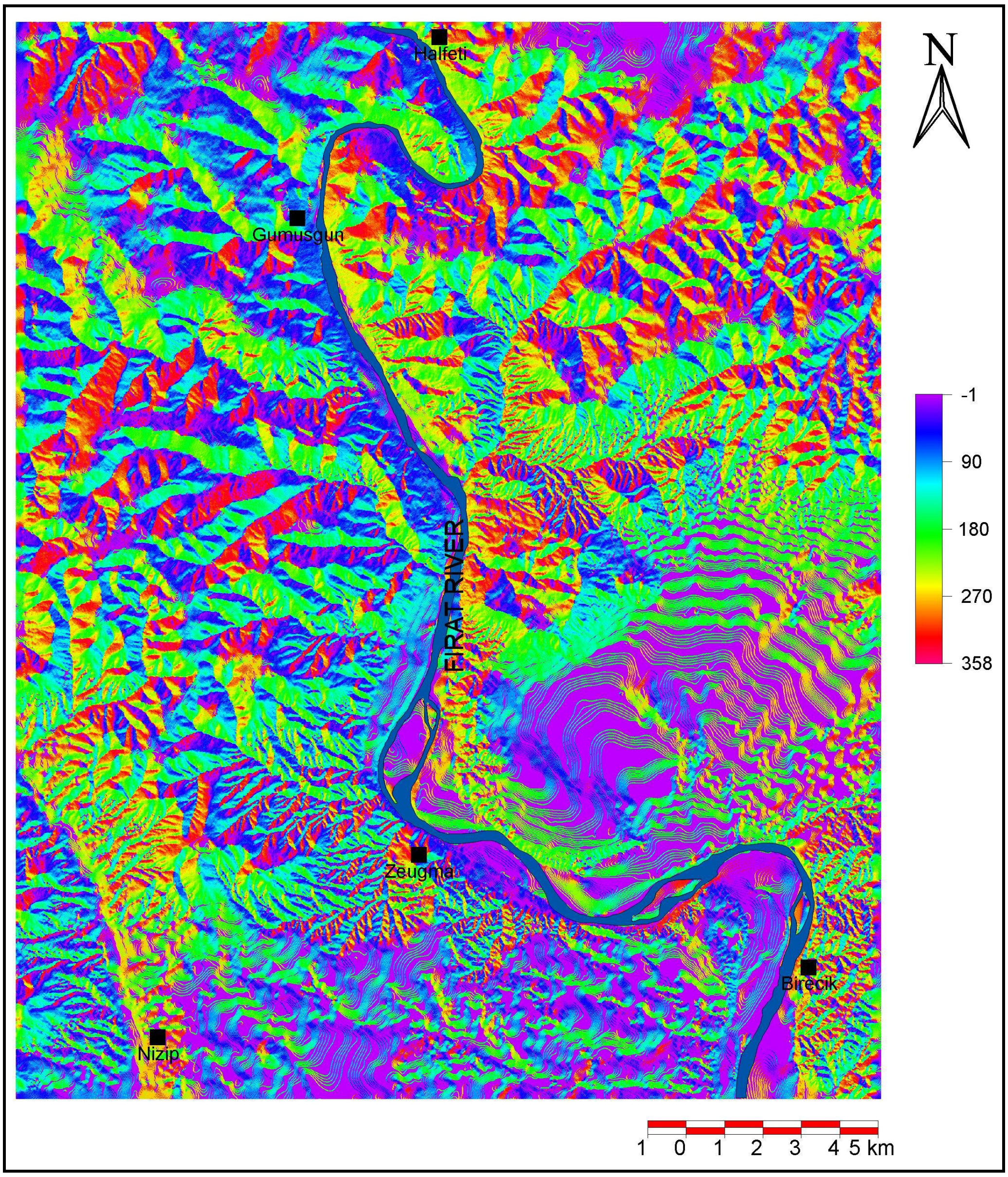


Figure 5.6. Aspect map of the area

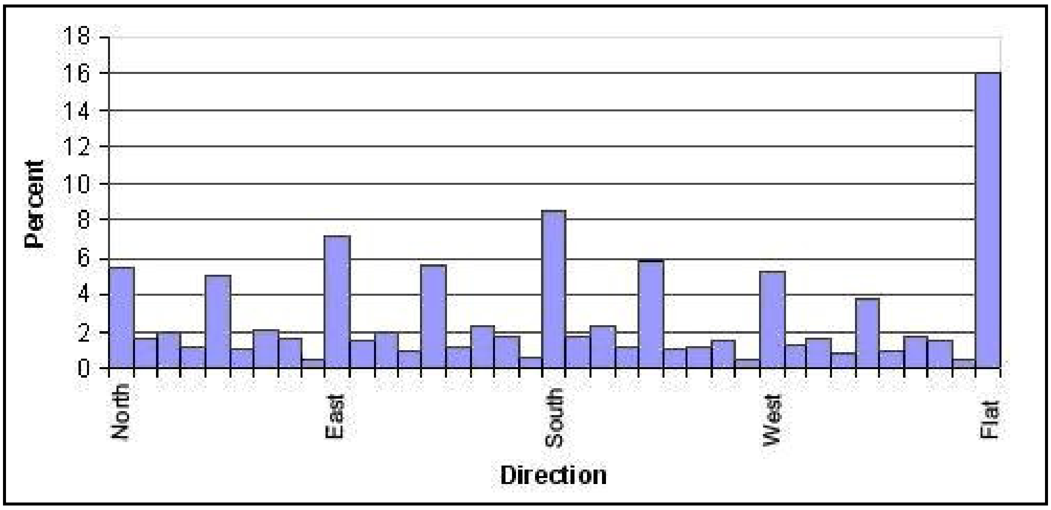


Figure 5.7. Histogram of the aspect values of aspect map shown in Figure 5.6.

5.2. Fırat River Flood Plain

Fırat River is one of the most noticeable morphological elements of the study area. A section of the river from Halfeti in the north to Birecik in the south is observed in the area. Two properties of Fırat River will be explained here which are variation of the flood plain from north to south, and the general course of the river characterized by some meanders.

Variation in the flood plain

The shape of the flood plain changes along the course of the river. As seen in the color coded relief map of the area (Figure 5.3) two basic differences can be observed along the route. These are: 1) the shape of the valley changes from v-shape to u-shape, from north to south, and 2) the width of the flood plain increases similarly in the same direction. To quantify the nature of this change a set of profiles are drawn across the river (Figure 5.8). Location of profile lines (A-A' to H-H') are shown in Figure 5.3.

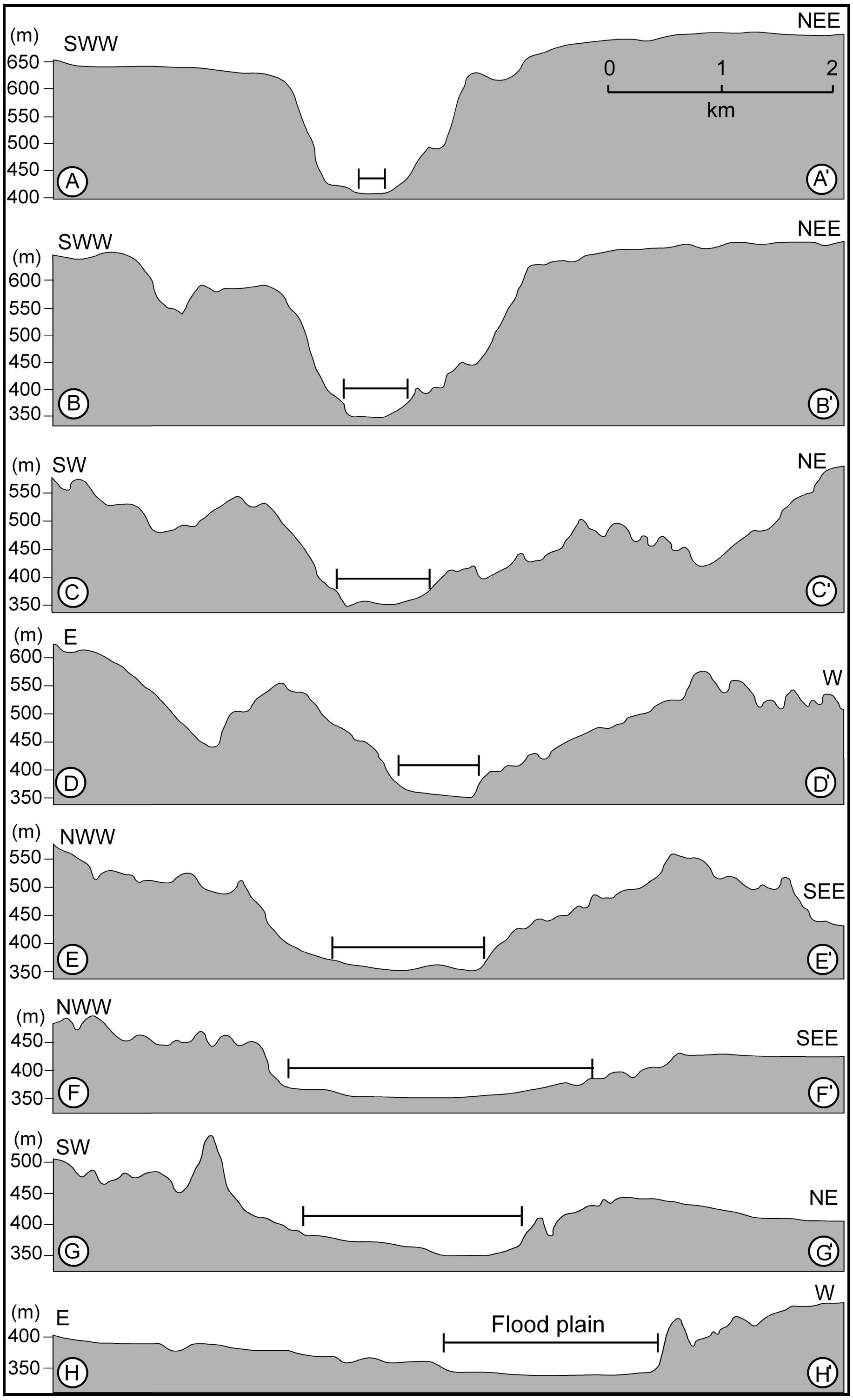


Figure 5.8. Profiles across Fırat River flood plain from north (A-A') to south (H-H'). (Vertical exaggeration is X5). Locations of profiles are shown in Figure 5.3.

The width of the flood plain is about 300 m in the north of the area at profile A-A'. This width with minor variations is almost the same between Halfeti and Gümüşgün. South of Gümüşgün the width gradually increases and reaches to a maximum of 2650 m at profile F-F'. The depth of the valley, on the other hand, decreases from about 400 m in the north to 100 to the south. Therefore, the depth/width ratio changes from approximately 1 to 1/25 from north to south.

Meanders of the Fırat River

Along the course of the river two sections are characterized by the presence of meanders. The first meander is located to the north of the area between Halfeti and Gümüşgün. Panoramic view of this meander is shown in Figure 5.9. An important property of this meander is that it is totally developed within a V-shaped valley where the depth/width ratio is the maximum in the area. Besides, there is no evidence of recent deposition at the outer curves of the meanders. All these suggest that this meander is not developed in the recent tectonic period but rather inherited from the older periods. Therefore, the meander can be classified an "entrenched meander" formed due to a rapid uplift of the area.

Figure 5.9. General view of meander between Halfeti and Gümüşgün. The picture is taken about 4 km north of Gümüşgün looking towards south. The water body in the picture is a part of the Birecik Dam Reservoir, not the river channel.

The second meander is located in the southern part of the area between Zeugma and Birecik. This is the area analyzed in the aerial photographs as explained in the previous chapter. A general view of this meander is shown in Figure 5.10.

There are several curvatures along the course of the river resulting in a set of adjacent meanders. In all meanders the valley floor is flat and wide (more than 2 km) and the valley is U-shaped. Similarly, in all meanders new deposits are formed in the inner banks. In the regional geological map (Figure 2.1) this is the area where Quaternary alluvium and old alluvium are exposed side by side.

At the outer banks of the meanders, on the other hand, erosion takes place. Steep slopes parallel to the eastern margin of the flood plains in the vicinity of Birecik (Figure 5.10) are examples of currently eroded areas. These areas as indicated by a narrow strip of steep slopes (greater than 25 degrees) in the slope map (Figure 5.4). Therefore, these meanders are active today and are the products of the recent tectonic activity.

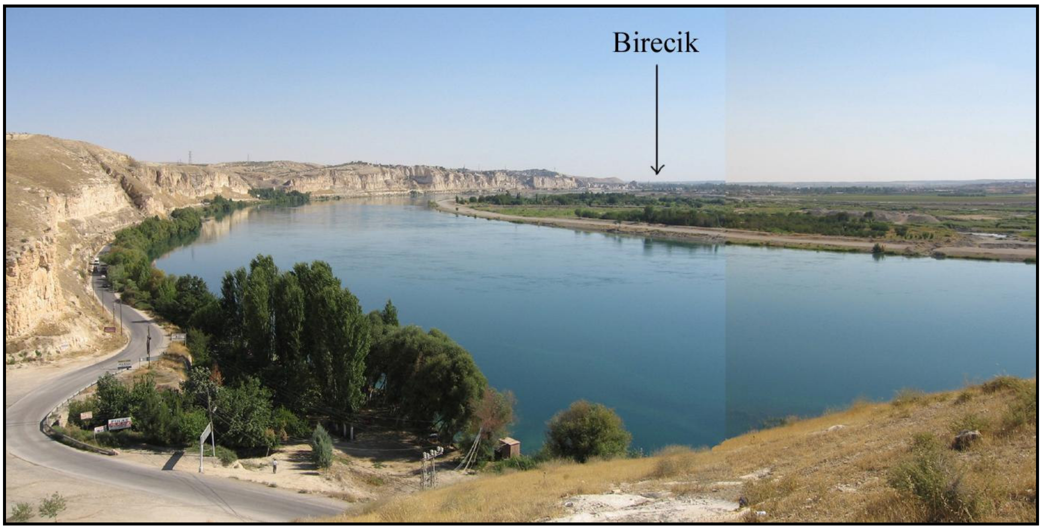


Figure 5.10. A view of the section of meanders between Birecik and Zeugma. (View to southeast)

5.3. Analyses

Four morphological analyses are carried out using the digital elevation map and its derivatives. These analyses are: 1) to test the elevation of Gaziantep and Fırat formations throughout the study area, 2) to investigate the visibility of certain points in the area, 3) to predict the source area for the water supply, and 4) to evaluate the nature of the ancient route.

5.3.1. Elevation of Gaziantep and Fırat Formations

According to the regional geological map the rock units exposed in the area are horizontal (Figure 2.1). Although there are a few dip/strike measurement in the area most of the area is claimed to possess horizontal bedding. Similar observations are made in the vicinity of the area. Dip amounts detected in the vicinity of the major fault passing east of Belkis Hill are good evidences on the nature of bedding. These dips are, first of all, gentle as indicated by their amounts ranging from 3 to 8 degrees. Secondly they are all located in the very close vicinity of fault plane that suggests drag folding. Therefore, the dip amounts in the area should be expected to be horizontal except around fault planes.

The analysis carried out at the elevation of the boundary between two formations aims to see the spatial distribution of this boundary in order to test the horizontal nature of layers. In the first step of analysis, elevations of the pixels along the boundary are cropped using a buffer zone of two pixels. The resultant file is evaluated for their elevations using a histogram at 50 m interval. Accordingly it is determined that the boundary is mostly located at the interval of 550 and 650 m. Based on this data, a map (Figure 5.11) is prepared that divides the elevation into three regions as 1) elevation less than 550 m, 2) elevation between 550 and 650 m, and 3) elevation greater than 650 m. The boundary of Gaziantep-Fırat formations is drawn on this map as a line in red color. This boundary under normal conditions is expected to be in purple interval if horizontal bedding is considered.

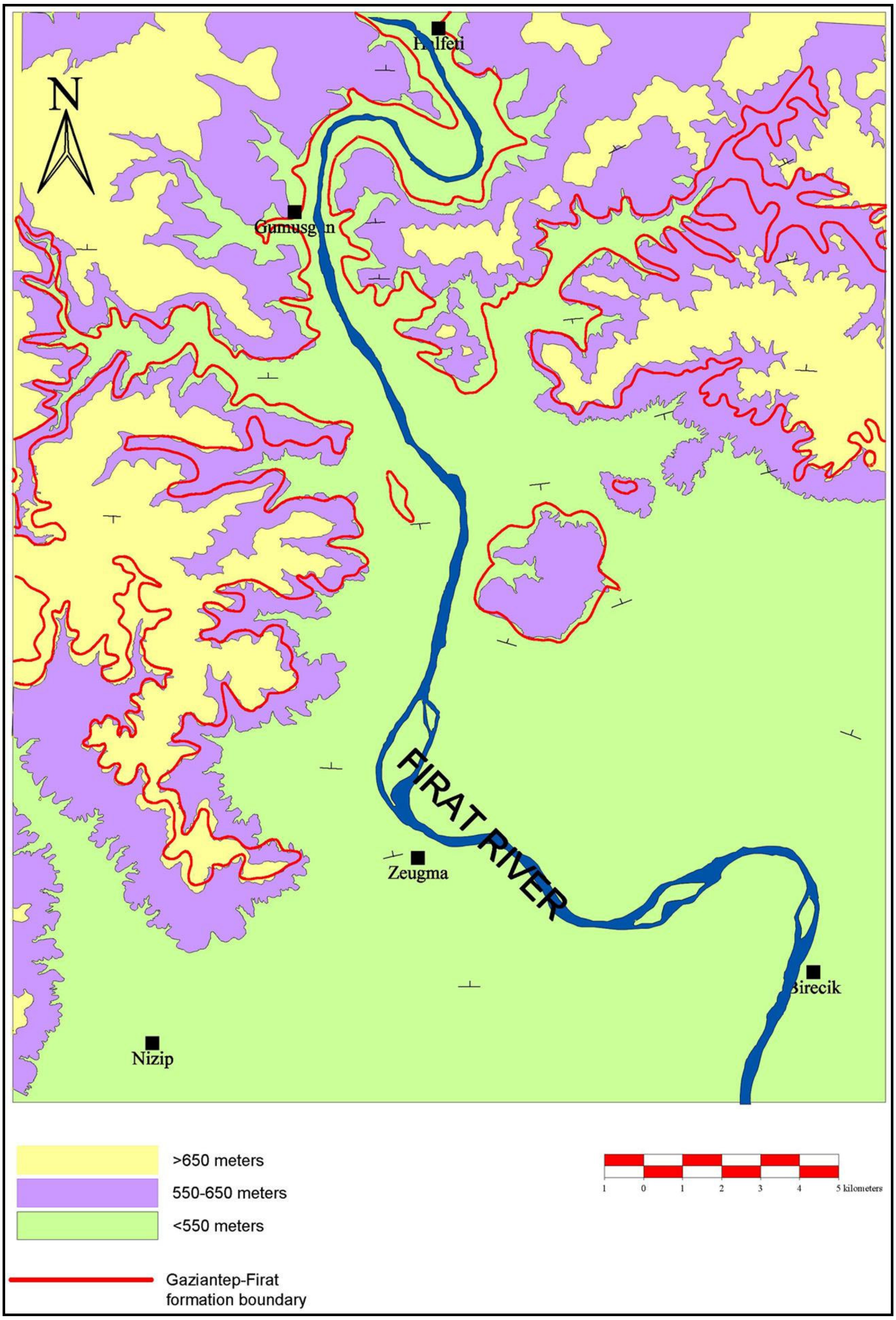


Figure 5.11. Map of three elevation intervals (<550 m, 550-650 m, >650 m) and the boundary between Gaziantep and Fırat Formations.

Based on the visual analysis of the map in Figure 5.11 it can be suggested, however, that the bedding is not horizontal throughout the area. This boundary has different characteristics in different parts of the area. It is obvious that, in the northern part of the area (south of Halfeti); the elevation of the boundary is below 550 m. Southeast of Halfeti the boundary is between 550 and 650 m. In the southern parts of the area around Zeugma, on the other hand it is above 650 m. Therefore, there is a general and gradual decrease in the elevation towards the north. This observation is supported by the attitudes of the bedding planes measured in the field that suggest a consistent northerly dipping. In the central part of the area there are a few measurements that show a southerly dipping which are aligned in a zone oriented in E-W direction. Two possible explanations for this deflection in the dips are: 1) there are folds in the area that trend in E-W direction; 2) these southerly dips are the drag folds of a fault in the same direction. A short fault shown in the geological map (Figure 2.1) in this part can be considered as an evidence of the second reason.

5.3.2. Visibility Analysis

Researches on visibility in the formal studies began in the 1980s with the developments in software technology and GIS. The studies are conducted in various fields such as urbanism, architecture, archaeology, geography and geology. Llobera (2003) categorized these studies on visibility into two as in “urban” landscape (i.e. built environment) and “natural” landscape. In the visibility assessment of natural landscape, different techniques in the production of viewsheds such as single viewshed analysis, cumulative viewshed analysis, fuzzy viewsheds and accuracy assessments have been introduced.

The accuracy of a viewshed is first discussed by Fisher (1991, 1992). He proposed fuzzy viewshed method which is based on the idea that an object is visible in different degrees of clarity to different observers in the same conditions or the same observer under different conditions. In the fuzzy viewshed, the values of each raster cell represent an object's level of clarity, ranging from 1 (clearly visible) to 0 (not visible). Levels between 0 and 1 indicate lower levels of clarity which can be characterized in terms such as ''usually visible,'' ''sometimes visible,'' and ''visible only under very favorable conditions'' (Dennis, 2006).

Wheatley (1995) introduced 'cumulative viewshed analysis' which combines single viewsheds in order to investigate visibility. This method relies upon the combination of visibility maps, which are produced from different locations and constructed of binary cells, where the value of 1 refers to visible cell, and a value of 0 refers to invisible cell, through basic addition generation of viewshed rasters.

The use of visibility analysis in the formal archaeological studies has been accelerated since 1990s with the developments in the application of GIS methods in the archaeological problems. Lake and Woodman (2003) described the history and present state of non-GIS and GIS based archaeological visibility studies in detail. Most of the visibility studies in the archaeology such as Gaffney and Stancic (1991, 1992), Ozawa et al. (1995), Wheatley (1995) investigates intervisibility of archaeological monuments. Chapman (2003) used GIS based approach in the visual analysis of a Neolithic monument. He investigated the relationship between the morphology of the monument and its visibility to chronologically earlier monuments by using cumulative viewshed method. Ertepınar (2005) investigated the distance from which Seljuk caravanserais became visible by using single viewsheds to understand the whether there was an attempt to hide the caravanserai or not. Ulusoy (2006) explored the importance of visibility of Galatian Forts at Ancyra (Ankara) in the site selection criteria. Aydın (2006) attempted to discover the visibility of Lycian settlements from a certain distance.

In the visibility analysis a "viewshed map" is generated in order to compute the area that is visible from a reference point on the elevation raster. The areas on the map that are visible are called "the viewshed" (Heywood et al. 1998).

The principle of a viewshed analysis is the production of lines of sight (LoS) (Fisher, 1991). From source to the end cells, if there is no obstruction in the way of LoS, in other words, if there is no cell with elevation value greater than the elevation of the source cell, then the end cell is visible. If not, it is marked as non-visible. The resulting raster map has binary value: visible cells and not visible cells which have values of 1 and 0 respectively.

There are some parameters that should be selected in the process of viewshed production. Some important ones are height of observation point, vertical scale and view distance. (Microimages TNT-MIPS, 2008)

Height of observation point in most cases is equal to the height of an average person. In this analysis a value of 2 m is assigned to this parameter. Vertical scale is important only for the visual presentation of the output and does not affect the results. In this process vertical scale is selected as one. The view distance is the radius of the area where visibility analysis will be made. This distance is usually limited with the range of visibility of a human eye and can change from 10 to 75 km. Considering the limits of the study area no limit is assigned to this parameter.

In this study, the visibility analysis is carried out in order to compare the visibilities of certain locations that have archaeological importance. The viewshed maps are shown in Figure 5.12. The location of the points is selected randomly and do not justify any scientific concern. In all viewshed maps the red areas indicate the cells that can be seen from the source cell.

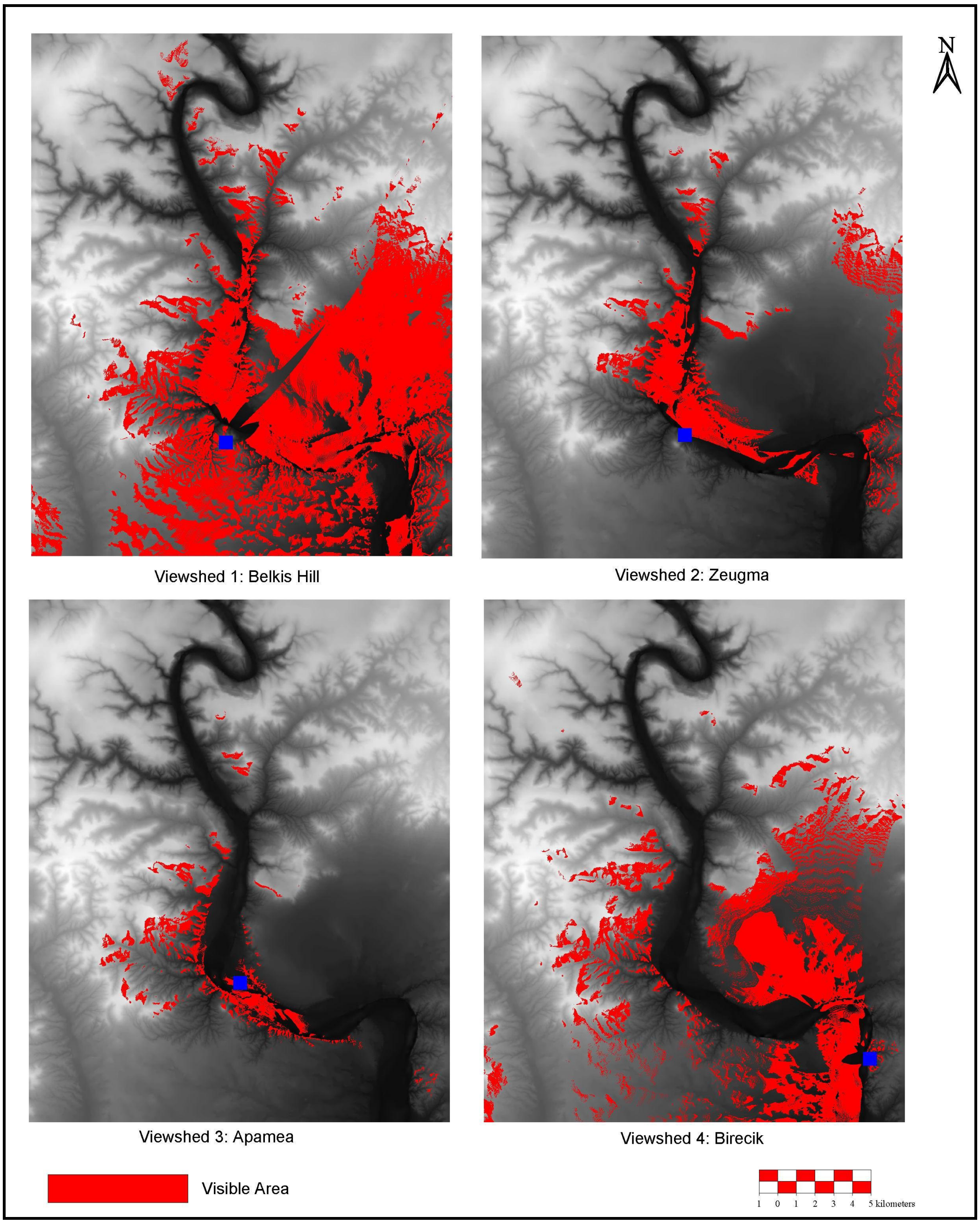


Figure 5.12. Viewshed maps prepared for four points. The blue point shows the location on the surface for which the visibility analysis is made.

The points on the surface selected for the visibility analysis are top of Belkis Hill (Viewshed 1 in Figure 5.12), lower part of Zeugma (Viewshed 2), center of Apemea which is buried today under the Birecik Dam reservoir (Viewshed 3), and center of Birecik (Viewshed 4).

Comparison of the viewshed maps suggest that a small shift on the surface can produce different viewsheds based on difference on elevation. This is clear in the difference for the first two maps (Belkis Hill and Zeugma). From Belkis Hill all the southeastern and southern parts of the area and some sections of the flood plain almost to Halfeti are visible, while from Zeugma only the flood plain in the vicinity and some parts of Birecik area are visible. From Apamea, a small part of the area, mostly the western banks of the Fırat River are visible. Birecik, on the other hand, although is located on the eastern bank of the Fırat River at lower elevations can see a large area compared to Zeugma and Apamea.

5.3.3. Possible Sources for Water Supply

There are several large cisterns located at the top of Belkis Hill that provide water for Zeugma. Some remnants of the water systems that distribute the water from these cisterns to the city are reported in the literature. Considering the drainage basin of the top of Belkis Hill, the cisterns should not be expected to be filled with rainfall. The water, therefore, should be transported by pressure pipes from other regions which are above the elevation of the Belkis Hill (571 m). Therefore, a map is prepared that shows the areas greater than 571 m (Figure 5.13).

Regions greater than 571 form two large areas to the east and west of the Fırat River. The eastern area can be excluded considering the problems of piping in active flood plain. Therefore, the source(s) for the water should be in the area to the west of the river. This source, however, can not be further localized due to the lack of data such as the locations of the springs or possible ancient reservoirs.

Figure 5.13. Map showing potential areas of water sources (>571 m) to provide water to Zeugma

5.3.4. Evaluation of Ancient Route

The ancient routes passing through Zeugma in N-S and E-W directions are drawn by Comfort et al. (2000) and Comfort and Ergec (2001). An attempt is made here to evaluate the route in E-W direction using the elevation and slope maps of the area.

Ancient E-W route (Figure 5.14) passes through Nizip to Zeugma then to eastern bank (Apamea) with a bridge over the Fırat River in the vicinity of Zeugma. Although the exact location of the bridge today is not known it is estimated considering the topography and the location of Zeugma. The road, on the eastern bank, follows the most suitable topography and reaches Birecik.

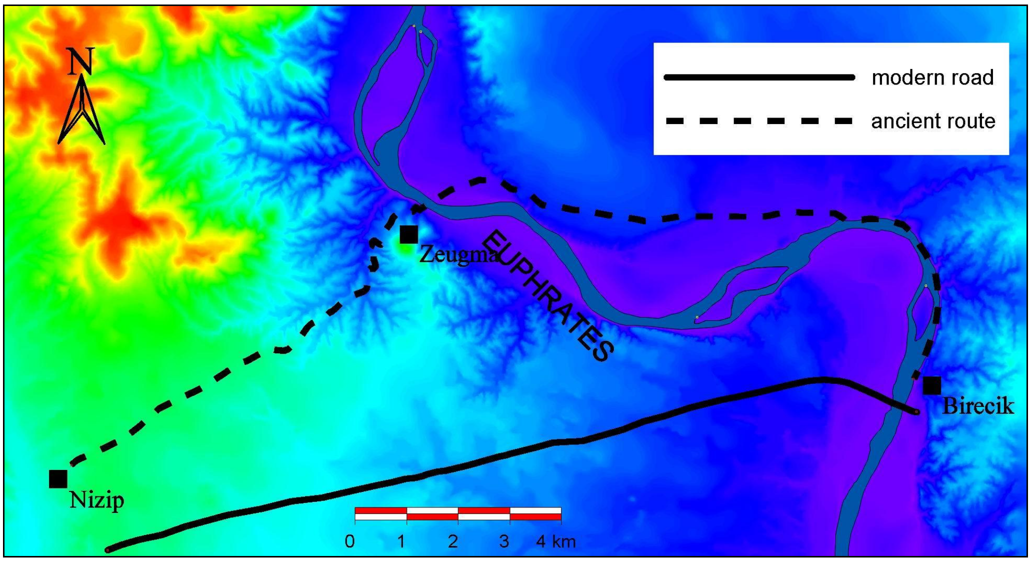


Figure 5.14. Ancient and modern routes in the vicinity of Zeugma.

The modern road between Nizip and Birecik runs south of the ancient road. It is shorter in distance and is connected to the bridge right in the west of Birecik. Two histograms are prepared for the slope map that shows the slope amount variation along the roads (Figure 5.15).

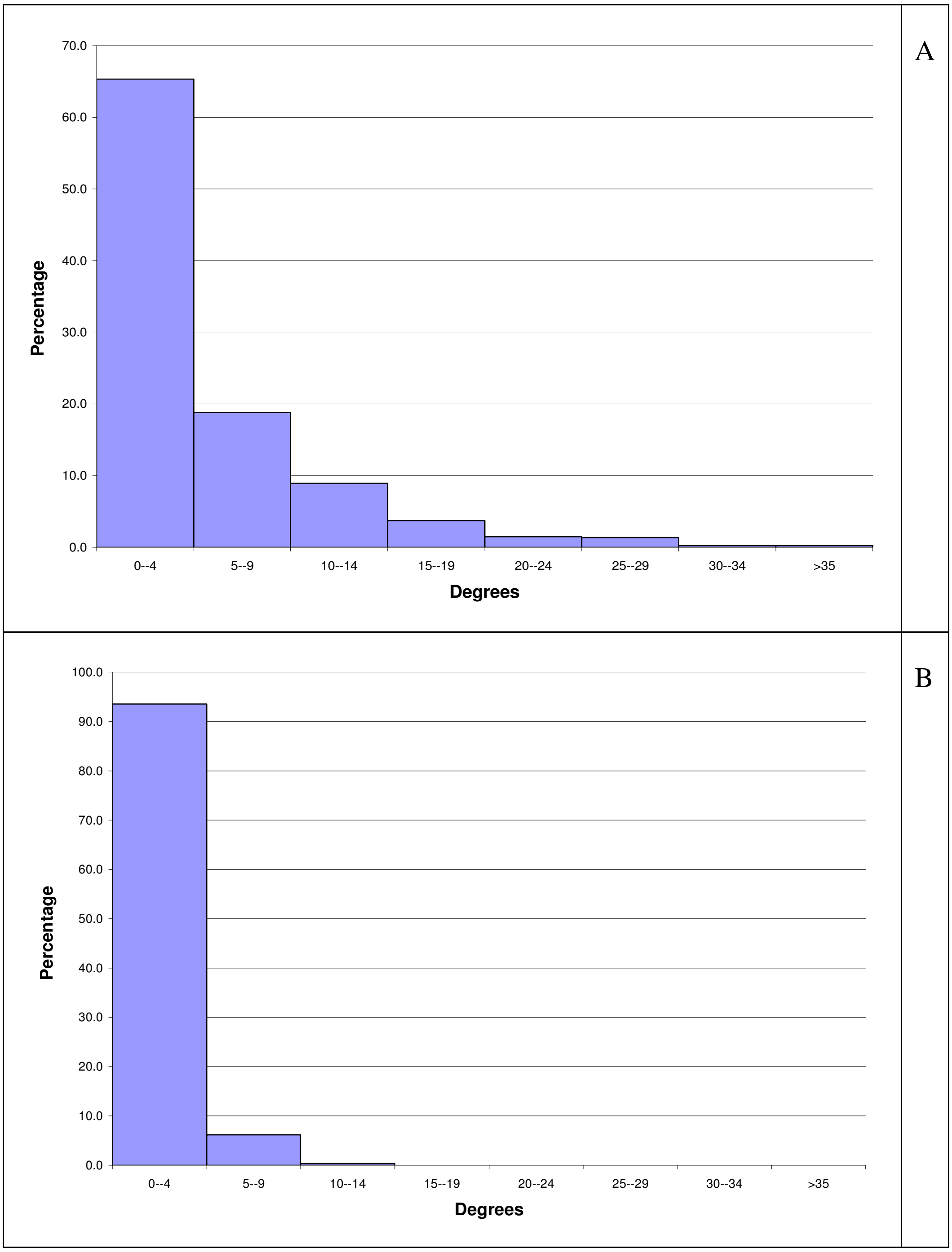


Figure 5.15. Histograms of the slope values along the route of ancient road (A) and the modern road (B).

In both histograms the maximum slope amount is observed at 0-4 degree interval. The percentages of this interval are 65 for ancient and 93 for modern roads. This suggests that both roads use the minimum slopes in the area. Comparison of the slopes, however, indicates that the ancient road is a bit steeper than the modern road.

Slope values depicted in the histograms are not correct which is resulted from the algorithm of the software that computes the slope. This algorithm is illustrated in the sketch topographic map in Figure 5.16. In the figure, the topographic contours (solid lines) and the road (dashed line) indicate that the road is horizontal and therefore the slope amount should be equal to zero. However, while calculating the slope amount the software considers slope amount of the adjacent pixels (4 or 8) and assigns a slope value. Therefore, the slope of a point, for example at A, is calculated in the direction of the arrow which is not horizontal. The reason for a gentler slope for modern road is due to the fact that the road runs at almost right angle to the topographic slope therefore a more accurate slope value is produced for the modern road. That means the ancient route also utilizes the minimum slope as shown in Figure 5.16 since the road is parallel to the topographic contours.

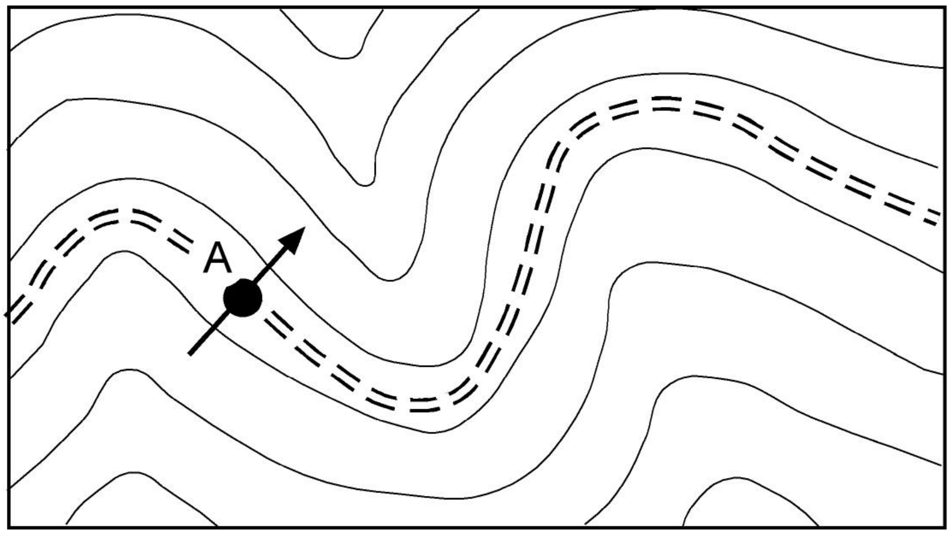


Figure 5.16. Wrong calculation of a horizontal road (dashed) on a sloping surface indicated by topographic contours (solid). The arrow indicates direction of slope calculated for the road at point A.

CHAPTER 6

ANCIENT QUARRY

The question on the source of archaeological remains such as monuments, building stones in the Zeugma lead this study to the search of ancient quarries in the region. Kennedy (1998) reports the existence of quarries with no detailed information. The present excavation team of Zeugma provided some information on the location and the nature of the Roman quarries used for Zeugma. The biggest quarry is located around Gümüşgün village about 17 km north of Zeugma (Figure 2.1). Two visits are made to the quarry to make observations and to take samples. The quarry is located on the western side of the valley and is exposed as a continuous outcrop for a few hundred m (Figure 6.1).

Figure 6.1. General view of ancient quarry 17 km north of Zeugma (view to north)

The quarry excavated in a massive limestone layer within Fırat Formation (Figures 6.2, 6.3). Two most prominent features of the quarry are that it is massive and it is free of joints.

Figure 6.2. A close up view of the quarry (notice the person for scale).

Figure 6.3. A view of the quarry showing the Roman marks on the wall of excavated blocks

On the samples which are acquired from the lower and upper levels of the quarry microscopic analysis is conducted. The microscopic views of both levels are shown in Figure 6.4. According to the microscopic analysis, the lithology is pore free, fossiliferous limestone. When it is compared to the lithologies forming the Gaziantep Formation, the Fırat Formation in which the quarry is located is less porous, more intact with less mud content.

A.

B.

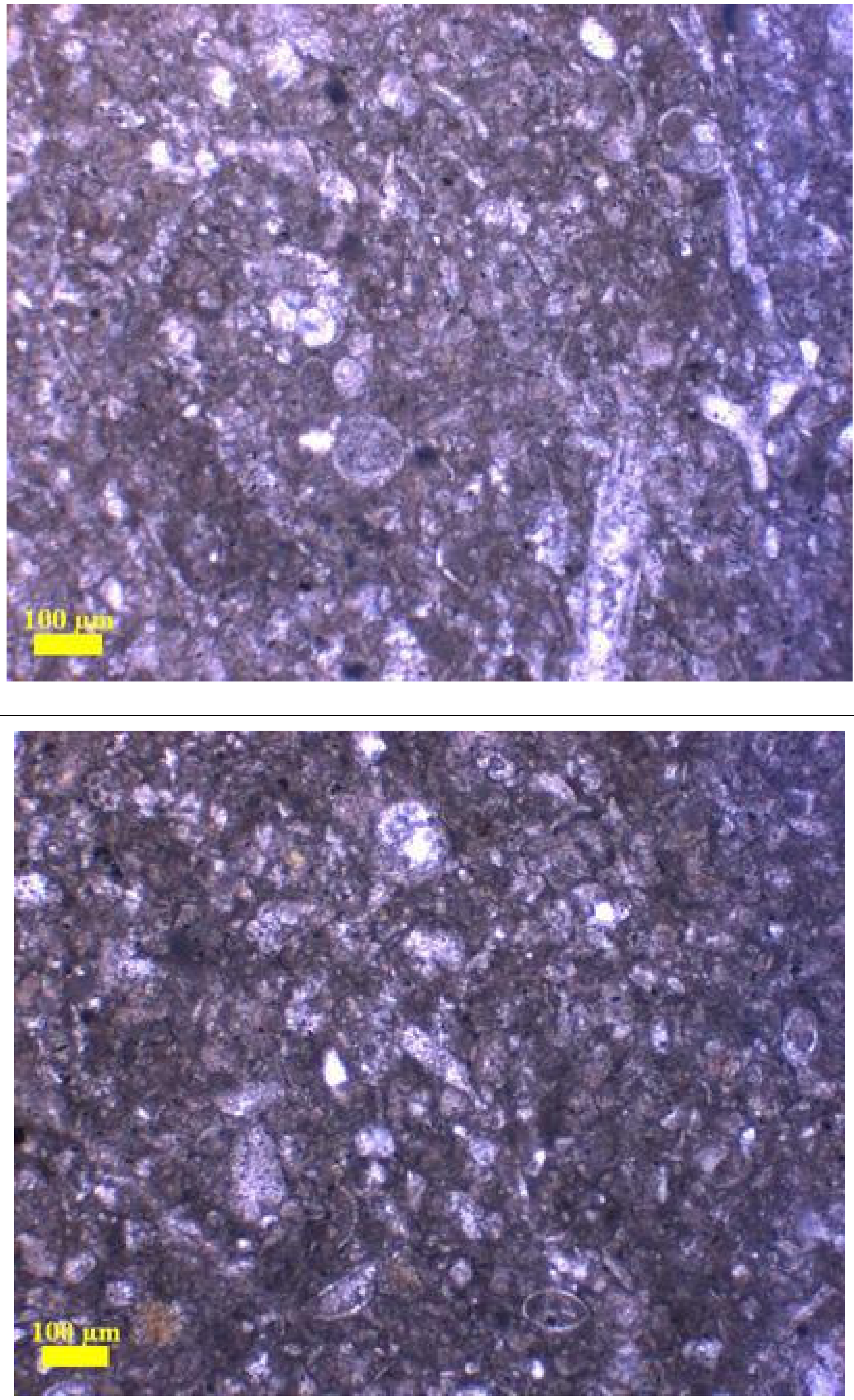


Figure 6.4. Microscopic views of the lower (A) and the upper (B) levels of the quarry

CHAPTER 7

DISCUSSION AND CONCLUSIONS

The main headings to discuss in this chapter are: 1) geology of the area, 2) Fırat River flood plain, 3) results of the aerial photo analysis, 4) morphological analysis, and 5) rock quarries of Zeugma. Necessary recommendations will be made while discussing these features.

7.1. Geology of the Area

Field studies carried out in this study indicate that Zeugma is located in a certain section of Gaziantep Formation which is dominantly composed of limestones. This section is divided into four distinct units identified as, from bottom to top, clayey limestone, thick bedded limestone, chalky limestone and cherty limestone.

The main conclusions on the relationship between Zeugma and these units are that:

- The house units of Zeugma according to the observations in present excavation site are located within clayey limestone. Because of intense jointing and the sheared clayey horizons failures occur in these rooms as they are exposed to the atmosphere.

- Rock tombs are carved in thick bedded limestone. The thickest bed is located almost in the middle part of the sequence. Therefore, spatial distribution of this bed can be used to predict location of unknown tombs.

Talus deposits are common in the area which are represented by semi-consolidated to loose, angular sediments deposited on the flanks of Belkis Hill and cover the ancient city. This unit could not be mapped due to the scale of the map. However, mapping the talus and distinguishing the natural talus deposits from human induced one can contribute to predict the location and the extent of the ancient city.

Joint survey is left out of the scope of this study. However a comparative study of the joints in the field and in the city will contribute to the understanding of the room carvings and be used in the taking measures against engineering behavior of the carved areas such as collapse.

A major normal fault is identified in the area that strikes NW-SE and dips NE. Eastern block of the fault is downthrown with an amount of about 80 m. The main field evidence for this throw is the position of horizontal cherty limestone of both sides of the fault. There might be other smaller faults within the area or close vicinity as indicated by the presence of thick bedded limestone that hold rock tombs at different altitudes in the region. No observation could be made on the lateral component of the fault.

7.2. Fırat River Flood Plain

The flood plain of Fırat River is included in the area for a length of more than 30 km. Most of this flood plain today is filled by the reservoir of the Birecik Dam. Since topographic maps of pre-dam period are available, it is possible to investigate general characteristics of the flood plain.

The flood plain changes from north to south along its route in two aspects. These are the depth and the width of the valley. The valley gradually changes from V-shape to U-shape from north to south. The width of the valley floor increases in the same direction. Based on these properties it can be concluded that the course of the river can be categorized into two segments. The northern segment (between Halfeti and 5 km south of Gümüşgün) displays characteristics of a “valley” while the rest shows properties of a “flood plain”. This segmentation can be attributed to the presence of Fırat Formation in the northern part which is more resistant than Gaziantep Formation.

There are two meandering streams in two sections of the Fırat River. These are located between Halfeti and Gümüşgün in the north and between Zeugma and Birecik in the south. Morphological characteristics of these meanders suggest that the northern meander is an “entrenched meander” inherited from older period. The southern one, on the other hand, is currently being formed and therefore belongs to the recent period.

7.3. Aerial Photo Analysis

Two sets of the aerial photographs are analyzed for the Zeugma-Birecik section of Fırat River to detect possible changes between the years 1953 and 1992. The results of the analysis indicate that (Figures 4.5, 4.6 and 4.7):

- About 12 % of the area has changed within 39 years and the rest 88 % is unchanged.
- Geometry of flood plain has not changed in this interval and keeps its initial margin conditions. However, the total area of flood plain is reduced with an amount of 1.6 % (Table 4.3)
- The river channel is located almost in the same route with almost minor differences. Area of the river channel increased with an amount of 1.5 %.
- The islands formed within the flood plain are the most active regions that comprise maximum changes. Two islands are newly formed west of Birecik. The island in the east of Zeugma, on the other hand started to disintegrate in the new period.

Two dams are constructed in the upstream direction of the Fırat River. These are Keban and Atatürk dams. Atatürk dam is completed in 1992 which is the year for the latest aerial photographs used in this study. Therefore, no effect of this dam is expected on the results of analysis. Keban dam, on the other hand, is completed in 1974 almost 18 years before the latest aerial photographs are provided. Since the construction of the dam over the river will reduce amount of sediment influx, control amount of water released from the dam and thus diminish the energy of the river, the major change is expected to be in flood plain which also includes the islands.

As seen in the change matrix (Table 4.3) the total area of island increases from 5.3 to 8.5% within 39 years. This increase is mostly provided from flood plain (8400 pixels which is approximately 25% of island). That means the river can easily bifurcate to develop an island within the flood plain, due to its low energy. Therefore it can be concluded that construction of Keban Dam is one of the main factors responsible for the changes observed in both flood plain and island.

In change detection analysis regarding the rivers, the season of the aerial photograph acquisition is important because the season determines amount of water present in the river channel. Therefore two photograph sets should belong to the same month in order to evaluate them under the same conditions. The analysis indicates that the river has increased from 10.1 to 11.6 % from 1953 to 1992. The reason for this change, however, can not be indentified because there is no information on the production month of the aerial photographs.

7.4. Morphological Analysis

Digital elevation model (DEM) and its derivatives (relief, slope and aspect maps) form the basis of morphological analyses carried out in the area. The purpose of these analyses is to show the use and the power of the GIS techniques that can be applied to such sites.

Four analyses made in this study (1-testing the elevation of boundary of Gaziantep and Fırat formations using the relief map, 2-investigating the visibility of selected points in the area, 3-predicting the source area for the water supply, and 4-evaluating the nature of the ancient route) are all the subjects for more detailed investigations. In such analysis a certain input field data are required that will increase the reliability and the accuracy of the results. Therefore, these analyses should be considered first attempts for morphological analyses that will be initiated more detailed future works.

1- In the first analysis (the elevation of boundary of Gaziantep and Fırat Formations) the input data used is 1/100.000 scaled geological map. This scale can be considered coarse that leads to low resolution output map. With a larger input map, however, a more accurate, high resolution boundary map could be prepared that can contribute to the geological structure such as faults and folds.

2- As a preliminary study, visibility analysis is performed in archaeological sites or modern settlements to evaluate the suitability of the site from the site selection point of view. In this study, limitations related to human factor, absence or presence of vegetation, atmospheric conditions are not considered in the calculations of viewsheds. Four source locations that have archaeological importance are selected to produce viewsheds. Output viewsheds shows that there is a considerable variation in the areas of four viewsheds. Larger areas can be seen from higher elevations; the visible areas are bounded by the high topography in the viewsheds of lower locations. From visibility aspect, Belkis Hill is an important geomorphological feature of Zeugma, and the visibility of Zeugma should be studied statistically in order to understand the role of visibility in site selection studies.

3-The analysis carried out for the water resources is based only on the elevation of cisterns over Belkis Hill. Considering the elevation of cisterns it can be suggested that the water is transported from a long distance through pressure pipes. Location of the springs should be a must in such analysis in order to predict the most probable source area. However this study is missing the information on the spatial distribution of the springs over the area. Therefore no attempt could be made to identify potential water sources.

4- Route analysis is especially important if there are two alternative roads between two end points. The elements of route analysis are slope of the road, distance between the end points and direction of slope. These elements are determined depending on the scope of the study. In this study, two roads connecting Nizip to Birecik are evaluated. One of them is ancient that passes through Zeugma, the other one is modern and it passes 5 km south of Zeugma (Figure 5.14).

In order to evaluate the shifting of road from ancient route to modern road, slopes of both roads are compared. The results of histograms reveal that ancient route follows topography with higher slope amount than the modern road. However, when the topographical map is examined, it is observed that ancient road passes parallel to the topography (Figure 5.16) and hence it is expected to have smaller slope amounts. These unexpected amounts of high slope values for ancient road is due to the slope algorithm of GIS software which results in wrong values.

In evaluating the routes, settlements that a road passes through are important features as well as the topography. In this study ancient route follows the topography that leads to Zeugma, since Zeugma has a very important place in the antiquity. The bridge of the city allowed for the passage of the Fırat River in the middle Euphrates. But throughout the time, the city lost its importance whereas Birecik remained occupied. The road leading to Zeugma was no longer in use, causing shifting of routes to other settlements such as Birecik.

7.5. Rock Quarries of Zeugma

Certain field observations are made in the largest rock quarry of Zeugma. This observation including petrographic analysis of the rocks exposed in the quarry, however, is not enough to quantify and evaluate the quarry. Two aspects missed in this study about the quarries are:

- Geometry of the quarry and the volume of quarried material should be determined. This task can be performed with sophisticated instruments and require a certain time.

- Lithological characteristics of the rocks in the quarry should be compared with the characteristics of the structures (e.g. columns) existing in the ancient site.

REFERENCES

Aydın, K. E., 2006. *Examining the Lycian Sites by Using GIS,* Master of Science Thesis, Middle East Technical University, The Graduate School of Natural and Applied Sciences, Ankara

Chapman, H. P., 2003. Rudston 'CursusA'- Engaging with a Neolithic Monument in its Landscape Setting Using GIS, *Oxford Journal of Archaeology*, 22:4, 345-356.

Comfort, A.C., Abadie-Reynal, C., & Ergeç, R. (2000). Crossing the Euphrates in Antiquity: Zeugma Seen from Space. *Anatolian Studies*, 50, 99–126

Comfort, A.C., Ergec R. (2001). Following the Euphrates in Antiquity: North-South Routes around Zeugma, *Anatolian Studies*, 51, 19-49.

Dennis, E. O., 2006. Assessing the Level of Visibility of Cultural Objects in Past Landscapes, *Journal of Archaeological Science*, 33:3, 405-413

Ertepınar, Kaymakçı P., 2005. *Geoarchaeological Investigation of Central Anatolian Caravanserais Using GIS*, Master of Science Thesis, Middle East Technical University, The Graduate School of Natural and Applied Sciences, Ankara.

Fisher, P., 1991. First Experiments in Viewshed Uncertainty: the Accuracy of the Viewshed Area. *Photogrammetric Engineering and Remote Sensing*, 57, 1321–1327.

Fisher, P., 1992. First Experiments in Viewshed Uncertainty: Simulating Fuzzy Viewsheds. *Photogrammetric Engineering and Remote Sensing*, 58, 345–327.

Fulat, İ. A., 2005. *Investigating Time Series Shoreline Changes by Integration of Remote Sensing and Geographical Information Systems*, Master of Science Thesis, Middle East Technical University, The Graduate School of Natural and applied Sciences, Ankara.

Gaffney, V., Stancic Z., 1991. *GIS Approaches to Regional Analysis: A Case Study of the Island of Hvar*, Znanstveni Institut Filozofske Fakultete, Ljubljana

Gaffney, V., Stancic Z., 1992. "Diodorus siculus and the island of Hvar, Dalmatia: testing the text with GIS", In: G. Lock, and J. Moffett (1991)(Eds) *Computer Applications and Quantitative Methods in Archaeology,* 113-125. Oxford: Tempus Reparatum, British Archaeological Reports International Series S577

Guild, L. S., Cohen, W. B. and Kauffman, J. B., (2004). Detection of Deforestation and Land Conversion in Rondônia, Brazil Using Change Detection Techniques, *International Journal of Remote Sensing*, 25:4, 731-750

Heywood, I., S. Cornelius, Carver, S., 1998. *An Introduction to Geographical Information Systems*. 2nd ed. Prentice Hall.

Jensen, J. R., Im J., 2007. Remote Sensing Change Detection in Urban Environments, In: Jensen, R.R.; Gatrell, J.D.; McLean, D. (2007) (Eds.) *Geo-Spatial Technologies in Urban Environments Policy, Practice, and Pixels*, 7-31. Springer Berlin Heidelberg

Kennedy, D. L. (1998). Zeugma, The South-East Anatolia Development Project, and fieldwork on The Turkish Lower Euphrates, In: Kennedy, D. L. and Freeman, P. W. M., (1998), *The Twin Towns of Zeugma on The Euphrates. Rescue Work and Historical Studies*, Portsmouth, RI (JRA, Supplementary Series 27)

Kennedy, D. L. and Bunbury, J., (1998). Geography and Environment, In: Kennedy, D. L. and Freeman, P. W. M., (1998), *The Twin Towns of Zeugma on The Euphrates. Rescue Work and Historical Studies*, Portsmouth, RI (JRA, Supplementary Series 27)

Kennedy, D. L. and Kennedy J., (1998). The Twin towns and The Region, In: Kennedy, D. L. and Freeman, P. W. M., (1998), *The Twin Towns of Zeugma on the Euphrates. Rescue Work and Historical Studies*, Portsmouth, RI (JRA, Supplementary Series 27)

Lake, M. W., Woodman P. E., 2003. Visibility Studies in Archaeology: A Review and Case Study, *Environment and Planning B: Planning and Design*, 30, 689-707

Llobera, M., 2003. Extending GIS-Based Visual Analysis: The Concept of Visualscapes, I*nternational Journal of Geographical Information Science*, 17:1, 25 – 48

Lu, D., Mausel, P., Brondízio, E. and Moran, E., (2004). Change Detection Techniques, *International Journal of Remote Sensing*, 25:12, 2365-2401

Microimages TNT-MIPS, 2008. (http://www.microimages.com/getstart/pdf/ Terrain. pdf), Microimages Downloads (Online Reference)

Munyati, C., (2000). Wetland Change Detection on the Kafue Flats, Zambia, by Classification of a Multitemporal Remote Sensing Image Dataset, *International Journal of Remote Sensing*, 21:9, 1787-1806

Nichol, J., Wong, M. S., (2005). Satellite Remote Sensing for Detailed Landslide Inventories Using Change Detection and Image Fusion, *International Journal of Remote Sensing*, 26:9, 1913-1926

Ozawa, K., Kato T., Tsude H., 1995. Detection of Beacon Networks Between Ancient Hillforts Using a Digital Terrain Model Based GIS", In: J. Huggett, N. Ryan (1995) (Eds), *Computer Applications and Quantitative Methods in Archaeology*, 157-162, Archaeological Reports, Oxford.

Singh, A., 1989. Digital Change Detection Techniques using Remotely Sensed Data, *International journal of Remote Sensing*, 10:6, 989-1003

Summak, M. S., 2008. A Brief History of Zeugma, http://www.zeugmaweb.com/zeugma/English/engindex.htm, Accessed on 5 May 2008 (Online Reference)

Ulu, Ü., (1996). 1:100.000 Ölçekli Açınsama Nitelikli Türkiye Jeoloji Haritaları Serisi No. 42 Urfa – K 25 Paftası

Ulu, Ü., Genç Ş., Giray S., Metin Y., Çörekçioğlu E., Örçen S., Ercan T., Yaşar T. and Karabıyıkoğlu M., (1991). *Belveren-Araban-Yavuzeli-Nizip-Birecik Alanının Jeolojisi Senozoyik Yaşlı Volkanik Kayaçların Petrolojisi ve Bölgesel Yayılımı*, MTA Derleme Rap. No. 9226, Ankara (Unpublished)

Ulusoy, D., 2006. *Archaeology of the Galatians at Ancyra from the Hellenistic Period Through The Roman Era*, Master of Science Thesis, Middle East Technical University, The Graduate School of Social Sciences, Ankara.

Wheatley, D., 1995, Cumulative Viewshed Analysis: a GIS-based method for investigating intervisibility, and its archaeological application, In: G. Lock and Z. Stancic (1995) (Eds) *Archaeology and Geographical Information Systems: a European Perspective:* 171-186. London: Taylor & Francis.

Wilson, H. H. and Krummenacher R., (1957). Geology and Oil Prospects of The Gaziantep Region; Available Information in Technical fields of NV Turkse Shell, 1963 Petroleum activities in Turkey. Petroleum Administration Publication Bult. No. 8

Yoldemir, O., (1987). Suvarlı-Haydarlı-Narlı-Gaziantep Arasında Kalan Alanının Jeolojisi, Yapısal Durumu ve Petrol Olanakları, T.P.A.O. Raporu No. 2275 (Unpublished)