EARTHQUAKES AND ANCIENT SITE SELECTION IN WEST ANATOLIA

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ABSTRACT

EARTHQUAKES AND ANCIENT SITE SELECTION IN WEST ANATOLIA

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This study investigates the relationship between the ancient settlements in west Anatolia and physical, environmental parameters including topography, rock and morphological classes. Modern settlements are also included in the study to analyze if the response has changed to these parameters from past to the present. The databases created in the study include three topographic attributes (elevation, slope and aspect), rock type, ancient settlements and modern settlements. Analyses performed in the study involve distance and density analyses, morphological analysis; distribution within the rock types both for ancient and modern settlements.

The results of the study demonstrated that 1) the active faults produced attractive topography to settle, 2) people preferred the vicinity of the fault line as settlement location, and 3) they were not aware of the earthquake potential of their location. Therefore, because of the advantage of the location they did not consider to change the place as indicated by rebuilding their settlement repeatedly at the same place after it is damaged.

Key words: earthquakes, active faults, Greek and Roman period, west Anatolia, GIS

ÖZ

BATI ANADOLU BÖLGESİNDE DEPREMLER VE ANTİK YER SEÇİMİ

TOKMAK, MUSA

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Ortak Tez Yöneticisi: Prof. Dr. Musa Kadıoğlu

Mart 2012, 157 sayfa

Bu çalışma, antik yerleşimlerle bu yerleşimlerin sahip olduğu topografik, kaya ve morfolojik tipleri gibi fiziksel ve çevresel parametreler arasındaki ilişkileri incelemekte. Bu çalışmada modern yerleşimlerde yer verilerek zaman içinde depreme olan tepkinin geçmişten günümüze değişip değişmedi analiz edilmeye çalışılmıştır. Çalışmada üç topoğrafik değer (yükseklik, eğim, bakı), kaya türü, antik yerleşimler ve modern yerleşimlerin veritabanları yaratılmıştır. Çalışmada, antik ve modern yerleşimler için uzaklık ve yoğunluk analizi, morfoloji analizi; her iki yerleşim için de kaya türlerinin dağılımın analizi yapılmıştır.

Bu çalışmanın sonuçları şunları göstermiştir 1) aktif faylar yerleşim için uygun topoğrafyalar oluşturmuştur, 2) yerleşim yeri olarak insanlar fay hattına yakın yerleri seçmişlerdir, ve 3) onlar yerleşim yerlerindeki deprem potansiyelinden farkında değildiler. Buna ilaveten, yerleşim yerlerinin avantajından dolayı, zararda görseler tekrardan binalar yaparak yerlişim yerlerini değiştirmeyi düşünmemişlerdir.

Anahtar kelimeler: deprem, aktif faylar, Yunan ve Roma dönemi, Batı Anadolu, GIS

To My Family

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CHAPTER I

INTRODUCTION

1.2. Purpose and Scope

The main motivation behind this study is based on two facts commonly observed in Turkey. These are: 1) Turkey is geologically located within an active area. Active tectonism in most cases is the primary reason for the natural hazards. Most of the hazards such as earthquakes, landslides, volcanic eruption, tsunami etc are either direct results or triggered by the active tectonism. Earthquakes which are the main focus of this study negatively affect the society as they result in loss of human life and commodity. Last earthquakes (1999 Izmit-Kocaeli earthquake and 2010 Van earthquake) are typical examples. 2) Turkey is a country very rich in archaeological sites (settlements and others) of different periods. Most of these settlements are believed to suffer particularly from the earthquakes. The excavation reports of some ancient settlements are the evidences for this belief. Information on the affect of earthquakes on the ancient settlements is so extensive that the damage in some cases cannot be simply explained by the "magnitude" of the earthquakes. For example, the same city is repeatedly ruined by the earthquakes and is rebuilt at the same location.

The purpose of this thesis is to evaluate the location of settlements in relation to active faults existing in the area. The main hypothesis in this study is that there is a genetic relationship between the active faults and the location of the settlement. A set of assumptions can be raised to test this relationship:

- Active faults can shape the earth and produce a suitable landform to settle. This is although a fact already known in the geology it should be tested in the area investigated.

- Ancient people built their settlements close to the active faults. Since the faults modify the earth surface and produce attractive landform for settlements, the settlements should be checked for their location with respect to active fault lines.
- Although the earthquake is known by the ancient civilizations, they did not recognize the "fault line" so that they insist to rebuild their settlement in the same location.

These assumptions that should be tested in an area where 1) there are active faults, 2) the faults shaped the earth surface to produce attractive settlement locations, 3) there are statistically enough ancient sites in the area, 4) there are records of ancient earthquakes in this region. Therefore, the scope of the thesis is limited in historical period and geographic location in order to achieve the purpose:

1) Ancient settlements selected should belong to a relatively narrow time interval to keep the consistency in their response to the earthquakes. Considering the quantity of known ancient settlements, the Greek and Roman periods are selected for the investigation.
2) Study area is defined as Western Anatolia because a) there is a large concentration of Greek-Roman period settlements in this region, and b) the whole region is tectonically active (rather than a belt) as already known by its "horst and graben system".
3) Modern settlements are also included in the study in order to justify the change occurred in the region since the ancient times.

A methodology is developed in the study area to seek the relationship between the location of the settlements and the active faults that may produce earthquakes. However, since there is not a complete "fault map" of the area, the morphology and geology of the region are utilized to infer the fault traces. Therefore, the scope of the thesis is based mainly on the investigation of the morpho-geological features of the study area considering the settlement locations. Details of this relationship between the settlement location and the fault traces will be tested in some selected areas as "case studies".

1.2. Study Area

The study area covers some parts of the western Anatolia in a wedge shape bounded by the Aegean coast at the west (Figure 1.1). The final boundary is decided after the compilation of the ancient sites so that the areas that do not possess any sites are excluded. The area covers approximately 47520 km2 and lies in the Zone 35 (north) of the UTM projection system with ED 50 datum.

Six modern provinces are included in the study area. These are Izmir, Aydın, Manisa, Muğla, Denizli and Uşak. The first three provinces are almost totally located in the area whereas the last three are partially included.

Three major rivers, namely, Büyük Menderes, Küçük Menderes and Gediz, are almost entirely located within the area. All these rivers are flowing westward and reach the Aegean Sea. These rivers have wide fertile flood plains which might play an important role in the settlement history of the region.

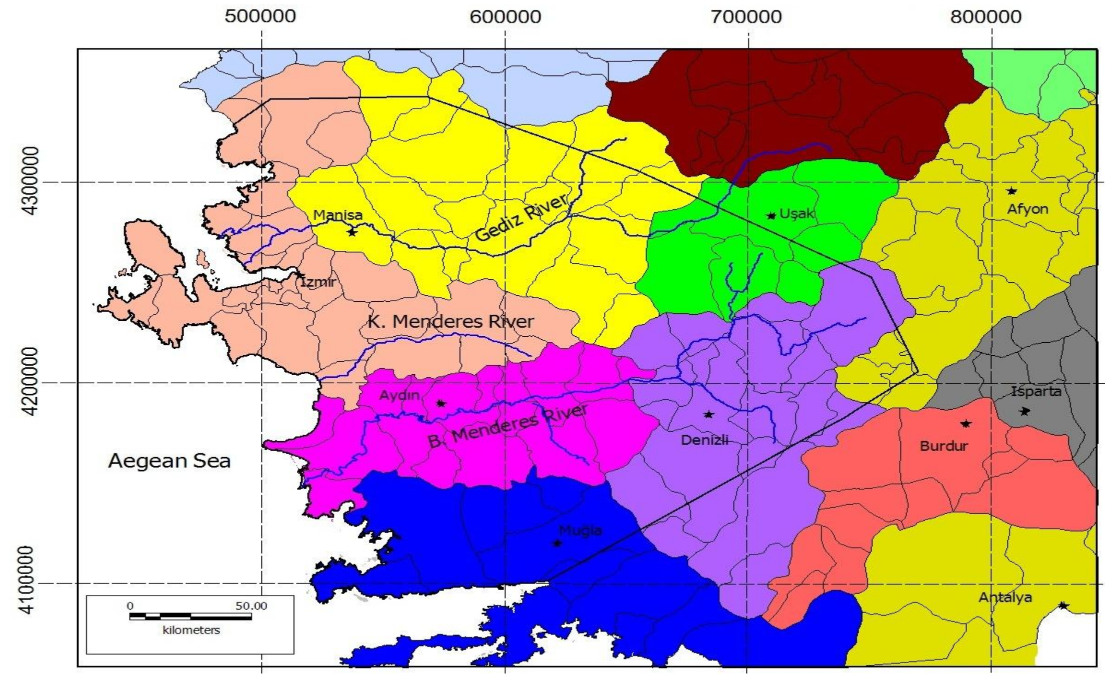


Figure 1.1. Location map of the study area.

1.3. Method of Study

This thesis is completed as an office work that is composed of mainly of data compilation and computer processes. The most time consuming stage of the thesis is the compilation of ancient and modern sites. Since there is not ready catalogues for these data, they are all selected from necessary base maps one by one and digitized.

The fault data is one of the most essential data input data for this study. At the initial stage of the thesis an attempt is made to gather the fault data from different geological sources and create a database. However, because of the lack of data and /or inconsistency in the fault traces, later it is decided not to use the fault data and instead utilize the morphology to infer the fault data.

Geology map is obtained from Mineral Research Institute of Turkey (MTA) and used without any modification. Therefore, no field studies are carried out to improve the geology map.

The main software used in this study for GIS applications is Mapinfo version 8.5. All digitization processes are carried out and databases are created using this software. Microsoft Excel is used to prepare the resultant charts and histograms.

1.4 Organization of Thesis

The thesis is organized as nine chapters as follows:

Chapter 2 gives short description of ancient cities used in this study.

Chapter 3 introduces basic information as background on the: 1) earthquake and mythology, 2) earthquake perception by ancient philosophers, 3) earthquake traces in ancient settlements, 4) major ancient earthquakes in western Anatolia, and 5) earthquakes and ancient construction techniques.

Chapter 4 describes geology of the study area with a particular emphasis on active faults.

Chapter 5 presents data that used in the study. In that chapter, three sets, the processing steps and the results are introduced.

Chapter 6 describes the method and the analysis carried out for the investigation of the relationship between ancient and modern settlement locations in relation to faults.

Chapter 7 is the case study. Several selected sites cities will be evaluated to investigate the relationship between the location of the ancient sites and the active faults.

Chapter 8 is about the active faults and the settlements. In this chapter the relationship between the location of the settlements and the active faults compiled by MTA will be investigated

Chapter 9 discussess the results and concludes the final remarks of this study.

CHAPTER II

ANCIENT CITIES USED IN THE STUDY

This chapter describes the ancient cities of western Anatolia used in this study. There are several sources showing the locations of the ancient cities within the study area. Although most of the sites are well-known and are repeated in different sources, there are still some inconsistencies among some catalogues considering the location and name of the city. The “Tubinger Atlas des Vorderen Orients” is used for the identification of the ancient cities (Figure 2.1). Some of these cities are excavated and present sufficient data while some others are known only by name. A brief description of these cities is given below in alphabetical order.

Figure 2.1: Ancient Greek and Roman period cities used in this study (Tubinger Atlas des Vorderen Orients (TAVO): Series)

Table 2.1 A short view to Ancient Cities

ANCIENT CITY	LOCATION
Aigai	Köseler Manisa
Airai/Eirai	Kuşadası İzmir
Akrasos	İlyaslar Manisa
Alabanda	Doğanyurt Aydın
Alinda	Karpuzlu Aydın
Amyzon	Koçarlı Aydın
Anineta	Bögdecik Manisa
Antiocheia	Aksehir
Aphrodisia	Karacasu Aydın
Apollonias	Sıçak Muğla
Appollonos Hieron	Buldan Denizli
Attaleia	Salihli Manisa
Attouda	Sarayköy Denizli
Aurelioupolis	Salihli Manisa
Barglia/Bargylion	Bodrum Muğla
Blaundos	Uluğbey Uşak
Brioulla	Kuyucak Aydın
Daldis	Kula Manisa
Didyma	Didim Aydın
Dionysopolis	Çal Denizli
Elaia	Zeytindağ İzmir
Ephesus	Selçuk İzmir
Erythrai	Ildır İzmir
Eumeneia	Çivril-Dinar Afyon
Euromos	Milas Muğla
Gordos	Gördos Manisa
Halicarnassus	Bodrum Muğla
Harpasa	Esenköy Nazilli
Herakleia	Bafa Aydın
Hierokaisareia	Salihli Manisa
Hieropolis	Denizli
Hydai	Midas Mugla
Hyllarima	Yatağan Muğla
Hypaipa	İzmir
Keramos	Milas Muğla
Klaros	Degirmendere İzmir
Klazomenai	Urla İzmir
Koloe	Kula Manisa
Kolophon	Didim Aydın
Kyme	Aliaga İzmir
Labranda	Milas Muğla

ANCIENT CITY	LOCATION
Lagina	Yatağan Muğla
Laodikeia	Goncalı Denizli
Lasos	Milas Muğla
Lebedos	Seferihisar İzmir
Magnesia	Manisa
Magnesia ad Meandrum	Ortaklar Aydın
Mastaura	Nazili Aydın
Metropolis	Torbalı İzmir
Miletos	Söke Aydın
Mobolla	Muğla
Mossyna	Denizli
Mylasa	Milas
Myndos	Bodrum Muğla
Mynneuses	Bögdecik Manisa
Myrina	Aliaga İzmir
Notion	Kuşadası izmir
Nysa	Sultanhisar Aydın
Orthosia	Yenipazar Aydın
Palaiapolis	Beydağ İzmir
Panionion	Söke Aydın
Pergamon	Bergama İzmir
Philadelphia	Alaşehir Manisa
Phokaia	Foça İzmir
Phygela	Kuşadası izmir
Pitane	Candarlı İzmir
Priene	Aydın
Sanaos	Simav Kütahya
Sardis	Sart Salihli Manisa
Satala	Salihli Manisa
Settai	Kula Manisa
Silandos	Karaselendi Manisa
Smyrna	İzmir
Stratonikeia	Eskihisar Mugla
Tabala	Kula/Manisa
Teos	Seferihisar İzmir
Theodosiopolis	Kula Manisa
Thyateira	Akhisar Manisa
Tralleis	Aydın
Trapezopolis	Babadağ Denizli
Tripolis	Buldan Denizli

Aigai: It is an ancient Greek city in Köseler village in Manisa, Turkey. It was situated over a high altitude of Mount Güldağı. Both Herodotus and Strabo mentioned Aigai as a member of the Aeolian confederation. It was also an important sanctuary of Apollo (Negev and Gibson, 2001).

Airai: It is an ancient city near Kuşadası-Davutlar İzmir. It was situated Ada peninsula on the coast of Demirci village and the ancient city has some ruins today but the city not totally uncovered (Finlay and Tozer, 1877).

Akrasos: It is an ancient city near Ilyaslar village in Kırkağaç Manisa. There are little archaeological traces in the ancient city. The main architectural elements of nowadays are blocks, columns, ties, etc (Ramsay, 2010).

Alabanda: It is an ancient Greek city near Doğanyurt (Araphisar) village in Aydın. The city was founded by a Carian hero Alabandus. The ruins of Alabanda consist of a theatre and many other buildings. Few inscriptions are also found in the ancient city (Duyuran, 1960).

Alinda: It is an ancient city of Caria in Anatolia. It is situated on a hilltop near the town of Karpuzlu in Aydın. Alinda is firstly founded by Karians. The ruins of Alinda include a Roman amphitheater in relatively good condition and a number of remains of temples (Akşit, 1982).

Amyzon: It is an ancient city 30 km south of Koçarlı in Aydın. Amyzon is firstly excavated by Louis Robert. There are some remains of buildings and a number of large vaulted underground chambers. There are some Byzantine structures in the city as well (Ma, 1999).

Anineta: It is an ancient city in Caria. It is located in Bögdecik Village in Manisa. Little is known about the ancient city. It was located between Nysa and Tripolis (Umar, 1993).

Antiocheia: The location of the ancient city lies southwest of Aksehir on the border between Pisidia and Phrygia. According to the Greek geographer Strabo, Antiochia was founded by the colonists from Magnesia. The city was excavated by the British archeologist W.M.Ramsay in 1912 (Duyuran, 1960).

Aphrodisia: It is located near the Geyre village (Karacasu, Aydın). The city was built near a marble quarry. In the Hellenistic and Roman periods, this marble quarry was mined largely by the Aphrodisian people. The city was protected by the Goddess of Beauty, Aphrodite and marble sculpture of Aphrodisias became famous in the Roman world. The ruins of temple of Aphrodite and the baths, the agora, city walls, the odeon, the hippodrome and the City Gate are the main remnants of the ancient Aphrodisia (Joukowsky, 1986).

Apollonia: It was located near Sıçak village in Muğla. It was an ancient Lycia city (Bryce, 2009).

Appollonous Hieron: It is located near Bozalan village in Budan Denizli. It was within the Lydian region. The city was suffered from an earthquake in Tiberius time (Colvin, 2004).

Attaleia: It was an ancient city located near Sardis ancient city, Salihli Manisa (Sevin, 2001). There is no more information about the ancient city hence it was not uncovered yet.

Attouda: It is located in southwest of Sarayköy (Denizli). Attuda was on the border between Caria and Phrygia in the ancient times. As with other ancient cities in Lycus Valley, Attuda was founded in the Hellenistic era. Because of the location of the Hisarköy vilage on the site, there are a few ruins (Murray, 1878).

Aureliopolis: It was an suffragan of ancient Sardis. The city is in Salihli Manisa (Binhom, 1840). There is no more information about Aurepolis.

Bargylia: It is located in the Bodrum peninsula. After conquering the city, Alexander the Great used the city as a military base in the fifth century BC. The main remnant of the ancient Bargylia consist of a Roman temple which was scattered over the area, ruins of the theater, city walls from the Byzantium period and some parts of the necropolis (Newton and Pullan, 2011).

Blaundos: It was an ancient city Sümenli village (Uluğbey, Uşak). The date of its original establishment is unknown but the city was re-founded as a Macedonian military settlement in Hellenistic times. The main remains of the ancient city are some building fragments on the hilltop acropolis (Ramsay, 2004).

Brioulla: There is no information about the exact location of the city. It is estimated that the city is located around Bilara Village (Kuyucak, Aydın) (Ramsay, 2010).

Daldis: The ancient city was located 35 km from Kula Manisa. It was a Greek city. The ancient city was not excavated (Mitchell, 2001).

Didyma: It is an ancient Ionian city in the modern Didim. The main remain of the ruins is a temple of Apollo, the Didymaion (Fontenrose, 1988).

Dionysopolis: The city is located Ortaköy village in Çal (Denizli). It was firstly founded by the Seleukos. Dionysopolis was later occupied by the Pergamon king. The main ruin is the temple of Apollon Lermenos (Ramsay, 2004).

Elaia: It is located near Zeytindağ in İzmir. There is no more information about it hence there is no excavation (Talbert, 1998).

Ephesus: It is one of the twelve cities of the Classical Greek era and was the second largest city of the Roman Empire with more than 250.000 inhabitants in the first century BC. It was also the second largest city in the world (Cremin, 2007). Ephesus is located near Selçuk, İzmir possessing one of the seven churches of Asia. The Temple of Artemis was completed around 550 BC in Ephesus. In 401 AD the temple was destroyed. In 614 AD the city was destroyed by a severe earthquake. Due to the silting up of the city by Cayster River (today's Küçük Menderes), Ephesus commercial importance was decreased (Foss, 2010).

Erythrai: It is an ancient Greek city located near to Ildır (Çeşme-Izmir). The city is partly excavated. It developed its trade due to good relationship established with Egypt, Cyprus and other western cities. A theater is preserved in the ancient city (Akurgal, 1978).

Eumeneia: The city is located near Çivril (Dinar, Afyon). It was founded by Pergamon King Eumenes II. There was a medical school in Eumeneia and medicine was accepted as a science by its citizens (Ramsay, 2004).

Euromos: It is an ancient city near Milas (Manisa). After Mylasa (today's Milas), Euromos was the most important city in the region. A well preserved Temple of Zeus, a ruined theater are the main remnants of the ancient city (Akurgal, 1978).

Gordos: It is an ancient city near Gördos province in Manisa. There is no more information about the ancient city hence there is no excavation (Foss, 1990).

Halicarnassus: It is an ancient Greek city at the site of modern Bodrum (Muğla) and located in southwest Caria. The city was founded around 1000 BC by Dorian settlers from Greece. The tomb of Mausolus, one of the seven wonders of the ancient world, was built between 353 and 350 BC in Halicarnassus. Mausoleum is the general term for a large tomb. The entire height of the Mausoleum was 50 meters (Akşit et al, 1980).

Harpasa: It was located in near Esenköy (Nazilli, Aydın). It was in Caria. The city was located on terraces of the Asar hill. The theatre in the city shows the features of Hellenistic period (Thomas, 1866).

Herakleia at the Latmos: Herakleia is located on the eastern shoreline of the Bafa Lake. The lake at that time was connected to the Aegean city. It was founded in the 5th century BC as a Carian settlement. The city took its name from famous mythological figure, Herakles. The city had a regular plan because of the defensive purposes. The city became a commercial importance by the sea trade (Cohen, 2006).

Hierokaisareia: It is an acient city near Sazabey and Beyoba villages (Salihli, Manisa). The name of the city was given by the Emporor Augusos. The meaning of the “Hierokaisareia” is “holy village”. The city was sacked by Macedonian King Philippos V. In 201 BC and Bthynia King Proussia in 155 BC. Today there is not any protected ruin in the ancient city (Habelt, 2006).

Hieropolis: The city is founded in second BC located near a thermal spring. The city name was given for the honor of Telepos' wife, Hiera. In 1957 Italian scientists Paolo Verzone started to excavate the city (Türkoğlu, 1990). Many sections of the city collapsed because of the earthquake, such as large columns along the main street were erected again. Many statues and friezes were transported. Many statues of Hieropolis were transformed to the museums of London, Berlin and Rome (Herrmann, 2000).

Hydai: The city is located in Damlibogaz (Midas-Mugla). The city was silted up with alluviums carried by the Sarıçay. Hydai means "water" in ancient Greek language. In older times, Hydai's ceramics were famous and they were exported to Rhodes (Küçükeren, 2007).

Hyllarima: It is an ancient Roman city near Derebağ village in Yatağan Muğla. There is no more information about the ancient city hence there is no excavation (Marchese, 1989).

Hypaipa: It is located in the Günlüce village (Ödemiş, İzmir). The name means "rocks" in ancient Greek language. The city served a tax collecting center in the IX century BC (Oaks and Nesbitt, 2005).

Keramos: It is located north of coast of Gökova Gulf (Milas, Mugla). Keramos was famous with its ceramic arts in 3000 BC. The city was flourished from the 6th century BC to 3rd century AD (Küçükeren, 2007).

Klaros: This ancient city was a prophecy center of Colophan which was one of the twelve Ionic cities. It is located in Değirmendere in İzmir. It was built between ancient cities of Colophon and Notion. The Temple of Apollo like in Didyma and Delphi was center of prophecy. According to the Homeric Hymns, the history of the city goes back to sixth and seventh centuries BC (Akurgal, 1978).

Klazomenai: It is located in Urla (İzmir). The city was firstly built on the mainland but after the Ionian Revolt from Persians, it was moved to an island just off the coast. Alexander the Great connected the island with mainland with causeway (Newton and Pullan, 2011).

Koloe: This is a small ancient city near Kula (Manisa). There are a few ruins in the city and there is no information about it (Chaniotis et al., 2006).

Kolophon: The city is located in Değirmendere (Didim, Aydın). The city was one of the most important cities of Ionia. Because of the fertility of the area and close distance to the sea, Kolophon became a wealthy and commercial city. The city was under the rule of Persians until the Alexander the Great who captured and re-granted the city its domination. The ruins of the city are well preserved. Some of the ruins on the northern slopes still exist today (Akurgal, 1978).

Kyme: It was an ancient Greek city and was located near Aliaga (İzmir). It was founded at the 11th BC and the city inhabited until 16 th BC.Kyme was one of the important of the twelve cities of Aeolis. In the 5th Century BC, Kyme struggled to be free from the Persian control. But later Cyme was a city of Seleucids and Roma successively (Bakhuizen, 1985).

Labranda: It was a located on a hill 12 km northeast above Milas Muğla. The city inhabited since 6th centruies BC. The city was abondened in the 11th Century AD. The main building in the city is the Temple of Zeus. This shows that Labranda was a holy place. The other remants of the city include the ruins of stadium, the solid andor and a monemental tomb (Campbell, 2007).

Lagina: It was an anceint Greek city near Turgut, on the Yatagan-Milas road. It was a holy city that the goddess of moonlight and the Hekate temple were in Lagina. The excavation area was the first one that was carried out by Turkish scientists. These excavations have been carried out by Osman Hamdi Bey and Halit Ethem Bey. The friezes of the Hekate Sanctuary are being displayed in the İstanbul Archaeology Museum. The four side of the Hekate friezes have four different themes (Zeus, Carian Gods, a battle of the Amazons and a battle of Gods and Giants) (Smedley and Rose, 1845).

Laodikeia: It was an ancient Greek and Roman city. According to legend, it was founded by Antiochus II Theos of the Seleucid Kingdom in the 3th century BC. But some buildings and the monuments dates back to first century BC. Laodikeia was an important city until inhabited after a severe damage in 60 AD. The main ruins of the ancient city include stadium, gymnasium a bath complex and a temple of Zeus (Akurgal, 1978).

Iasos: It was founded near Kıyıkışlacık village in Milas Muğla. Iasos was formerly an island for protection purposes. The first excavation was done by Charles Texier. The walls, agora, theatre, gymnasium, baths are the remains of the city (Campbell, 2007).

Lebendos: It was one of the twelve Ionian cities. Lebendos was situated near Urkmez Village in Seferihisar, İzmir. It was on a very small peninsula which is called Kısık peninsula. Lebendos was one of the poorest and not an important commercial center of the Panionic league (Ramsay, 2004).

Magnesia: Magnesia was located in Manisa. The city was known as Magnesia ad Sipylum in antiquity. The city was destroyed in the reign of Tiberius. The emperor restored the city and later the city flourished through the Roman Empire (Küçükeren, 2007.

Magnesia Ad Meandrum: Magnesia was located in Tekinköy village in Ortaklar Aydın. The city can be seen on the way Ortaklar to Söke road. The Magnetes, came from Greek Mainland, founded the Magnesia. The first setllements of the Magnetes is not known but it is estimated that it was somewhere along the Meander river. Because of the Persian invasions and epidemiz outbreaks, the city moved actual location. The city preserved its status during the Roman and Byzantine period. Magnesia was positioned within a position in ancient times as its strategical and commercial importance. The city had a grid plan and city was surrounded wih a big wall. The ruins of Magnesia was good preserved and intact. This was due to silting up caused by the river. Carl Humann from the University of Belin started the first excavation in 1891. The teathre, temple of Zeus, agora, atlar of Artemis were unearthed from heavily sedimented site. The remnants of the ancient Magnesia are displayed in İstanbul, Paris and Berlin museums (Mitchiner, 1978).

Mastaura: The city of Mastaura was located near ancient city Nysa at the Maender Valley. The city is near Nazilli (Aydın). In ancient times it was a commercial center (Ramsay, 2004).

Metropolis: The classical city of Metropolis was located in Torbalı, İzmir. The city was firstly excavated in 1972 by archaeological field work led by Dokuz Eylül University. The earliest settlement at the site goes back to neolithic periods. During the Hellenistic kingdom of Pergamum, the city reached its zenith of economic and cultural. Temple of war god Ares was located in Metropolis (Ayliffe et al., 2003).

Miletos: It was an ancient Greek city on Maeander River near Aydın. The city was flourised before the Persian invasions. The first settlement of Miletos was not known due to the deposition of the sediments from Maeander River. But some findings in the excavation area shows that the history of Miletos goes back to Neolithic period. In 334 BC, the city was liberated from Persian rule. The New Testament mentions Miletos was a site where Paul met the elders of church of Ephesus in 57 AD (Akşit, 1982).

Mobolla: It was situated at the upper skirt of Muğla. In ancient Hittite inscriptions “Mobolla Caste” was mentioned. The city was located over a hill suitable for the defense purposes. At the lower plain of Mobolla sacred places reflecting Hittite, Frigian and Carian and Lykian periods can be seen. The ruins include a well preserved rectangular Mobolla castle, a medieval place debris stone blocks and burial grounds and tombs (Ramsay, 2010).

Mossyna: It was an ancient Greek city in Phrygia in the middle of Maeander valley. It was located between Dionysopolis and Laodikeia (Ramsay, 2004).

Mylasa: It is today’s Milas. It was the earlier settlement of the region. Mylasa was the fomer capital of Caria and Anatolia Mentese Beylik in the medieval period.

The former city was situated at Percin Kale, 3 km awaf from Mylasa. During the 4th BC, the city moved to its present site. The city was its zenith during the 4th century BC Mylasa supplied good quality marble to nearby cities. After the Carian capital move to Halicarnasus, Mylasa continued its importance throughout the Hellenistic and Roman periods. The main remants of the ruins of Mylasa are the Temple, Baltali kapi (the gate with axe) and the temple of Augustus (Freely, 1991).

Myndos: It was located on the coast of Bodrum peninsula, a few kilometres away from nortwest of Halicarnasus. The ancient site is now situated by today's Gumusluk village. It had a well protected harbor.The ancient city was built by King Mausolus in the 4th BC (Oswin, 2007).

Mynneuses: It was an ancient city near Doğanbey-Seferihisar in İzmir. The history of Mynneuses dates back to 500 century BC (Umar, 1979).

Myrina: It was one of the Aolian cities on the Sandarlik village in Aliaga, İzmir. It is very close to the ancient city Kyme. Myrina was noted for its huge necropolis which goes back to Hellenistic period. History of the ancient Myrina comes from the mythology and legend. According to the legend, Amazons visited the city and Amazon queen, Myrina, gave the city name. In the 3th century BC, an earthquake destroyed the city with other nearby cities of the Aeolian. With support of Emporer Tiberius, the city was constructed again. Another earthquake in the early of Christian era destroyed the city second time. The city was later rebuilt, however the importance of the city was demolished. Today, the ruins of the city are very little. The acropolis of the city and defense wall were excavated and some other tombs as well (Freely, 2004).

Notion: It was an ancient Greek city-state on the South of İzmir, very close to the Kusadası. It was located on a hill. Notion served as a harbor city to Colophon and Claros. Notion's harbour was an alternative one to the Ephesus harbour. The city dates back to the sixth century BC. In Roman times the city became prosperous and commercial center. But as the harbour was silted so the trade ceased and the city lost its importance. The first excavation was started in 1921 by a French team. The main ruins of the city are necropolis, temple, agora, defense wall and the theater (Parke, 1985).

Nysa: It was situated in Sultanhisar (Aydın). It was an ancient Greek city of Carian in Anatolia. The city was known as Athymbra in ancient times. Nysa in ancient Greek language means "Holy City".The city was built around hot springs in the 2nd century BC. Greek geographer Strabon described Nysa being situated on two sides of the stream .The ruins include a theatre, the stadium, council hall, the library and a Roman bath (Freely, 2004).

Orthosia: It is close to the Donduran village, Yenipazar (Aydın). The meaning of the "Orthosia" in Helen laguage is "honest, fair". The city participated to the Ionia Union in the 6th century BC and later the city passed under the rule of Persians. The tombs, graves and the theatre are the main remains of the city (Buccellati et al., 1999)

Palaiapolis: It is an ancient Greek city located near Beydağ (İzmir) and is now in the Beydağ province (Belleten, 2004).

Panionion: It is situated 15 km north of the ancient city of Priene near the Mount Mykale on the Dilek Peninsula. It is within the borders of the Davutlar Town of the Söke District in Aydin. Panionion was an important annual meeting place of Ionian League. The League members were amoung twelve Ionian Colonies. The meetings were done usually after the harvest. They had shared their problems about business, art, farming or sea trade. To the honor of the God Poseidon of Helliconia, a traditional festival was held every year. The excavations conduced by the Geman archeologist Wiegard revealed some very important artifacts. The ruins of a circular wall on St. Ilias Crest are considered to be the meeting place of Panionion (Dillon and Garland, 2010).

Pergamon: It was an ancient Greek city and the capital of the kingdom Pergamon during the Hellenistic period. It was situated on a conical hill rising above surrounding valley in Bergama İzmir. In ancient Greek language the city name means “Citadel”. In the early Christian era, the city church was a major center of Christianity and was one of the Seven Churches. The main ruins of Pergamon are hillside theater, the atlar of Zeus, the Acropolis, the propylaeum of the temple of Athena. The majority of its intact monuments now sit in Berlin’s Pergamon Museum (Akşit, 1982).

Philadelphia: It was founded in 189 BC by King Eumenes II of Pergamum. The city was named for the love of King Eumenes’s brother. The ancient city was the sixth of the Seven Churches of Revelation. In 17 AD, a devastating earthquake hit the city and it was rebuit with the help Emporor Tiberrius. The ancient city has several temples as ruins (Herbermann et al., 1913).

Phokaia: It is an ancient city in Foca İzmir. It was an Ionian city. It was founded on the coast of the peninsula. The ancient city had two natural harbours. They became one of the most important port cities of the ancient times. The city had five km diameter and even today it is a large settlement by modern standarts. During the Persian influence, the city lost its strength. The damage of the Persians caused so great that the city never regained its magnificence (Akurgal, 1978).

Phygela: The city was founded in northern part of Kuşadası, İzmir. According to the legends, Phygela was established by the soldiers of Agamemnon. The city was a Mykene ceramics centre (Tsetskhladze, 2006).

Pitane: It was a port and ancient Greek city and a member of Delian League. The city was situated in Candarlı, Bergama (İzmir). It was established by Amazons. The city’s name means the “city of women”. Alexander the Great tried to conquer the city but he was repulsed by the Persians (Freely, 2004).

Priene: It was situated in the Maender valley near Aydın city. It was an ancient Greek city. It was formerly on the sea coast, on the mouth of the Maender River. Due to the slow aggradation of the Maender riverbed, the harbour was silted over. The inhabitants found themselves within pest- ridden swamps and marshes and later city was moved to inland city. The city had a population nearly five thousand inhabitants. The city had four sections like Bouleterion, Agora, Demeter and

Theatre. The city was constructed of marble that was taken from nearby quarries. The drained systems were used as channels in the city. Priene was a wealthy city. All houses in the city had indoor toilets, ater supply and sewage systems. The city ruins consist of foundations, paved streets, stairways, monuments, walls and terraces. The ruins can be seen even today in the ancient city (Akşit, 1982).

Sanaos: It was located today's Simav (Kütahya). Graved rock tombs, architectural blocks, altar, stone quarry are the main visible ruins in the ancient city (Foss, 1985).

Sardis: It was an ancient city at the location of Sart village, Salihli-Manisa. It was the capital of ancient kingdom of Lydia. Sardis was also one of the important cities of the Persian Empire. Sardis was one of the Seven Churches of Asia. Due to the military strenght, the situation on an important highway through to the interior to the Aegean coast and the fertile plain, Sardis was an important city in ancient times.The first excavation was done by Princeton University in 1910-1914. The Temple of Artemis and many Lydian Tombs were unearthened. The artifacts were added to the collection of the Metropolitan Museum of Art in New York (Duyuran, 1960).

Satala: It was located near Salihli (Manisa). It was a Roman period city (Matthews, 1998).

Settai: It was located between ancient cities Daldis and Silandos. The city is not uncovered and there is no information about it (Fahd, 1975).

Silandos: It was situated in the Karaselendi village, Kula (Manisa). The history of the ancient city was not identified. There was no regular excavation (Herrmann and Malay 2007).

Smyrna: The city is situated in Izmir city. Smyrna was located an advantageous port which ease of defence and good inland connections. The first settlement was founded around the 11th century BC as an Aeolian settlement. Smyrna was the birth place of Homer. The first excavations were carried of by English-Turkish team led by Prof. Dr. Cook and Prof. Dr. Akurgal between 1948 and 1951. The ruins of ancient Smyrna consist of an Agora, Underground sanitation system and the fortifications around the city (Cadoux, 1938).

Stratonikeia: It is an interior city of Caria. It was located at Eskihisar village in Yatagan-Mugla. The ancient city's first name was "Chrysaoris/Idrias" that were mentioned by the ancient writers Herodotus, Strabo and Pausanias. Seleucid King Antiochos changed the city name to Stratonikeia. The Seleucids, The Ptolemaics, The Macedonians and Roman Imperial conqured the city and region of the city has changed hands. In the Roman periods the city had a good and planned the building programme. The city was built on a grid plan. The city's main ruins are fortification walls, city gate with its monumental fountain and the continuing colonnaded street, gymnasion, bouleuterion, bath house, theater, temple and water building (Negev and Gibson 2001).

Tabala: It was an ancient Greek city near Kula (Manisa) and there are few ruins in the ancient city. There is no available information on this city in the literature. The name and the location are based on Tubinger Atlas (1977).

Teos: It was ancient Greek city and was situated slightly below the coast, 5 km far away from Seferihisar (İzmir). Teos was among twelve cities comprising the Ionian League. Teos was noted for its wine, a theatre and the Temple of Dionysus. According to the ancient historians Teos was founded in the 9 BC by the Minyans. And some other groups later came from various parts of Ionia and Athens and settled in Teos. Two perfect harbors provided very advantageous trade with other cities in the Aegean and the Mediterranean. The main ruins of Teos are Temple of Dionysus, the theatre, Gymnasium *(*Tsetskhladze, 2006).

Theodosioopolis: It was an ancient city near Kula (Manisa). There is no available information on this city in the literature. The name and the location are based on Tubinger Atlas (1977).

Thyateria: It was situated in Akhisar (Manisa). The archaeological findings show that the history goes back to 3000 BC. The city was a busy trade center and was one of the Seven Churches of Revelation (The new Encyclopaedia Britannica, 1974)

Tralleis: It was founded very close to modern Aydın city. According to the legends, the ancient city was established by the Argostians and the Tralleissians. In 334 BC, the city was occupied by the Alexander the Great. The ruin of gymnasion built in the 2nd century AD, agora, a theatre, stadium and necropolis are the buildings that still remain in the ancient city (Conder, 1824).

Trapezopolis: It is located near Bekirler village in Babadağ (Denizli). It is a Roman period ancient city. There is not enough information about the city and its history. There are a few ruins on the site (Thonemann, 2009).

Tripolis: It is situated 40 km to North of Denizli, in the east of Yenicekent, Buldan. It is located on the slopes of Buyuk Menderes River. It was an ancient city very close to the Laodikeia and Hierapolis. Tripolis was a trade and agriculture centres. The ruins in the ancient city belong to the Roman and Byzantine period. They are a theatre, a bath, a city building, fort and city walls and a necropolis (Boulanger, 1960).

CHAPTER III

BACKGROUND ON ANCIENT EARTHQUAKES

In this chapter a background information on the "earthquakes and the antiquity" will be given. The main concern of the chapter is to be able to answer the question "whether the ancient people were aware of the fault line". For this reason the chapter is divided into four sections.

In the first section a review of the myths on the earthquakes will be given to understand the perception of ancient people about the earthquakes. This is followed by a section on the opinion of ancient (Greek) philosophers about earthquakes. The third section is devoted to the recognition of ancient earthquakes in archaeological excavations. The fourth section lists the known destructive earthquakes in western Anatolia. The last section investigates the construction techniques used in ancient times to reduce the effect of the earthquake.

3.1 Earthquake and Mythology

The perception of earthquakes by ancient people is important for this study because most it is assumed that the ancient people were not aware of the basic geological processes and the traces of the fault lines. Therefore, their opinion on the earthquakes can give valuable information for their criteria in the site selection. For this reason, a survey on the earthquake perception is made using internet sources. Four some regions, several different myths exist that complicate the compilation. However, the purpose of this survey is not to compile all beliefs and hence here only a selection from this survey that covers different parts of the earth will be presented to give an idea on the ancient earthquake perception. Locations of the regions described below are illustrated in Figure 3.1.

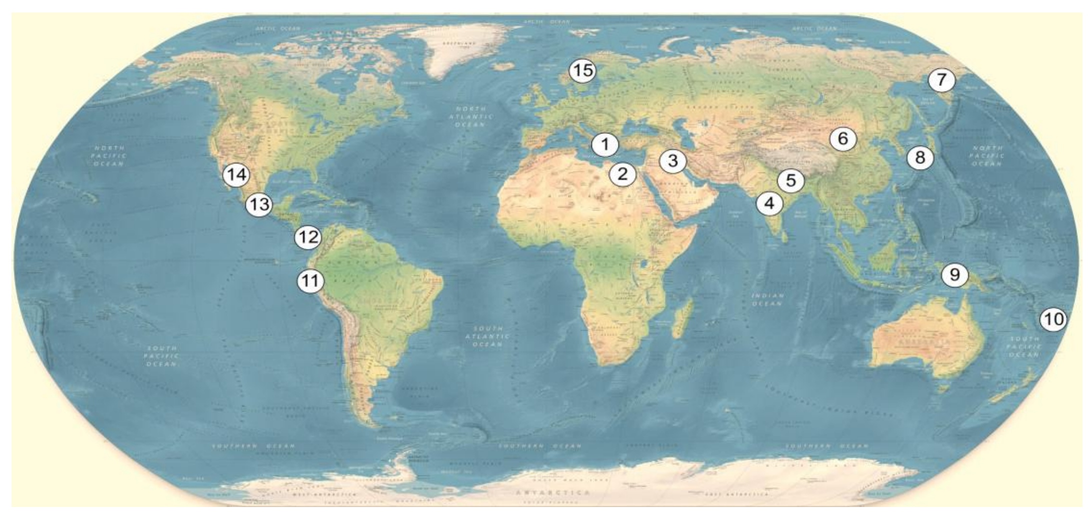


Figure 3.1. Location of the regions described in the text for their myths on earthquake.

Greek mythology: In Greek mythology (1 in Figure 3.1), Poseidon was the cause and god of earthquakes. When he was in a bad mood, he would strike the ground with a trident, causing this and other hazards. He also used earthquakes to punish and inflict fear upon people as revenge. His unpredictable, violent behavior earned him the nickname "Earth-Shaker" (Hard, 2004).

Egyptian mythology: In ancient Egypt (2 in Figure 3.1) Gebb (also known as Seb or Keb) is the god earth and supplied the minerals and precious stones found in the earth as a god of mines and caves. Earthquakes were thought to be the result of his laughter (www.ancientegyptonline.co.uk/geb.html, http://en.wikipedia.org/wiki/Geb, http://ancienthistory.about.com/od/gebmyth/Geb.htm).

Sumerian mythology: According to Sumerian mythology (3 in Figure 3.1) the Sumerian gods are said to have created human beings from clay. The gods often expressed their anger and frustration through earthquakes and storms (www.crystalinks.com/sumerreligion.html).

Hindu mythology: In Hindus of India (4 in Figure 3.1) people believed that eight elephants held up the land. When one of them grew weary, it lowered and shook its head, causing an earthquake. According to another version of the myth, all eight elephants are balanced on the back of turtle which stands on the coils of a snake. If any of these shift or move an earthquake occur (www.sacred.texts.com/hin/hmvp/hmvp21.htm).

Kukis of Assam (NE India): People in NE India (5 in Figure 3.1) believed that there is a race of people who lived inside the earth. They sometimes shook the earth to find out if anyone still lived on the surface. When the Kukis felt a quake, they shouted "Alive! Alive!" to assure the people within the earth that someone was still there (Center for Earthquake Research and Information at the University of Memphis, www.ceri.memphis.edu).

Mongolia and China: According to legend in Mongolia and northern Chine (6 in Figure 3.1), a gigantic frog, which carried the earth on its back, quakes periodically, producing slight earthquakes (Center for Earthquake Research and Information at the University of Memphis, www.ceri.memphis.edu). According to some sources Buddha threw golden sand on the frog to build the earth. When the frog moves earthquakes result (Earthquake Legends, Wikipedia).

Kamchatka: People of Kamchatka (Siberia-Russia) (7 in Figure 3.1) believed that a god named Tuli drove an earth-laden sled pulled by dogs. The earth is located within the sled. When the dogs stopped to scratch, the earth shook (Center for Earthquake Research and Information at the University of Memphis, www.ceri.memphis.edu).

Japanese mythology: In Japanese (8 in Figure 3.1) mythology Namazu is a giant catfish that causes earthquakes. Namazu lives in the mud beneath the earth, and is guarded by the god Kashima who restrains the fish with a stone. When Kashima lets his guard fall, Namazu moves suddenly causing violent earthquakes. After the destructive earthquake near Tokya in 1855 a new type of color print known as "namazu-e" (catfish pictures) became popular in the city. Since then numerous pictures are drawn depicting giant catfish that caused the earthquakes. Two examples of these pictures are shown in Figure 3.2. The current "Earthquake Early

Warning logo" used by the Japan Meteorological Agency is a yellow catfish (Namazu) (Smits, 2006; Smits and Ludwin, 2006)

Figure 3.2. Three examples of color prints on Japanese Catfish (namazu). Top: A crowd attacks namazu after 1885 earthquake, Bottom left: God Koshima tries to control namazu during an earthquake with a sword, Bottom right: Koshima kills namazu with a stone (Smits, 2006; Smits and Ludwin, 2006)

New Zealand: In New Zealand (9 in Figure 3.1) they believed that the Mother Earth had a child which is the "god Ru" inside her womb. Earthquakes were caused by the baby stretching and kicking (Federal Emergency Management Agency, www.fema.gov).

Polynesia: Ancient people of French Polynesia (10 in Figure 3.1) believed that Ngendei is the creator, and head of all the original gods of Fiji and the supporter of the world. He is described as half snake and half rock. Every time he moves there is an earthquake. Ngendei is also god of the harvest and king of the land of the dead (Avant, 2005).

Peru: In Peru (11 in Figure 3.1) people believed that whenever their god visited the earth to count how many people were there, his footsteps caused earthquakes. To shorten his task, the people ran out of their houses to shout "I'm here, I'm here!" (Center for Earthquake Research and Information at the University of Memphis, www.ceri.memphis.edu).

Costa Rica: Costa Rica (12 in Figure 3.1) is located in a tectonically active area in Central America. The land is always moving there and most of the people live in fear of the active volcanoes. Therefore, there are several tales from ancient tribes about the earthquakes and volcanic eruptions. For example, people of Guanacaste (or Gatusos) believed that the heart of the mountain of their Aztec ancestors had some magical power and could control the earth and its earthquakes. According to a myth of Mayans which are the ancestors of present day Chorotegas people, the earth is square and at each corner stood a god (Vashakmen) watching over the people. Whenever the earth became overcrowded; they pull on the corner and shake the earth to make some people fall off (Ancient Myths and Legends of Costa Rica, www.costaricapages.com; Fire Mountains and Earth Shakers, http:// thecostaricanews.com/fire-mountains-and-earth-shakers-costa-All.docrica-legends-and-myths/6401).

Mexican Indians: According to Mexican Indians (13 in Figure 3.1) El Diablo, an Indian god, made a giant rip in the ground so that he and his cohorts did not have to take the "long way around" whenever they wanted to stir up mischief on the earth (Center for Earthquake Research and Information at the University of Memphis, www.ceri.memphis.edu).

Indians (Southern California): Native people (Gabrielino Indians) living south of California (14 in Figure 3.1) believed that long time ago, when most of the world was water, Great Spirit decided to make a beautiful land with lakes and rivers that turtles carried on their backs. One day the turtles began to argue and three of the turtles began to swim east, while the other three swam west. The earth shook! It cracked with a loud noise. The turtles could not swim far, because the land on their backs was heavy. When they saw that they could not swim far away they stopped arguing and made up. But every once in a while, the turtles that hold up California argue again, and each time they do, the earth shakes (Center for Earthquake Research and Information at the University of Memphis, www.ceri.memphis.edu).

Norse mythology: Scandinavian people (15 in Figure 3.1) explained the earthquakes as the violent struggling of the god Loki. When Loki (god of mischief and strife) murdered Baldr (god of beauty and light) he was punished by being bound in a cave with a poisonous serpent placed above his head dripping venom. Loki's wife Sigyn stood by him with a bowl to catch the poison, but whenever she had to empty the bowl the poison would drip on Loki's face causing the earth to tremble. (http://historyofgeology/fieldofscience.com/2010/09/earthquake-myths-terrible-fenris -wolf.html).

Modern understanding of the earthquakes is different from the ancient perception. This is most probably because of awareness and information provided in the last century. Understanding of the theory of plate tectonics, increasing knowledge on the faulting (its active nature, location etc) and recent destructive earthquakes along the well-known fault zones contributed to this perception. There are, however, still some problems in the modern understanding of earthquakes.

According to a survey conducted by American Red Cross of Greater Los Angeles and the Earthquake Country Alliance seven common misunderstanding of the earthquakes are determined which are referred to as "seven earthquake myths" (Table 3.1).

Table 3.1 Modern myths about earthquakes (The information here is provided in partnership between the American Red Cross of Greater Los Angeles and the Earthquake Country Alliance for the awareness of earthquakes).

Myth 1 "<u>Big earthquakes always happen in the early morning!</u>"

It's common for people to notice the earthquakes that fit the pattern and forget the ones that don't. Earthquakes have proven to strike at all times throughout the day. Several recent damaging earthquakes occurred in the early morning, so people tend to believe all big earthquakes happen then.

Myth 2 "<u>Earthquake faults can open wide enough to swallow people and buildings!</u>"

A popular literary device is a fault that opens during an earthquake to swallow up an inconvenient character. Gaping faults exist only in fiction. During an earthquake, the ground moves across a fault, not away from it. If the fault could open, there would be no friction. If there was no friction, there would be no earthquakes.

Myth 3 "<u>California will split apart from the United States and sink into the ocean!</u>"

Those envious of sunny California and its beaches would like to believe this myth. The motion of plates will not cause California to sink, as western California is moving horizontally along the San Andreas fault (the land on both sides of the fault are converging and getting closer together), and up around the Transverse ranges (mountains to the northeast of the LA basin). The ocean is not a great hole into which the state can fall, but is itself land at a somewhat lower elevation with water above it.

Myth 4 "<u>We must have good buildings because we have good building codes!</u>"

What if buildings were built before a code was enacted? Codes may be updated, but the older buildings are what exist. This is why retrofitting older buildings is a key responsibility of the building's owner. Simply checking to make sure YOUR building has been retrofitted, if necessary, can save lives!

Myth 5 "<u>Go for the doorway when an earthquake strikes!</u>"

A lasting earthquake image of California is a collapsed adobe home with the door frame as the only standing part, which spurred this myth of doorways as the safest place to be during a quake. Modern homes are built so that doorways are no safer than any other part of the house. You are much safer under a table.

Myth 6 "<u>Everyone will panic during the big one!</u>"

The idea that people generally always panic and run around madly during and after earthquakes, creating more dangerous situations for themselves and others, is a common belief. However, research shows that people are prone to protect themselves and help others during and after earthquakes. Most people don't get too shaken up about being "shook up!"

Myth 7 "<u>The weather is hot and dry…you know what that means. Earthquaaake!</u>"

It's a common belief that earthquakes are more common in certain types of weather. However, earthquakes start many kilometers below the region affected by surface weather. People notice earthquakes that fit a pattern and disregard the ones that don't. Every region of the world has a story about earthquake weather, but the type of weather is basically what the weather was like when they had their most memorable earthquake!

3.2 Earthquake Perception by Ancient Philosophers

Although ancient people suggested various reasons for the earthquakes to occur, the philosophers at the same time seriously thought about the origin of this hazard. According to the written documents, the seismic phenomena attracted the attention of particularly Greek philosophers. These philosophers had different thoughts about the cause of the earthquakes. They tried to explain scientifically the main reason behind this phenomenon. Some of these philosophers lived in Western Anatolia and experienced the ancient earthquakes. Earthquake mechanisms suggested by some of the philosophers mentioned in "Catalogue of Ancient Earthquakes in the Mediterranean Area up to the 10^{th} Century" (Emanuela et al., 1994) are briefly summarized below.

Thales of Milet : Thales was born in the city of Miletus around the mid 620s BC. He considered the earth which was swimming on water like a ship. The earthquakes caused regarded as shaking of earth on the water (Figure 3.3). To prove his attempts to explain, he pointed out that after each earthquake new fountains sprung up.

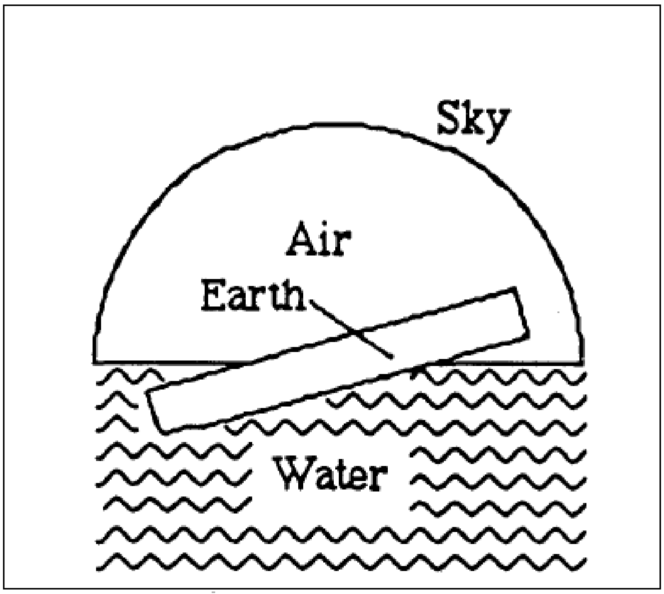


Figure 3.3 Thales of Milet's earthquakes mechanism (Oeser, 1992)

Democrit: He was born at Abdera, Thrace (460-371 B.C.). He believed that heavy rainfalls mixing with water enclosed inside the earth caused the earth to tremble.

Anaximenes: He was a Greek Pre-Socratic philosopher (585-528 BC) and one of the three Milesian philosophers. He is identified as a younger friend or student of Anaximander. He seems to accept the general earthquake theory of Thales. However, according to him, the earth is a like an old house in which the lower parts suddenly give way, thereby causing them to collapse which produce shaking at the earth's surface.

Anaxagoras: He was a Pre-Socratic Greek philosopher (500-428 BC). He was born in Klazomenae in Urla (İzmir). He explained the earthquakes like that as the lightest of all elements, streams upwards. If the upper stratum of the earth, that is usually completely porous, is plugged up as a con-sequence to the downpours, the ether will obtain an exit forcibly - by means of an earthquake.

Diogenes of Apollonia: He was an ancient Greek philosopher (5th century), and was a native of the Milesian colony Apollonia in Thrace. He believed air penetrates into the bowels of earth through the pores which appear in its surface naturally. When the pores are blocked with air inside, the air tries to find a new way to escape and air begins to move violently and that shakes the earth.

Archelaus: He was an Ancient Greek philosopher (5th BC), a pupil of Anaxagoras, and said to have been a teacher of Socrates. He asserted his earthquake theory as Diogenes of Apollonia. In his theory the main cause of earthquake was wind not air.

Aristotle: He was a Greek philosopher, a student of Plato and teacher of Alexander the Great (384-322 BC). He assumes that fires inside the earth make subterranean water boil and this produces vapor and tries to find an exit and thus leading to vibrations and earthquakes.

Straton of Lampsakos: He was born at Lampsacus near Lapseki, Çanakkale (330 BC - 280 BC). He assumed the earthquakes caused by the fight between cold and warm air.

Theophrastus: He was a Greek scholar (371-281 BC). He believed the earthquakes were caused by the collapse of subterranean caves.

Poseidonions: He was a Greek author (approx. 135-50 BC). Although he is known to have a theory on the occurrence of earthquakes, none of his writings still exists. He seems to be one of the first to recognize the enormous depth of the hypocenters and the extent of one and the same earthquake distributed over various countries.

Epicurus: He was an ancient Greek philosopher (341-270 BC). According to him, an earthquake can be produced by four original elements (water, earth, fire and air) and by others as well.

3.3 Earthquake Traces in the Ancient Settlements

There are many different methods and approaches to investigate the past earthquakes. The difficulties of the methods and techniques are because of the complexity of the natural event. The multidisciplinarity works are needed to investigate the past earthquakes.

The traces of past earthquakes can be studied as direct and indirect techniques. Direct techniques can be done via texts, books, illustrations that can give information about the earthquake damages, repairs, social effects, etc. Indirect methods can be structural. Deformation of the walls, surface faults, uplifts of harbors, etc can be traces for structural.

There is an increasing tendency towards the compilation of ancient texts and inscriptions about the earthquakes. One of the most important contributions of these compilations is the creation of “historical database” which can serve to earthquake studies in different ways. The illustrations about the ancient earthquakes, on the other hand, are useful tools to understand the recognition of the earthquake in historical times. Four examples of such illustrations are given in Figures 3.4 to 3.7.

The first illustration (Figure 3.4) is about the earthquake centered in Nice (Italy) that caused damage to Genoa and environs. This is considered to be the oldest seismic map that allows the investigator to determine extent of the damage.

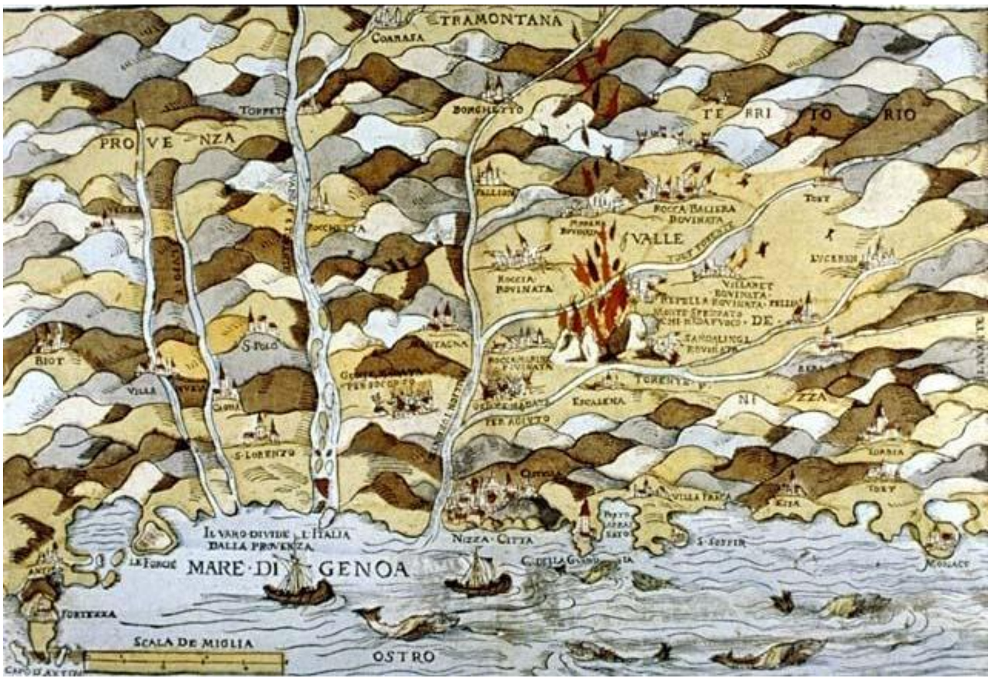


Figure 3.4 Earthquake damaged Genoa and environs (1564 AD) showing seven damaged towns, people fleeing and rescue crews arriving. (by Maggiol, Francesco). Source: Univercity of California, Berkeley, Pacific Earthquake Engineering Center, Online Archive, Jan Kozak Collection-KZ23.

Figure 3.5 Earthquake in Istanbul (March 5th 1556). Hagia Sophia dome and other buildings heavily damaged, many fatalities. Comet was sighted on March 5, 1556 and seen for 12 days. (Nuremberg, 1556). Source: University of California, Berkeley, Pacific Earthquake Engineering Center, Online Archive-Jan Kozak Collection-KZ20

Figure 3.6 Earthquake in Constantinople (Istanbul) April 19, 1878. Usual scenes of panic. Source: Univercity of California, Berkeley, Pacific Earthquake Engineering Center, Online Archive-Jan Kozak Collection-KZ769.

Figure 3.7 Heavily damaged city in Marmara Sea by 1509 earthquake and subsidence. People being "swallowed" by the earth. (Source Ambraseys and Finkel, 1990)

The second print (Figure 3.5) depicts the Istanbul earthquake of March 5th, 1556. One important aspect in this illustration other than the damage in the buildings and panic by people is the comet depicted in the image which is believed to be observed for 12 day.

Another Istanbul earthquake is illustrated in Figure 3.6 indicating the destruction, the panic and the fire after the earthquake.

Istanbul 1509 earthquake is one of the biggest earthquakes that affected the area from Izmit to Çorlu. Number of varies from 1000 to 13000 according to different sources. Aftershocks continued for 45 days. A fault rupture of about 70 km is estimated from the area and the intensity of the earthquake (Ambraseys, 2001). Figure 3.7 shows a scene after this earthquake.

The frequency and the magnitude of the ancient earthquakes are the difficult issues to compare with the today's datas.

There are many reasons that cause the damage for ancient cities. The damages can be from war, fire, human made damages, earthqukes, etc. For that reason, a special attention must be given in modern archaeological excavations. However, there are different evidences that can be recognized as indication of past earthquakes. Collapsed walls, crushed skeletons lying under fallen debris, toppled columns, lying parallel columns, slipped keystones are the main traces of past earthquakes. However, these traces can be from poor constructions or other factors. The damages can sumarized as follows:

Fault rupture: This is most widely seen earthquake damage and the faults intersects archaeological sides.

Sliding of arch blocks: Masonary arches are used in ancient buildings. When the earthquakes happens the keystones slid down. Arches blocks fall down firstly. The deforms of asymmetrical shows the sliding of arch blocks.

Horizontal shifting of large blocks: The earthquakes can only shift the buildings' stones from one place to other places. The other factors such as wetting and drying has a minor forces to change the stones.

Aligned falling of columns: Ancient building columns are made of carving the column from the whole block. Later they were shaped like drum and via casting they are connected. The drum-like blocks were added on each other. The earthquakes can shape the falling of blocks on the same directions. This can indicate the ancient earthquake in excavation sides.

Chipping of block corners: The slow penetration of water into the ancient stones causes weathering along the contacts of building stones. When time passes, the expansion and contraction happens on the stones and this is the main indication of deformation of blocks. When the earthquakes happen, the bending side of blocks can be chipped off. Figure 3.8 shows an example of this kind of deformation in two ancient cities in Minonian settlements. Figure 3.9 shows the active faults near the ancient settlements (Fassaoulas, 2001).

Figure 3.8 Some traces of ancient earthquakes in the city walls (Fassaoulas, 2001)

Figure 3.9 View of the Spili fault (close the ancient city) (Fassaoulas, 2001).

Collapsed walls: Many masonary buildings are added to each other either with cement or without cements. The horizontal forces such as earthquakes may cause the slide of the building blocks. The toppled stones by earthquakes are in contact with each other. Alluvial sand or other fine materials can be accumulated in voids and gaps of the stones. These materials joint the stones and cause not to move from each others. In Kisamos ancient side, the traces of collapsed walls can be seen. In 355 and 361 AD earthquakes harmed the city. Well-built blocks were destroyed.

Deformed walls and floors: The walls can be inclined toward both sides after the earthquakes. This is the main indication of the earthquakes in an ancient city. In ancient Avdat city, deformed walls and floors were observed after the excavation. The city were harmed after a devastated earthquakes in 631, 633 AD (Figure 3.10).

Through-cutting fractures: Many traces can be seen in ancient cities after the earthquakes. The through-cutting fractures are the fractures that happen on the surface of the buildings from top to below. The fractures can cause the division of the whole buildings.

Figure 3.10 City wall's displacements and shifts of individual Stones (A. M. Korjenkov and E.Mazor, 2003)

3.4 Major Ancient Earthquakes in Western Anatolia

Many ancient earthquakes devastated the west part of Turkey. The affects of the earthquakes were deep for the cities itself and inhabitants as social. Western Anatolia lies West Anatolia Fault zone. Many large active faults control Simav, Alasehir, Buyuk Menderes and Kucuk Menderes grabens. Western Anatolia experienced many earthquakes last 2000.

Ephesus, Troy, and Hierapolis were damaged by ancient earthquakes (Altunel et al., 2003). Cnidus was an important city in Hellenistic and Roman times. Cnidus was in a seismically active area. The city lies a fault line and the offset in the city buildings remains along the faults (Altunel et al., 2003). Round Temple of Aphrodite was vertically offsetted. Sanctuary of Demeter walls were displaced in 459 AD earthquakes (Altunel et al., 2003).

Didyma and Miletos were destroyed some earthquakes in 199-198 like other two islands, Thera and Therasia (Altunel, 1998).

Aphrodisias were struck by earthquakes in 241 AD. The city was later restorated and rebuild by the help of emperor (Altunel and Barka, 2001).

Symrna was ruined by earthquakes in 47 AD. An epigraphic that was taken on a wall in Samos island shows the earthquakes of Symrna (Adatepe and Erel, 1999)

According to the Sibylline Oracles, there are two passages that expressed an earthquake at Tralles in 27 BC was hit by an earthquakes and the well-built walls were damaged.

In 105 AD, the earthquake damaged the Kyme, Elaea, Myrina and Pitane (Adatepe and Erel, 1999)

3.5 Earthquakes and Ancient Construction Techniques

Due to the weight of the building, earthquakes affect the buildings because of its lateral forces. The building's resistance to eartquake vibrations depends on the material used in the building structures. Earthquakes traces can be seen in many ancient buildings as mentioned above. Many building techniques were used to reduce the affects of the earthquakes in Roman and Greek type of buildings. The earliest examples of these ones were the vault and mortar bounded masonry in Roman buildings. Neither of these was Roman invention. The vault was invented by the Egyptians and Mesopotamians around 3000 BC and was used by the Greeks from the 4th century BC onwards. The use of gypsum for making bonding mortars was common in Egypt. Vaults in a building reduce the affect of the earthquakes (Pieotti, 2005).

Masonary structures are generally less resistant to earthquakes. When they are reinforced, they will help to reduce the earthquake affects in buildings. Composite material, the stones and bricks are the reinforced materials.

The use of wood or timbers in Anatolia has existed since 4000 BC (Naumann, 1985). Timbers are also the resistant for the seismic waves. They are used in public buildings and private houses for covering facades or erecting reinforcements where buildings had been damaged in the earthqaukes. However, they are vulnerable to fires after earthqaukes or they were attacked by the insects and fungi which reduces the resistant affect of the timbers (Feilden, 1987).

CHAPTER IV

GEOLOGY OF THE AREA

Geology of the study area is important in this study for two reasons. The first is the distribution of the rock types existing in the area. An attempt will be made to seek a possible relationship between the lithology and the settlement location. This analysis may give an answer to the question if there is any specific rock type preferred as settlement sites. For this reason the most recent digital geological map provided from MTA will be used (Figure 4.1). This map shows the boundary of the individual outcrops as separate polygons which is advantage for this study. Using this property the rock types can be reclassified and the total number of the rock types can be reduced. In its present form, there are more than 100 different rock types ranging in age from Paleozoic to Quaternary in the area. Total number of individual polygons within the study area is 1154. Details of these rocks will not be given here, because in the next chapter, these rock types will be reduced to a meaningful number for GIS operations. Necessary information about the rock types will be given there.

The second reason for the importance of the geological maps is the faults existing in the area. The faults are the main concern in this study as they are the sources for the earthquakes. There are, however, two main problems related with the faults. These problems are:

- All the faults are not mapped in the area yet. At the initial stage of the study the geological maps for the study area produced from different researchers are compiled to create a “fault database” by digitizing the fault traces. However, due to the inconsistency among the maps and the lack of data in some parts this task is not completed. Mapping and evaluating all the faults by the field studies is technically/economically not possible and is out of the scope of this study.

- Since the historical earthquakes are produced by “active faults”, only the active faults should be dealt in this study. However, most of the maps show all the faults in the area without any distinction between active and inactive faults. Since the region is known to be tectonically active throughout the geological history and there are different types of the faults generated during different tectonic phases, it is clear that all these faults can not used in the study because there is criteria to differentiate the active faults from inactive ones.

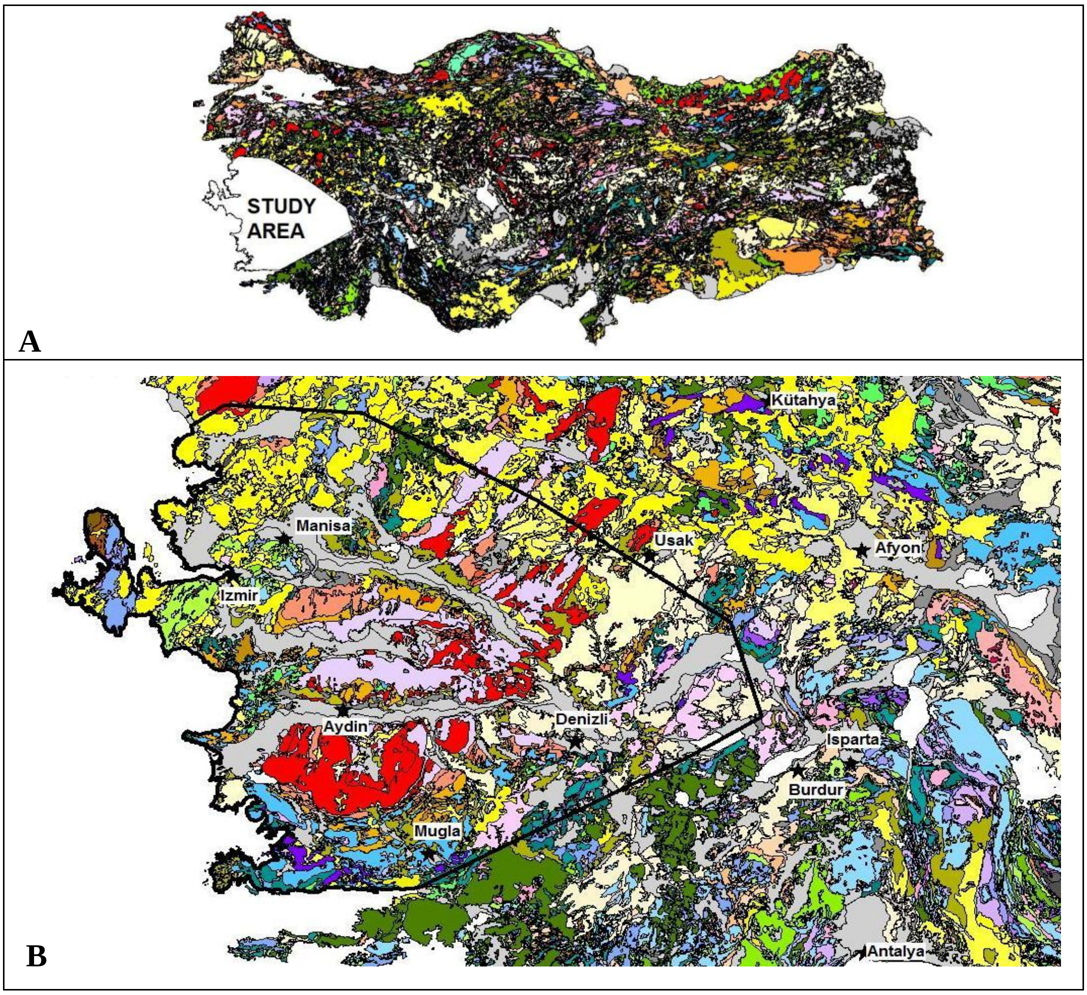


Figure 4.1 A) Location map showing the study area, B) original geological map obtained from MTA. (Note that an “explanation” is not given here for the rock types as this map will be dealt in detail in the next chapter. The balck line in the figure shows the extent of the study area.

Another attempt for the active faults in the region is made by using "Active Fault Map of Turkey" prepared by MTA. A copy of this map downloaded from www.mta.gov.tr is illustrated in Figure 4.2. It is already known that this map is not completed yet and is still under progress. The best evidence for the lack of some faults in the area is the Küçük Menderes Graben, which is known to produce historical earthquakes. Therefore, it is concluded that using the existing maps for the for settlement site evaluation would produce erratic results.

Figure 4.2 Active fault map of Turkey (Source: MTA, www.mta.gov.tr)

The most distinguishing geological feature of the area is the horst-graben system extending from gulf of Edremit at the north to gulf of Gökova at the south (Figure 4.3). There are about ten grabens oriented approximately in E-W direction (Yılmaz et al, 2000). Most of these grabens are totally covered by the study are including the best-developed and biggest two grabens which are Büyük Menderes and Gediz grabens (Ambraseys,1970). The origin and timing of these grabens are still under discussion. So far four theories are proposed for these grabens:

1- **Tectonic escape model**: The Anatolian block began to extrude westward with the initiation of right lateral motion along the North Anatolian Fault System that began by late Serravalian (~12 Ma; Dewey and Şengör 1979; Şengör 1982, 1987; Şengör et al. 1985; Görür et al. 1995).

2- **Orogenic collapse model:** Opening of the grabens is explained by the spreading and thinning of over-thickened crust following the latest Paleogene collision across Neotethys (Dewey 1988; Seyitoğlu and Scott 1991, 1992; Seyitoğlu et al. 1992). Therefore the start of the extension is much earlier than the first model (~18 Ma: Early–Middle Miocene)

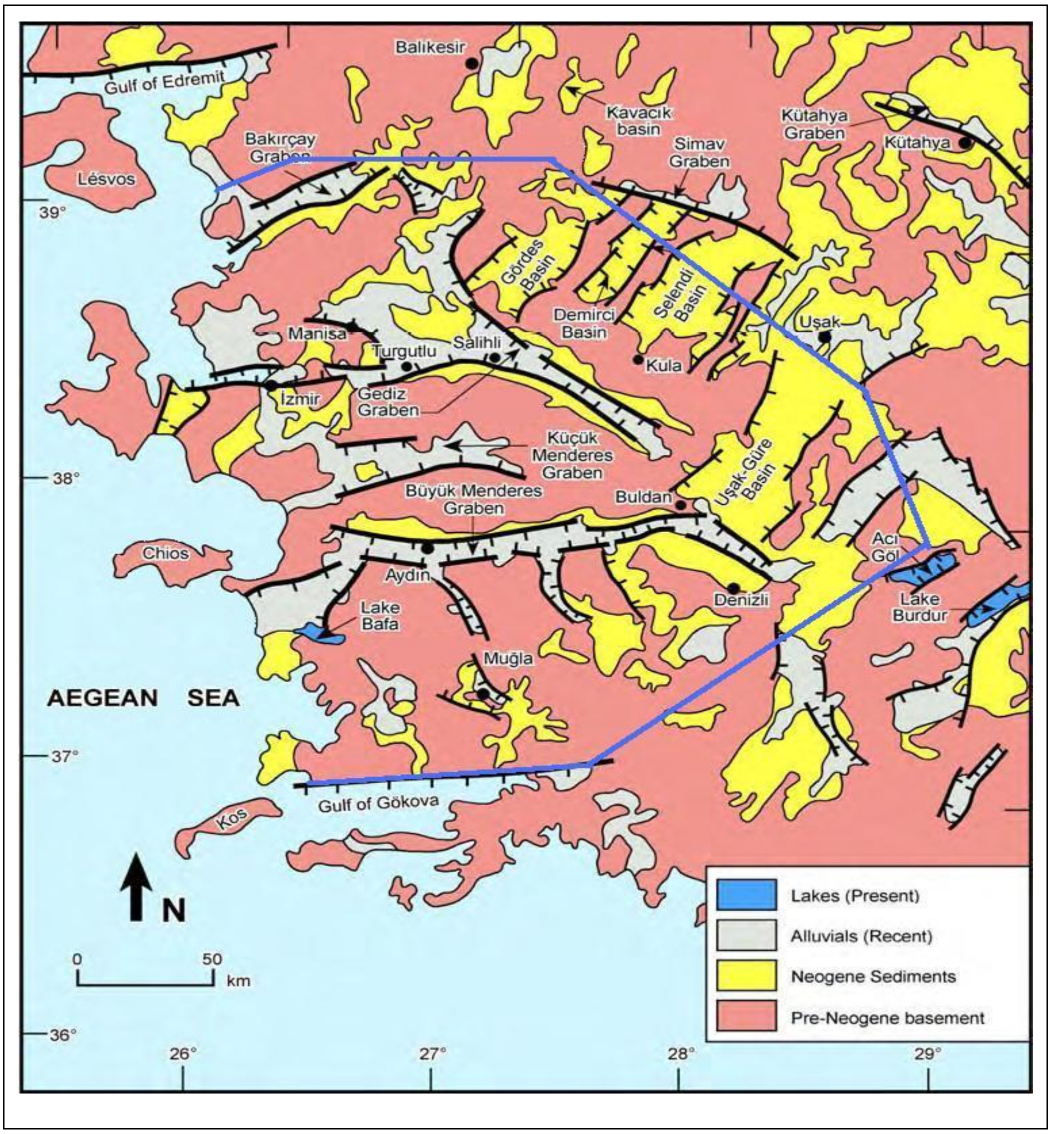


Figure 4.3 Simplified geological map of the western Anatolia showing the major grabens in the region (Bozkurt and Sözbilir, 2004)

3- **Back-arc spreading model:** Subduction rollback process and consequent southwestward migration of the Aegean Arc caused the extension in back-arc area. But there is no consensus over the inception of rollback process where proposed ages range from 60 Ma and 5 Ma (McKenzie 1978; Le Pichon and Angelier 1979, 1981; Jackson and McKenzie 1988; Kissel and Laj 1988; Meulenkamp et al. 1988, 1994; Thomson et al. 1998).

4- **Episodic, two-stage graben model:** Crustal extension in western Turkey is expressed by two distinct phases of extension being separated by a short-time interval of N−S crustal shortening during the late Serravalian−late Early Pliocene times (Koçyiğit et al. 1999a). The model considers the combined effect of two or more of the above mechanisms where an earlier phase of orogenic collapse in Miocene is superimposed by the modern phase of Plio-Quaternary extension commenced due to the westward escape of the Anatolian block (Koçyiğit et al. 1999, 2000; Bozkurt 2000, 2001, 2002, 2003; Yılmaz et al. 2000; Cihan et al. 2003; Koçyiğit and Özacar 2003; Bozkurt and Sözbilir 2004) along with the initiation of the North Anatolian Fault System (~5 Ma: Barka and Kadinsky-Cade 1988; Westaway 1994 or ~7 Ma: Gautier et al.1999; Westaway 2003).

These grabens are distinct with their morpologic characteristics. They are usually 100-150 km long and 5-15 km wide (Yılmaz et al, 2000) forming large flood plains. This is in turn an important factor in the selection of settlement site. Because these flood plains create large fertile agricultural regions. One problem, however, related with the scope of the thesis is that some of the grabens are old while some others are active (Ambraseys and Finkel, 1990). Therefore all the faults shown in the map (Figure 4.3) may not produce earthquake during the historical times.

CHAPTER V

DATA USED IN THE STUDY

This chapter explains the data sets used in this study. A total of seven data sets are used during the studies which are: topographic data, morphological classes, ancient settlement data, modern settlement data, rock data, seismic data and active fault map of the area. For each data set first a raw data is obtained from different sources and is processed for the final set to be used in the analysis.

5.1 Topographic Data

Topography is a three-dimensional representation of the Earth's surface on a two – dimensional surface including contour lines showing topographic features like mountains, plains, canyons and plateaus which are seen from overhead looking to ground. In this study, SRTM (Shuttle Radar Topography Mission) topographic data are used to quantify topography of the study area. SRTM is an international project pioneered by NGA and NASA used to obtain elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of the earth. SRTM, with 90 m pixel resolution and 16 m vertical accuracy, was taken during the 11 day flight with the Space Shuttle Endeavor in the year of 2000 (NASA SRTM, 2004).

SRTM data is used in this study to determine three topographic parameters (elevation, slope and aspect) for the whole area, ancient settlements and modern settlements. SRTM data is processed in Mapinfo software to produce initial elevation, slope and aspect maps. The data is extracted using a polygon that corresponds to boundary of the study area in raster format. Total number of pixels for the whole area is 925798 each with 90m x 90m size.

5.1.1 Elevation Map

The map shown in Figure 5.1 is the elevation model of the study area that ranges from 0 m to 2550 m in elevation. The lowest elevations are dominant around the coastal parts of the area and at the graben floors. The elevation gradually increases towards the west. The histogram of the area is divided into 100 m intervals starting from 0 m to 2550 m (Figure 5.2-A). The maximum percentage with 8.31 % is observed between 50 m to 100 m.

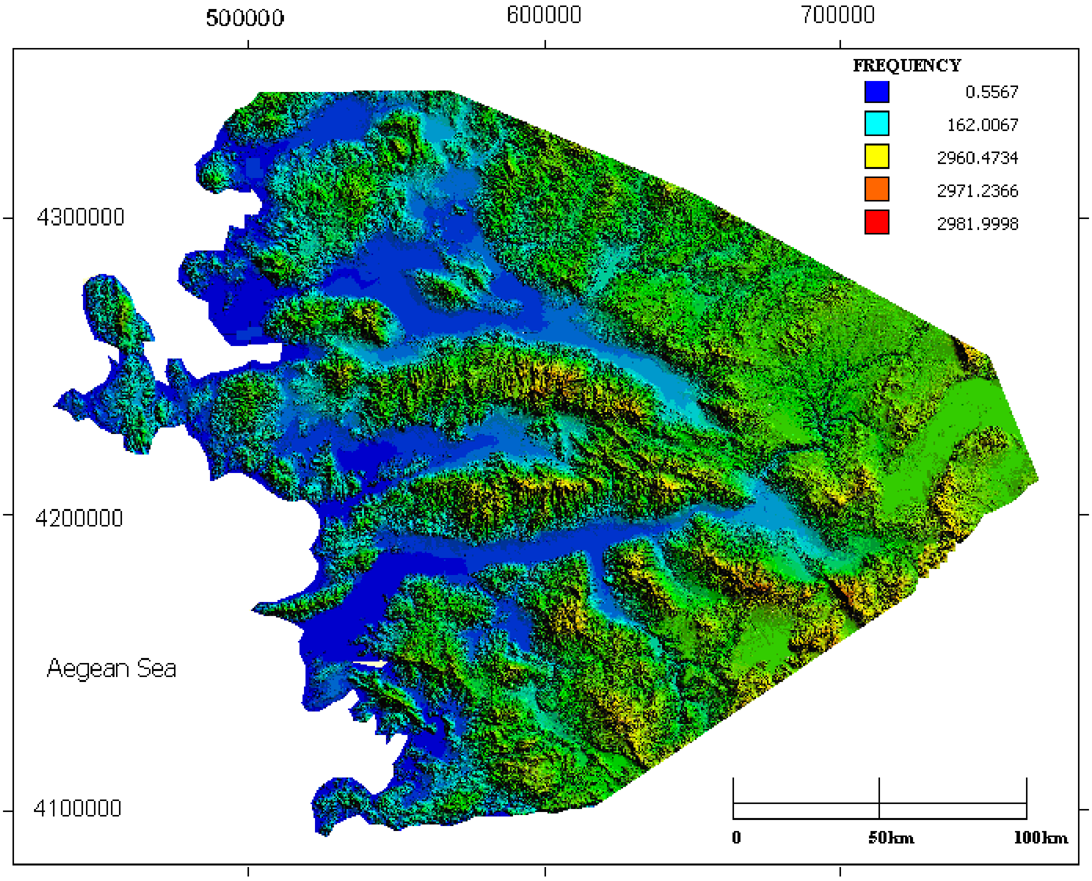
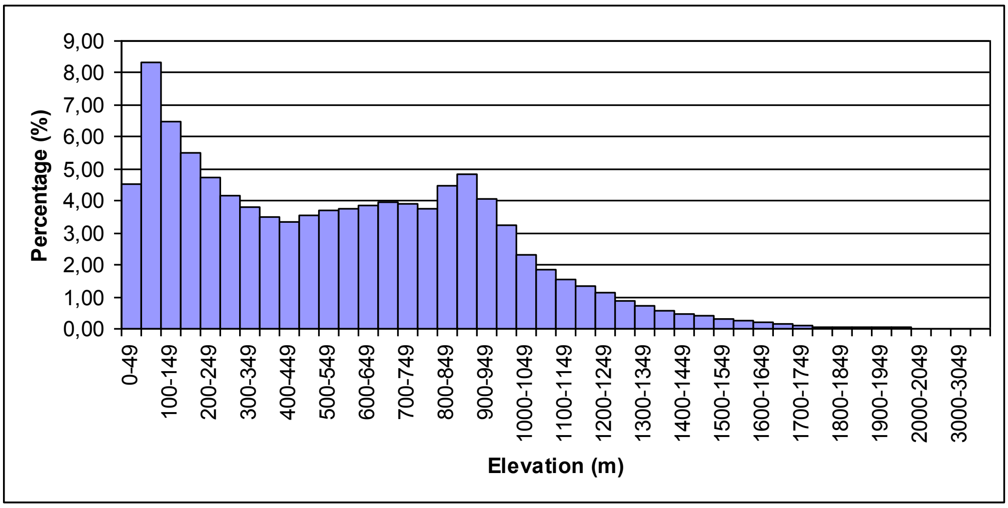


Figure 5.1 Elevation map the study area.

5.1.2 Slope Map

Slope map refers to the map amount of surface inclination at any point. The slope in the area ranges from 0 to 34 degrees (Figure 5.3). The histogram of the area with 1-degree intervals is given in Figure 4.4-B. The histogram suggests a maximum concentration at 0-1 degrees (10.9 %). The slopes above 30 degrees are negligible since their percentages are nearly 0.



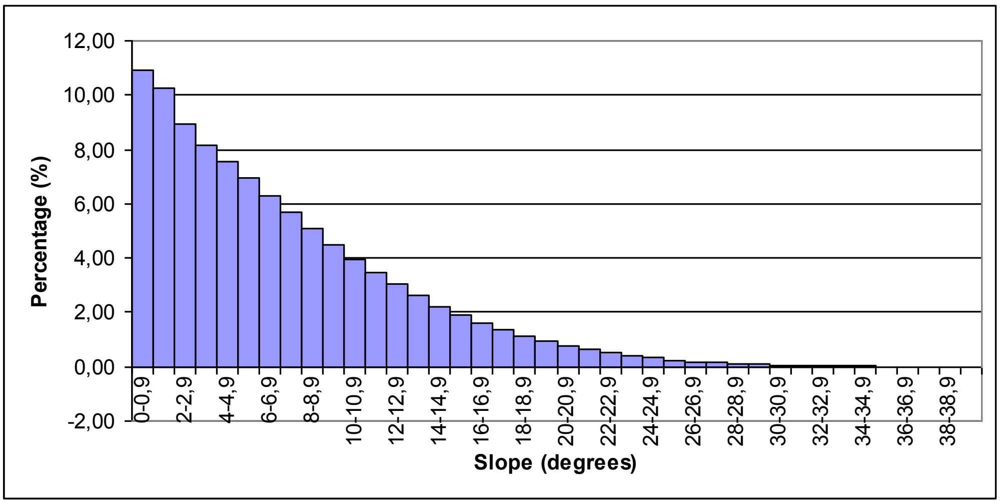


Figure 5.2 Histograms prepared from:
A) Elevation map for 100 m interval
B) Slope map for 2-degree intervals, and
C) Aspect map for 45-degree intervals

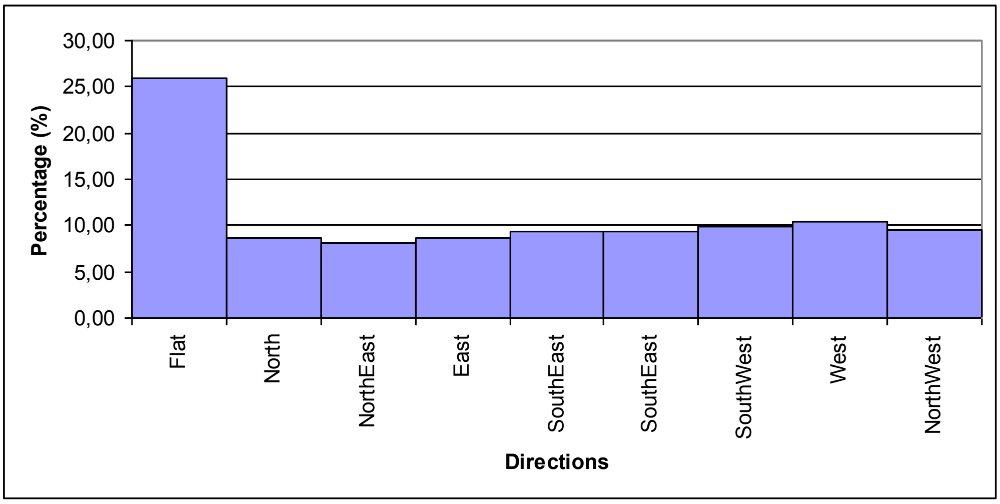


Figure 5.2 (Continued)

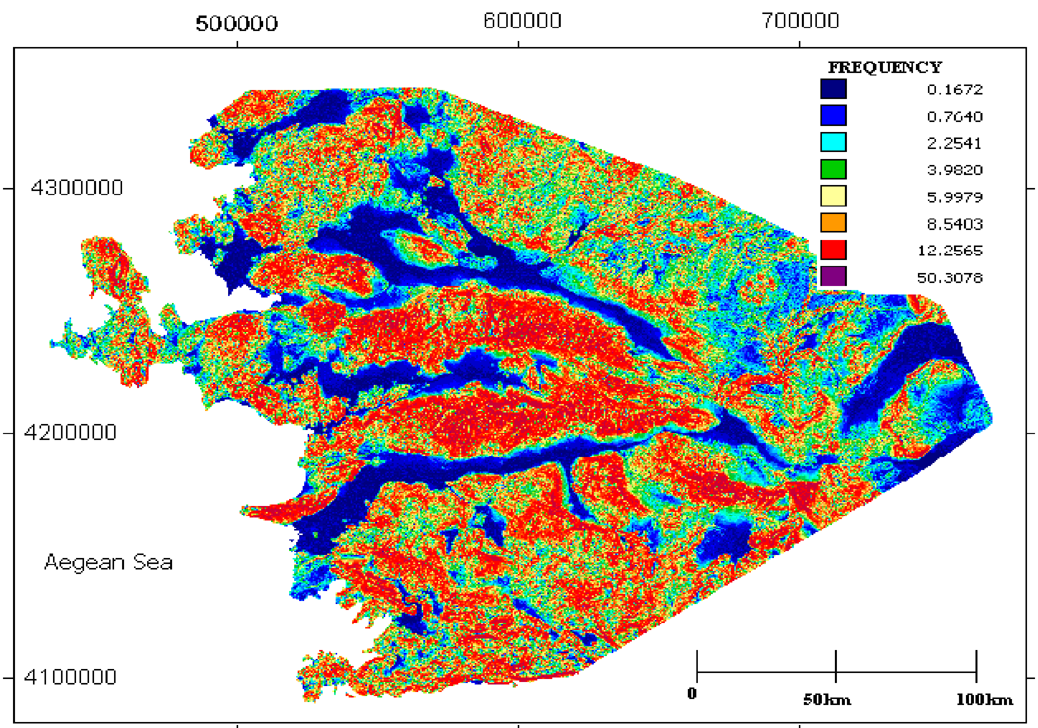


Figure 5.3 Slope map the study area.

5.1.3 Aspect Map

Aspect map is the map that shows the direction of slope in relation to north. Here simply 0 and 360 degrees refer to north, 90 to east, 180 to south and 270 to west. To avoid complexity in the direction, the whole range is divided into 8 intervals with 45 degrees. The flat areas where slope is less than 2 degrees have no aspect value; therefore, a value of -1 is assigned to such pixels. Considering the flat areas as a separate interval, the number of intervals increased to nine. Lower and upper units of each interval are shown in Table 5.1. During the calculation of these limits -22.5 and +22.5 degrees are added to eight principal directions. As a result, the nine intervals that will be used in the analysis are obtained to be north, northeast, east, southeast, south, southwest, west, northwest and flat (Figure 5.4).

The histogram prepared from the aspect values is illustrated in Figure 5.2-C. Flat areas have the maximum percentage (25.86 %); other eight directions, on the other hand, have percentages ranging from 8.61 to 10.45. Percentage of the west direction is slightly greater than other; north direction has the lowest percentage.

Table 5.1 Aspect ranges applied in this study.

DEGREE	CLASS
-1	Flat
338-023	N
024-068	NE
069-113	E
114-158	SE
159-203	S
204-248	SW
249-293	W
294-337	NW

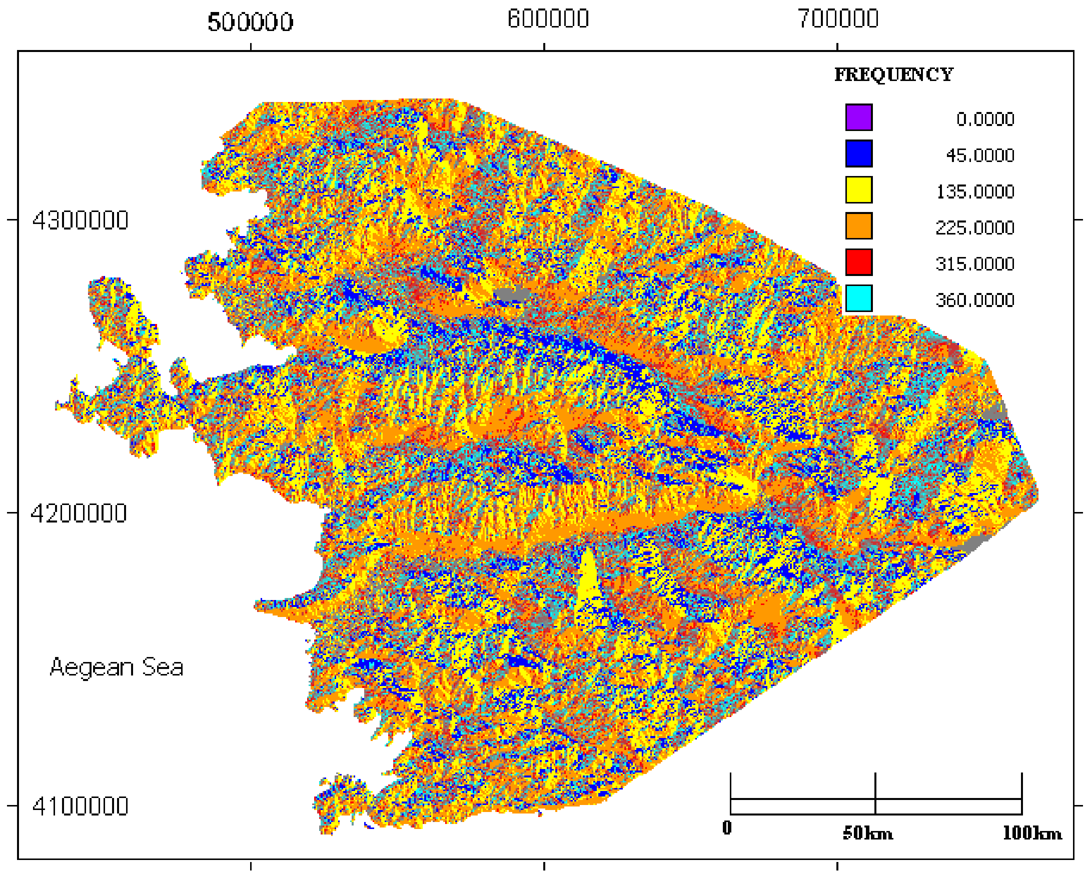


Figure 5.4 Aspect map the study area.

5.2 Morphological Classes

The morphological landform classes are used to seek a relationship between the settlement location and type of the landform. For this purpose, the whole area is classified into meaningful polygons each of which corresponds to different landform class. The main reason in the use of morphologic classes is to infer the active fault locations. As mentioned earlier there is not a reliable complete active fault map for the study area. Therefore, the faults compiled from the literature may produce false results. To overcome the problem, location of faults is inferred by morphological characteristics of the area. The nature of the active faults in the region is known to be “normal” according to almost all literature listed in previous chapter. Therefore vertical movements are expected along these faults. These movements will generate flat flood plains which are not dissected yet. Considering the width of these plains, it is assumed that any flat and wide area identified in the region should be associated with recent faulting. Therefore, if flood plains are identified, the margins of these plains will be marked by fault plains. A hypothetical example is shown in Figure 5.5.

The simplest way to identify the flood plains is using the “slope map”. Since the slope of the flood plains will be very small, a maximum threshold value should be assigned to correctly identify particularly the margins of the plain where a gradual increase in the slope value is expected. By trial and error it if found that the slope value of 6 degrees is the best threshold value for the identification of the flood plains. Therefore, a binary slope map is prepared with two classes; 1) between 0 and 7 degrees, 2) greater than 7 degrees. The first class will indicate the “flood plains” and the second class the “mountainous” areas.

Another factor should be considered in the region for the settlement sites, is the long shore line that defines the western boundary of the area. Considering the transportation for the trade, the coastal areas are also attractive regions for the settlement. Therefore, there might a different set of criteria for the site selection in coastal regions. For this reason, it is decided to separate a buffer area along the coastline as a distinct morphological class. In order to do this, a line parallel to the shoreline is drawn towards the land with a distance of 5 km (Figure 5.5).

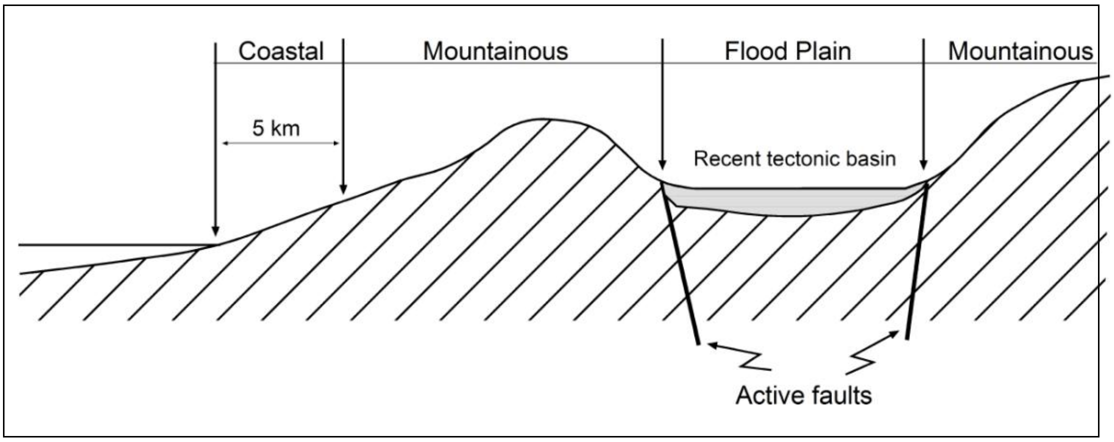


Figure 5.5 Hypothetical cross section illustrating three classes used in this study

Three major morphological classes, therefore, considered in this classification are "flood plains", "mountains" and "coastal". Brief information for each class is as follows:

Flood plain: Flood plain refers to the wide alluvial plains formed along major streams. These streams are flowing at the floors of the grabens mentioned in the previous chapter. They are characterized by a flat surface filled by alluvium. The maximum width measured from the final map is 178 km. This class covers 18.53 % of the area (Table 5.2).

Mountainous areas: This morphology class corresponds to the upper parts of an inclined surface. Ideally, it has a circular or elliptical shape in plan view. Geologically they are the horsts developed between the grabens. They cover 77.82 % of the area.

Coastal areas: This is the area between the shoreline and a buffer of 5 km towards the inland. It covers 3.65 % of the area (Table 5.2)

Table 5.2 Basic statistics of the three morphological classes used in the study

	Total area (km2)	Percentage
Flood plains	8777.7	18.53
Mountainous areas	36873.3	77.82
Coastal areas	1729.0	3.65

The final map is generated after 1) applying a slope threshold as mentioned above, and 2) assigning a buffer zone of km along the shore line. The output of this process is shown in Figure 5.6. This is the main map that will be used in the analysis explained in the next chapter.

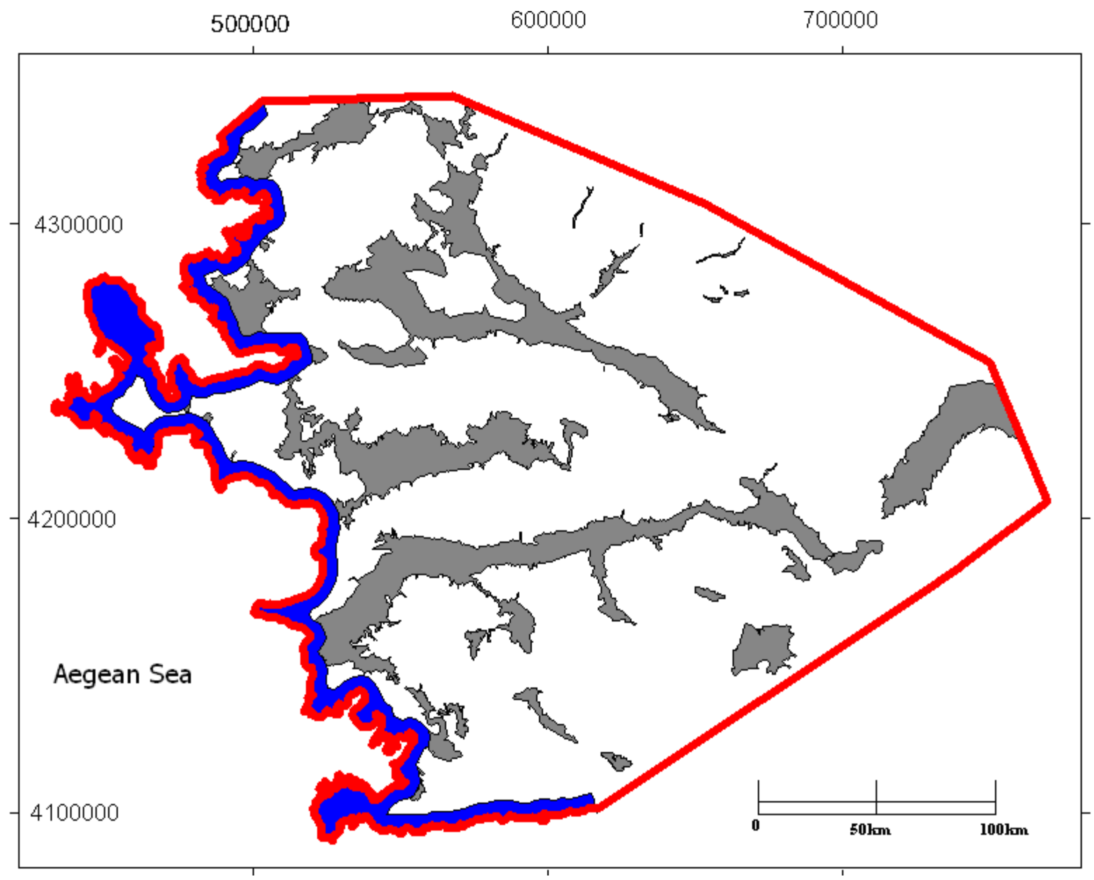


Figure 5.6 Morphological map of the study area

5.3 Ancient Settlements

Ancient settlements refer to the Greek and Roman cities that exist in the area and, therefore, constitute the most critical data as far as the purpose and the scope of the thesis are considered. This data, however, is the most problematic one because there is not a definite list of ancient cities. Presence of some settlements is still open to discussion. Details of these settlements are given in Chapter II. A plot of the settlements is shown in Figure 5.7. Complete list of ancient settlements is given in Appendix A.

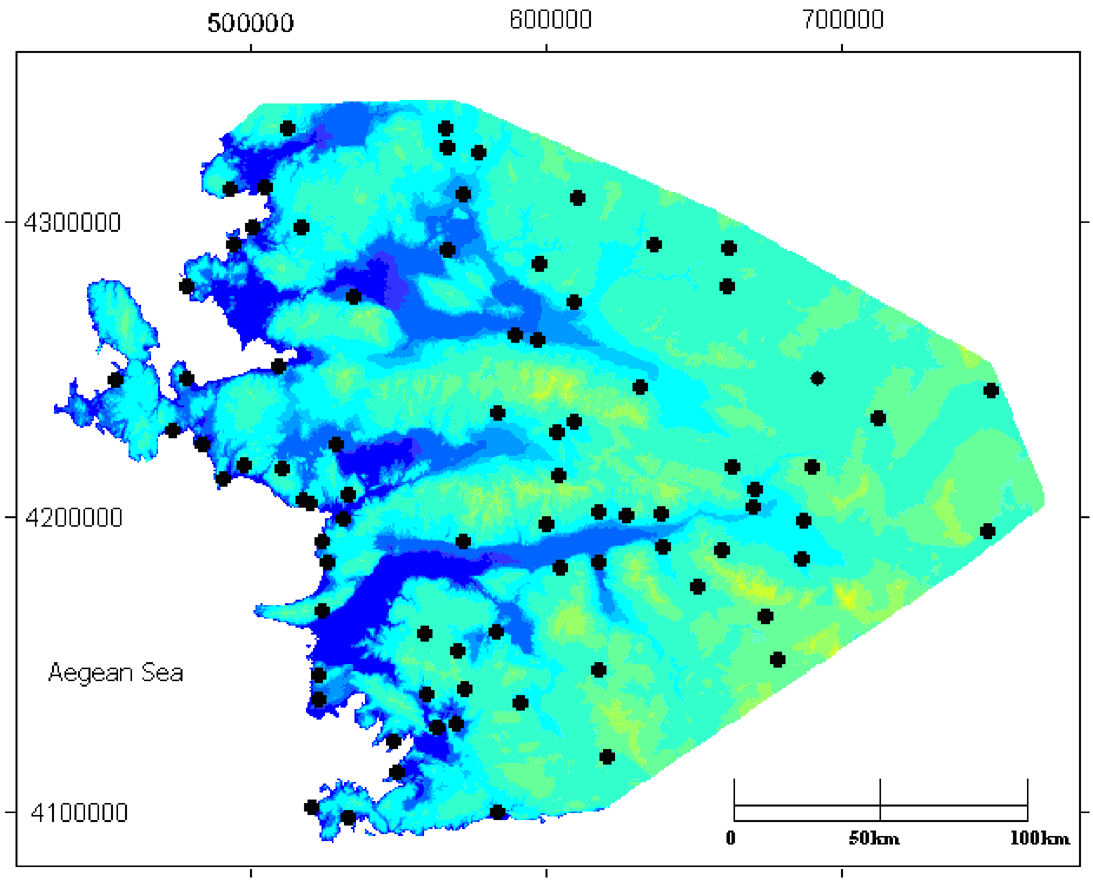


Figure 5.7 Distributions of Ancient Cities in West Anatolia

5.4 Modern Settlements

Modern settlements refer to the villages or cities that are settled today in the region. A database is created (Appendix B) that contains following information for the modern settlements: Name of the settlement, Coordinates (2 columns: Easting and Northing), and the population for the year 1965.

These settlements are identified using 1/100.000 scaled topographic map of the area prepared by the General Command of Mapping. Following criteria are applied during the selection of these settlements:

- The exact location of the settlement is easily identified on the map except for some problematic ones. For such settlements, which are usually scattered in the area and there is not a definite location for the site, any point in the close vicinity is selected. If observable, either the mosque or center of the settlement is marked for the location.

- No distinction is made as far as the size and population of settlements are considered. The main reason for this is that, the growth of the settlement is a later event and does not affect the decision that this site was selected as a suitable place for settlements. Therefore, all cities, counties and villages are recorded as settlement.
- Temporary settlements such as “yayla” (highland summer settlements) are not considered since they are not permanent settlements. Similarly small settlements associated with recent farming activity, and sub-villages (mahalle) or settlements grown around petrol stations are not considered
- Touristic sites developed in the recent years are not considered in this study. These settlements are the products of intense tourism activity in the region and can be considered as temporary settlements. Most of these settlements do not even exist in the topographic maps used which date back to 1966.
- Each settlement is represented by a point (a pixel) regardless of the size of the settlement. This point usually is the geometric center of the polygon that represents the settlement. A deviation in this measurement will not be more than a pixel (100 m) which is believed that it will not affect the result of the analysis.

The coordinates of the settlements were taken from topographic map and then they were transferred to database. The topographic attributes (elevation, slope and aspect) were extracted from DEM of the area. Lastly, the landform class, the nearest landform class and the position of the settlement within the class are read from the landform map.

Identified settlements are checked with two external sources: 1) Settlement names listed official web sites of cities, and 2) Village names published by the State Institute of Statistics for 1965 census of population. A plot of the modern settlements is shown in Figure 5.8.

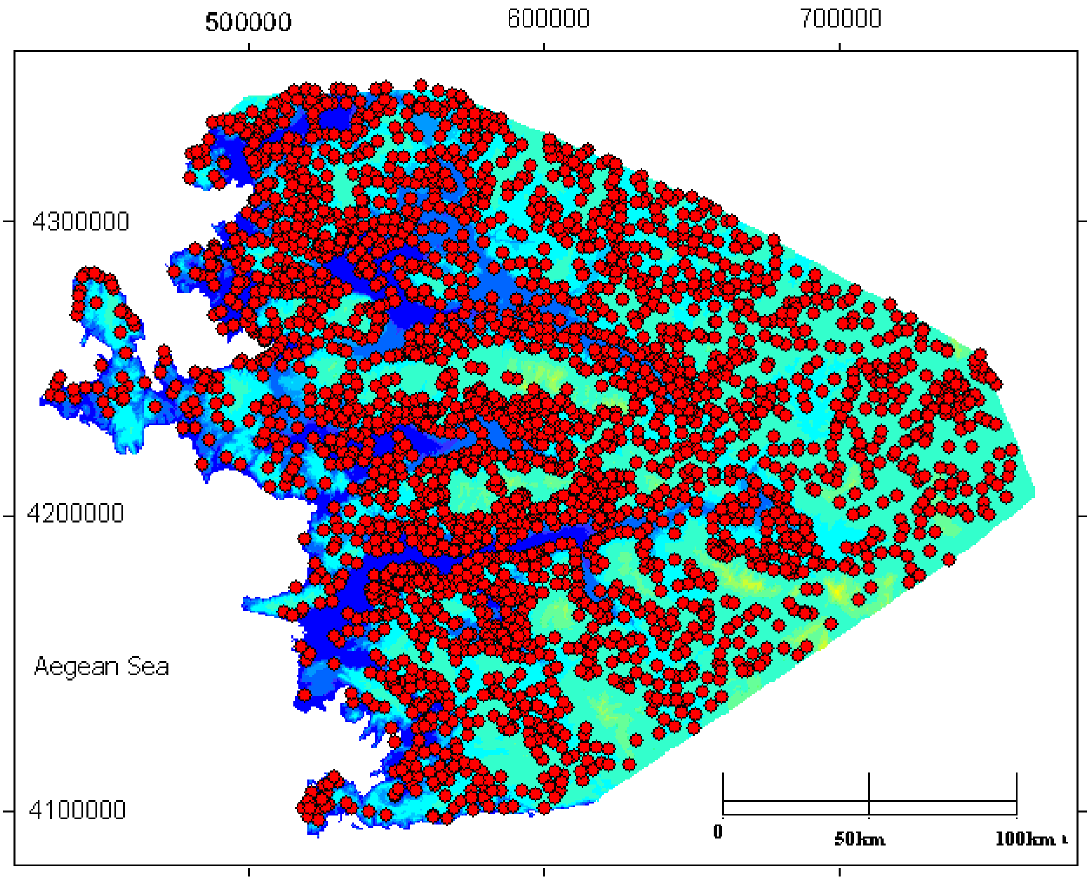


Figure 5.8 Distribution of modern settlements within the study area.

5.5 Rock Data

Rock types existing in the area are included in the analysis to investigate if a certain rock type is preferred or avoided during the selection of the settlement site. For this reason the digital geological map of the area obtained from MTA is used in this study. The original map is shown in Chapter III. The study area is included in two sheets at 1/500.000 scale, namely Denizli and Konya sheets.

The number of individual rock units in the original map is more than 100 with a total of 1154 individual polygons. This is a large number for GIS analysis and should be simplified for a meaningful analysis. Therefore, all the rocks units in the area are re-classified considering their age and lithological characteristics. In the resultant classified map, number of the units is reduced to 7 (Figure 5.9). Basic features of these classes are summarized in Table 5.3. A short description of each rock class is given below.

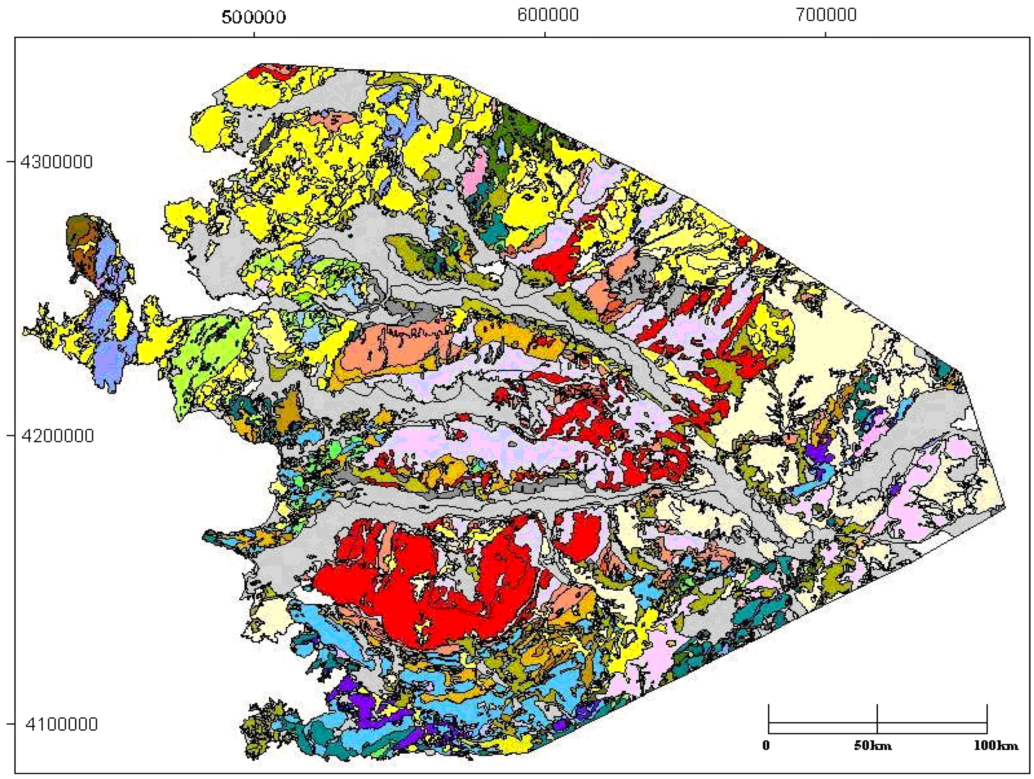


Figure 5.9 Top: Raw geological data (Source: MTA), Bottom: Reclassified (simplified) geological map of the area used in this study.

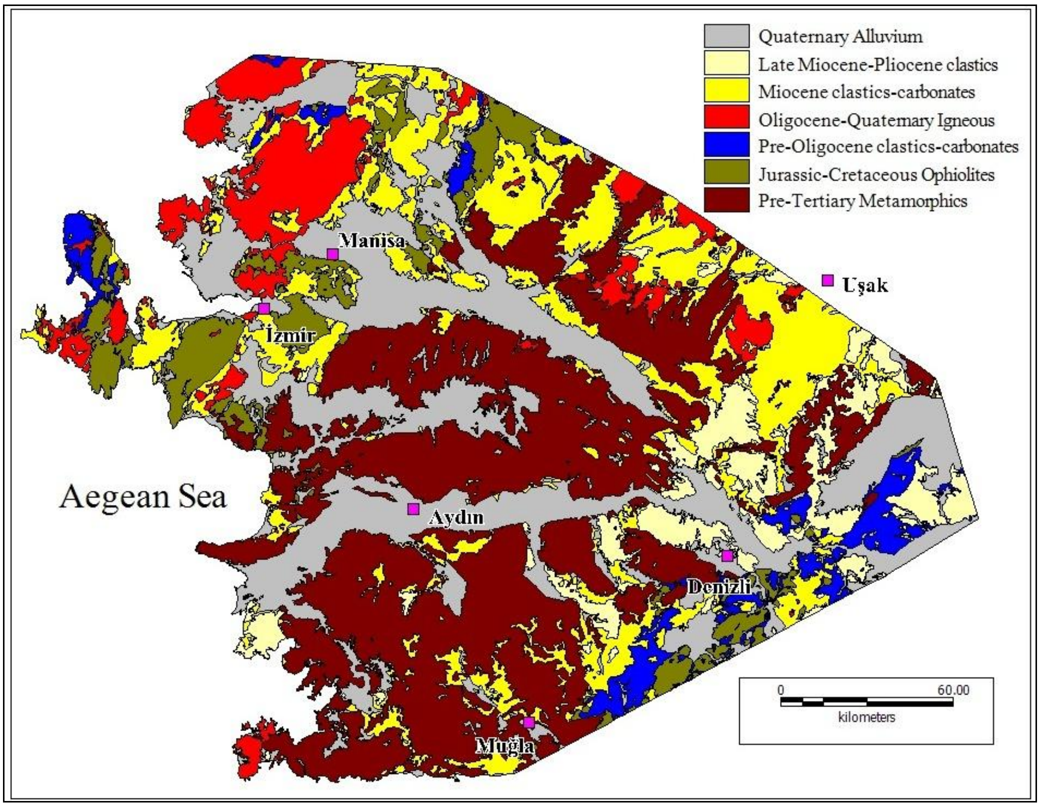


Figure 5.9 (Continued)

Table 5.3 Basic information on the rock types observed within the study area.

Name of Rock Class	**Age range**	**Number of polygons**	**% over the area**
Recent alluvium	Quaternary	189	23.8
Continental clastics	Late Miocene-Pliocene	108	6.4
Clastics & carbonates	Miocene	324	18.4
Igneous rocks	Oligocene-Quaternary	112	7.6
Clastics & carbonates	Paleozoic-Eocene	84	4.3
Ophiolites	Jurassic-Cretaceous	183	6.7
Metamorphic rocks	Precambrian-Cretaceous	156	32.6

Quaternary recent alluvium: These rock units are mostly associated with the fluvial deposits observed within the basin floors of the grabens deposited by the flowing rivers. They are the youngest unit in the area deposited by the active streams. Most of them are unconsolidated or semi-consolidated. This lithology has the second largest coverage in the area after metamorphic rocks with a percentage of 23.8.

Late Miocene-Pliocene continental clastics: This class is composed of 55 polygons of “Pliocene clastics” and 53 polygons of “Upper Miocene-Pliocene lacustrine clastics”. Most of these units are observed in the western part of the area between Muğla and Uşak (Figure 5.9). This unit is relatively a unit easily eroded; therefore, a gentle topography is formed where this unit is exposed. Total area covered by this class is 6.4 %.

Miocene clastics and carbonates: This rock unit is similar to the “Late Miocene-Pliocene clastics” which is different in two aspects: 1) The carbonate content is more in this class represented; 2) The sequences are relatively compacted and hard producing steep topography. It is composed of 30 polygons of “Miocene carbonates, marl and shale” and 294 polygons “Miocene continental clastics”. It covers 18.4 % of the area (Figure 5.9). The outcrops are mostly concentrated in the northern part between Manisa and Uşak, although some outcrops are scattered throughout the area.

Igneous Rocks: All igneous rocks in the area are gathered in this class regardless of their lithology and age. The class is composed of 53 polygons of various volcanic rocks (andesite, basalt, dacite, rhyolite and rhyodacite) of Miocene-Quaternary age, 38 polygons of Miocene pyroclastics, 14 polygons of “undifferentiated” volcanic rocks of Lower-Middle Miocene age, and 7 polygons of Oligocene to Miocene granitoids. Although the units are randomly scattered in the area, in general, they are concentrated in the northern part of the region (Figure 5.9). They cover 7.6 % of the area.

Paleozoic-Eocene clastics and carbonates: This unit comprises the most diverse rock types in the area considering both the lithology and the age. They have, however, the least aerial coverage with 4.3 %. The class is composed of sedimentary rocks (both carbonates and clastics) in a wide range from Paleozoic to Eocene. They are clustered in two regions, namely, in the southeastern part of the area around Denizli and in the western part between İzmir and Manisa (Figure 5.9). Total number of polygons for this class is 84.

Ophiolites: Ophiolites are the products of the continental collision and represented by the obducted slabs of different rock types. Out of the 183 polygons in this class 88 outcrops belong to “neritic limestone”, 7 to “pelagic limestone”, 31 to “flysch”, 34 to peridotite/serpentinite and 1 to spilitic basalt. 22 outcrops are mapped as “mélange”. They are mostly observed in the western part of the area and are the members of the well-known “Izmir-Ankara suture zone”. Smaller outcrops are located around Denizli (Figure 5.9). Total area covered by this unit is 6.7 percent.

Metamorphic Rock: This class is the most widespread unit and covers 32.6 of the area. The units in this class are the members of “Menderes massif” which form the basement of the all sequences in the region. It forms a single and large outcrop in the central part of the study area which is disintegrated by later geological events (Figure 5.9). It is composed of 156 outcrops of various metamorphic facies. Common rock types are schists, gneisses, phyllites, migmatites, calcshists, marbles and meta-granitoids and meta-clastics.

5.6 Seismic Data

Seismic data is important in this study in two ways: 1) They indicate an activity along the faults suggesting that the faults in the area are active; and 2) Distribution of the seismic data may be used to evaluate the location of the settlements. For these reasons, it is decide to carry out some analysis using the seismic data. During the compilation of the data, several attempts are made to provide the best database as far as the frequency, time span and accurate coordinates are considered.

Although accurate seismic data is available since 1970’s, the narrow time span covered by this data is believed not to represent activity in the whole region. For this reason the database for the last 100 years published by “Kandilli Observatory” is considered to be the most reasonable source to be used in this study.

Earthquakes in this database are obtained through the www.sayisalgrafik.com/deprem web page.

Data for the earthquakes between 1900 and 2011 is shown in Figure 5.10. The earthquakes in the figure are compiled for a rectangular area bounded by 25-30 longitudes and 36-39 latitude. The database includes a total of 16595 earthquakes with magnitudes equal to and greater than 3. This data is clipped out with the boundary of the study area and the earthquakes out of the area are excluded from the analysis. Number of the earthquakes in the final database to be used in this study is 6082. Table 5.4 shows the earthquakes used in the analysis. Large earthquakes occurred in the vicinity of area are illustrated in Figure 5.11.

Attribute table for the database include data, hour, latitude, longitude, depth and magnitude. Among these properties, however, only the coordinates are dealt in this study. Time of occurrence, depth of earthquake, its magnitude, for example, is not considered during the analysis.

Table 5.4 Earthquakes used in this study.

Magnitude	Frequency
3.0 - 3.9	5682
4.0 - 4.9	327
5.0 - 5.9	64
6.0 – 6.9	9

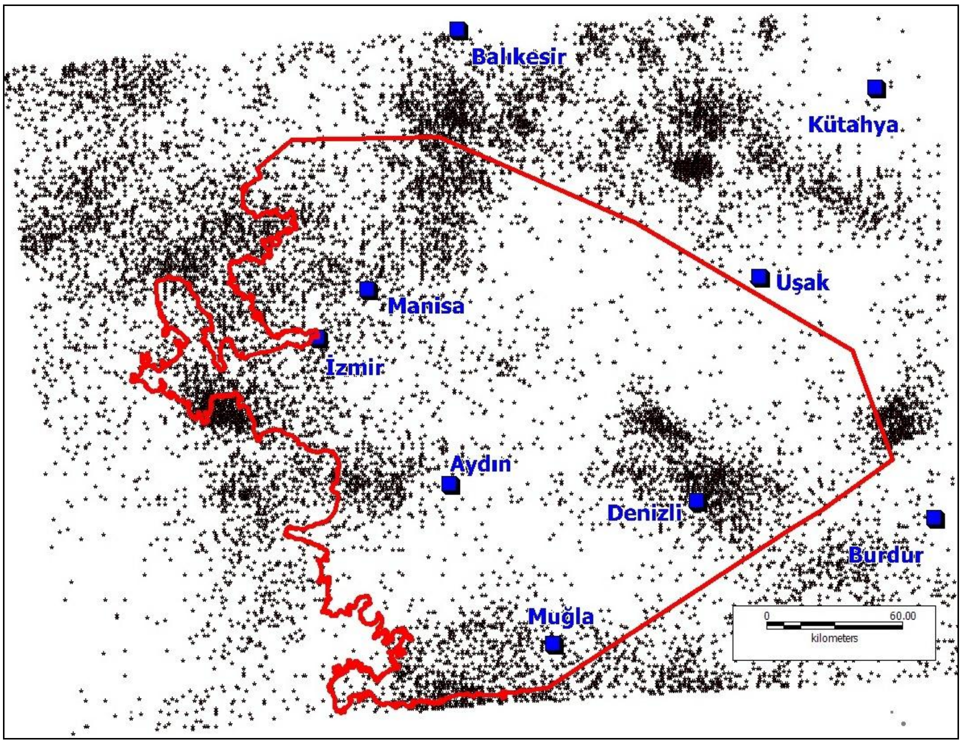


Figure 5.10 Distributions of Eearthquakes between 1900 and 2011

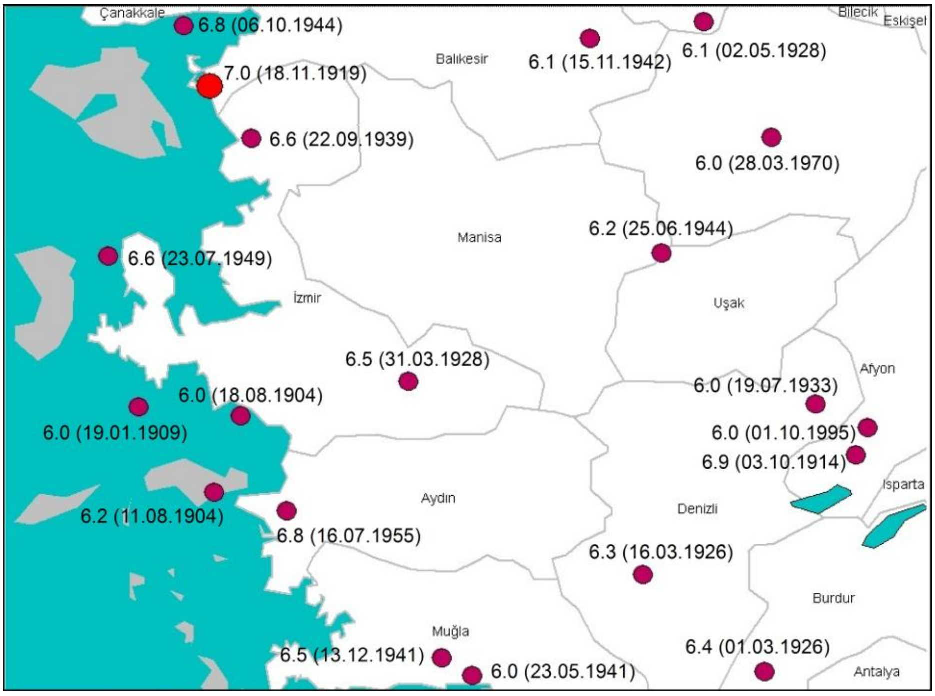


Figure 5.11 Large earthquakes occurred in the vicinity of area

5.7 Active Fault Data

Although the main purpose of this study is to investigate the relationship between the settlement location and the active fault, because of the lack of the data on active fault this relationship is tested by "morphological classes". However, towards the end of the thesis study MTA puplished the active maps of the area at 1/250.000 scale. Since the accuracy of these maps can be questioned (as missing some faults in some known areas) thye methodology of the thesis is not changed and these faults are not used to inspect the relation between the settlements and the faults. Instead, it is decided to use these maps as a mean of "accuracy assessment" made at the end of this study.

The active fault maps are first scanned, digitized, registered and mosaiced. Then, the fault lines are digitized and stored in a separate file. A sample raw map of these sheets is shown in Figure 5.12.

Figure 5.12 Active fault map obtained from MTA (İzmir)

CHAPTER VI

ANALYSES AND RESULTS

This chapter describes the analysis performed in this study to find the relationship between the data collected for the study area and ancient and modern settlements. First a simple methodology will be given that shows the major steps of the study followed by individual analyses carried out for the region.

6.1. Methodology

The methodology of this study consists of four major steps (Figure 6.1).

The first step is the creation of databases for the data to be used in theis study. Selection, organization and conversion to consistent formats are the main tasks in this step. Details of the data sets are explained in previous chapter. Five databases created for the study are as follows:

1) **Morphologic database**: This database is composed of three raster maps that contain elevation, slope and aspect values of the region. Morphology classes will also be produced from this database.
2) **Ancient settlement database:** This database contains coordinates of 81 ancient settlements as well as their morphological and rock type properties.
3) **Modern settlement database:** It is a similar database as for ancient settlements holding the attribute table for 2569 modern settlements.

4) Rock type database: This is a vector map that holds the rock type polygons from geological map reclassified for this study.

5) Seismic database: Coordinates of earthquakes reported by Kandilli Observatory for the interval 1900-20111 with magnitude greater than 3

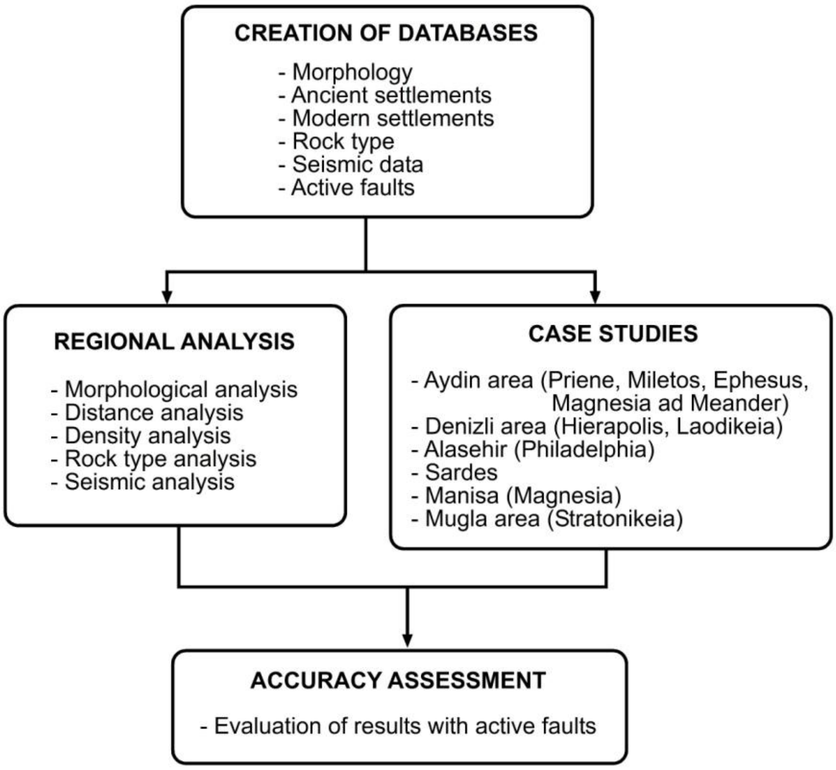


Figure 6.1 Flowchart showing the major steps of this study

The second step is the analysis of the data mentioned above. In this step, different analyses will be performed to seek the relationship between the settlements and other parameters. The analyses are as follows:

1) Morphological analysis

2) Distance Analysis

3) Density analysis

4) Rock type analysis

5) Seismic Analysis

The analysis and the results will be given in this chapter.

The third step is case studies performed for some selected areas where direct effects of the faults are investigated. A total of 10 ancient sites in six areas are studied in this step. This step is explained in Chapter VII.

The fourth step is the accuracy assessment of the results based on the active fault map prepared by MTA. Details of this step will be given in Chapter VIII.

6.2 Morphological Analysis

Morphological analyses are performed to quantify morphological characteristics of the region and the settlements (both ancient and modern). Elevation, slope and aspect values are three main morphological parameters calculated for the whole region and settlements in the previous chapter. Each parameter is investigated separately to see the relationship between these parameters and the settlements.

Elevation: Elevation histograms of both ancient and modern settlements are subtracted from the histograms for the whole area (Figure 6.2). Positive region in the histogram indicates that the percentage of the settlements is greater than the percentage of the region for this interval. Therefore, positive number suggests that this elevation is preferred as a site for settlements. Similarly, the negative areas suggest that these elevations are avoided as settlement site.

The histogram for ancient settlements clearly indicates that the interval 0-100 m has a positive value of more than 20 % which is the most preferred interval. This elevation corresponds to the coastal areas and the flood plain floors. The range between 0 and 200 m is positive suggesting that this interval is preferred as settlement site. The upper elevations of this interval correspond to the interior parts of the flood plains (graben floors) or their margins which are suitable for settlement. The range between 200 and 700 m, although irregular and inconsistent, is represented by values close to zero suggest that these elevations are neither preferred nor avoided. The elevation above 700 m, on the other hand, has consistently negative values suggesting that these elevations are avoided for settlement.

This histogram, therefore, can be interpreted as indicating three distinct intervals: 1) 0 to 200 meters preferred, 2) 200 to 700 m inconsistent interval, and 3) above 700 m avoided as settlement site.

Difference elevation histogram for modern settlement is prepared by subtracting the percentage of settlements from percent of the whole area (Figure 6.3). Positive and negative values in the histogram similarly indicate the preferred and avoided intervals, respectively. The pattern of the histogram indicates two distinct intervals: 1) 0 to 600 m elevations are preferred. However, the values of positive numbers gradually decrease as elevation decreases. This indicates that the modern settlements preferred the lower elevations more than the higher ones. 2) Elevations above 600 m are avoided as indicated by negative values. Both positive and negative values in the histogram for modern settlements are smoother than the ancient histogram because the number of the modern settlements is much bigger than ancient settlements.

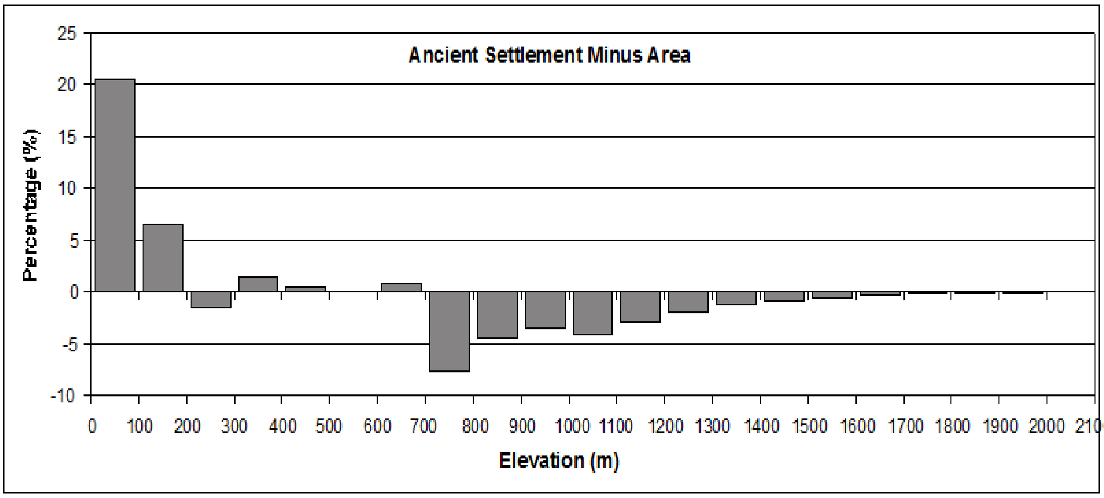


Figure 6.2 Subtracted histograms of ancient and modern settlements for elevation.

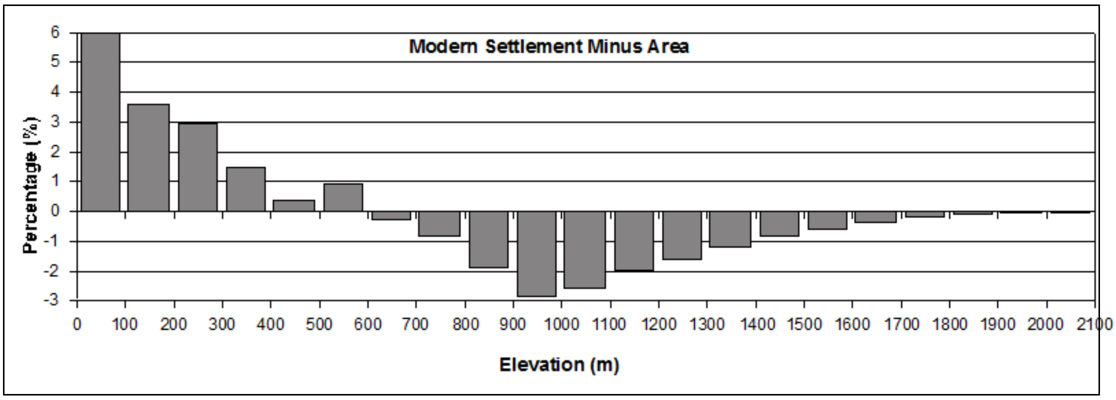


Figure 6.2 (Continued)

Comparison of two histograms indicates, in general, a similarity in the patterns of the elevation intervals. The main difference between the two histograms is an obvious shift in the value of that the elevation limits for two settlement types. The upper limit of elevation for the "preferred" interval is 200 m for the ancient settlements and is 600 m for the modern settlements. "Avoided" limit, on the other hand, starts at 700 m for the ancient settlements as indicated by a sharp change in the values. In the modern settlements, although the "avoided limit" starts at 600 m, it makes a peak value at 900 m. Accordingly, the lower limit of the modern settlement for avoided limits is greater than the ancient limit.

Slope: Similar diagram is prepared for the slope values by subtracting the histogram of settlement slope from the histogram of region slope. The results are given in Figure 6.3 for ancient and modern settlements for 2-degrees interval. Positive numbers in the diagram suggest "preferred" and negative numbers "avoided" intervals. These two histograms indicate that:

- For the ancient settlement, the range between 0 and 2 degree obviously indicate the preferred interval. This slope is mostly located in the flood plains and has the highest percentage in the histogram. The interval between 2 and 4 degrees has a negative value of about 1 % concentration and is followed by a positive range up to 8 degrees. Therefore this negative number is because of statistically small number of the ancient settlements. Ignoring this interval, the preferred slope values for ancient settlement will be between 0 and 8 degrees. The slope above 8 degrees has consistently negative values suggesting that these slope values are avoided for ancient settlement.

- For the modern settlement, the range between 0 and 8 degrees, is consistently characterized by positive values. The interval between 8 and 10 degrees has a value very close to 0. Starting with a slope value of 10 degrees, all larger slopes are avoided as indicated by consistently negative values in the histogram.

Comparison of two the histograms suggest that:

- Ancient settlements preferred almost flat areas as indicated by maximum concentration at 0-2 degree slope which is much higher than the modern ones.
- Upper limit of the avoided interval is 8 degrees for the ancient and 10 degrees for the modern settlements which do not suggest a radical change in time.

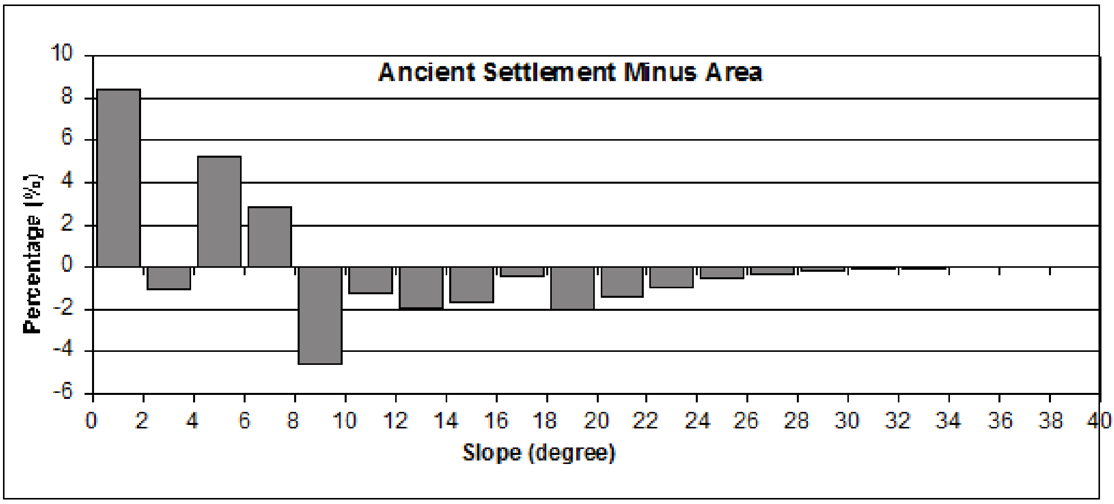


Figure 6.3 Subtracted histograms of settlements for the slope

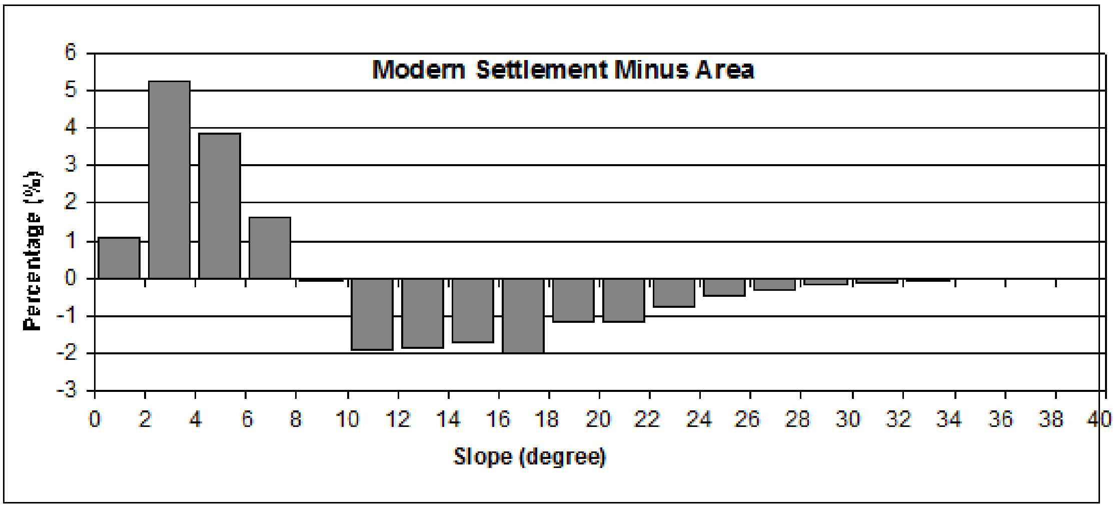


Figure 6.3 (Continued)

Aspect: Aspect values of the settlements are substracted from that of region to identify positive and negative regions. Results of the process are given in the histograms in Figure 6.4. Aspect values are divided into nine intervals including eight principal directions and the flat areas.

According to the information provided by these histograms:

- E, SE and SW slopes are preferred by both ancient and modern settlements
- N and NW facing slopes are avoided by both ancient and modern settlements
- NE and W are avoided by the ancient but preferred by the modern settlements
- Flat, NE and W are preferred by ancient but avoided by the modern ones,
- SE is avoided by the modern settlements; there is no data for ancient settlements,

The most preferred directions for the ancient settlements are Flat, E and S whereas the most avoided directions are N and NE. Modern settlements on the other hand preferred S and SW; avoided Flat, N and NW. The most radical change between two settlement types is observed in “Flat” areas.

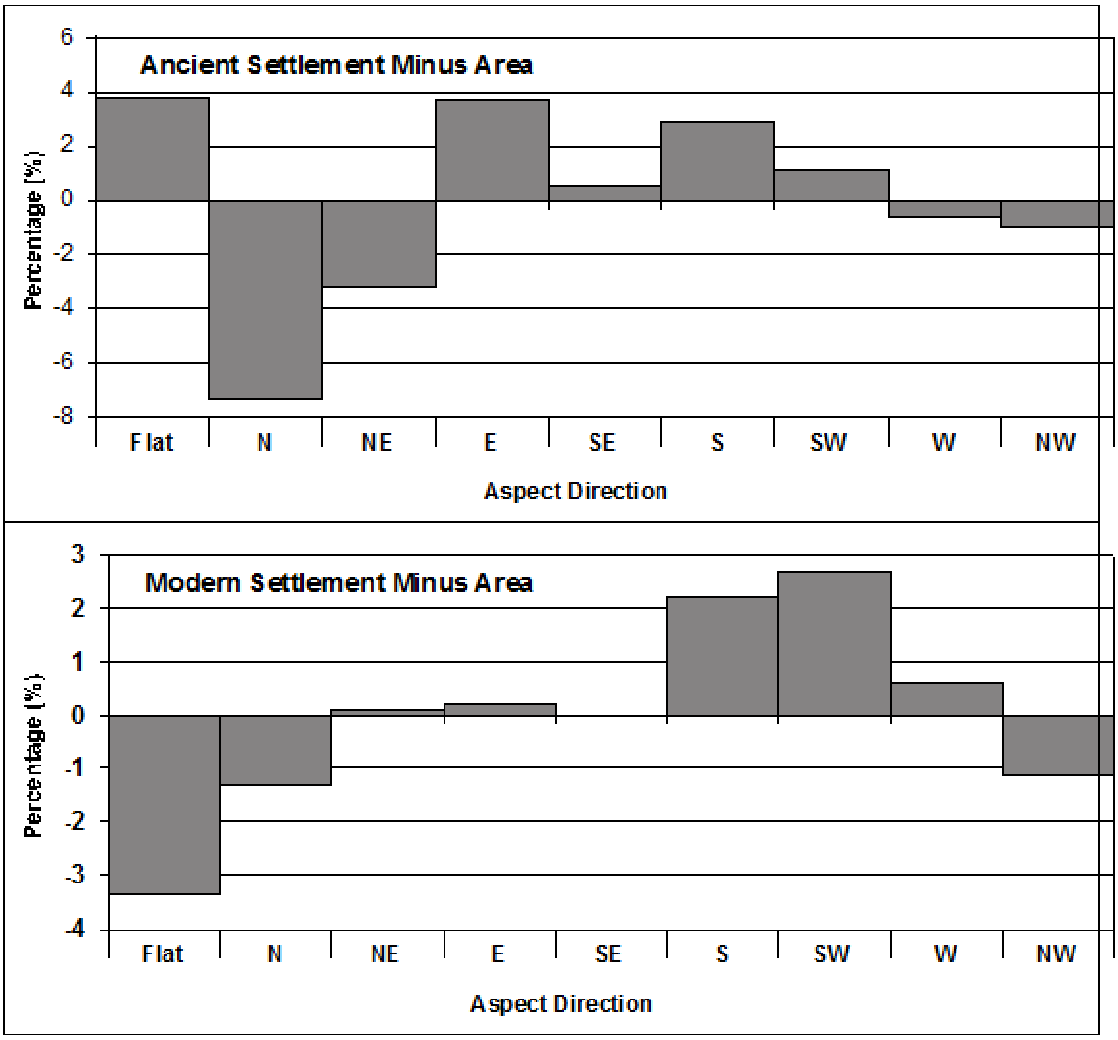


Figure 6.4 Subtracted histograms of settlements and the region for aspect values

6.3 Distance Analysis

Distance analysis aims to investigate how close a settlement is located to an active fault. Since there is no fault map used in this study, the margins of the morphological classes will be used to infer this relationship. A hypothetical example for the distance analysis is shown in Figure 6.5 where two morphological classes exist. Six settlements in the figure (A to F) are randomly distributed in the area. Four settlements (A, B, C and F) are located within "mountainous area" and two (D and E) in "flood plain". Two faults (X and Y) define the boundary of the two morphological classes which is the major assumption in this study.

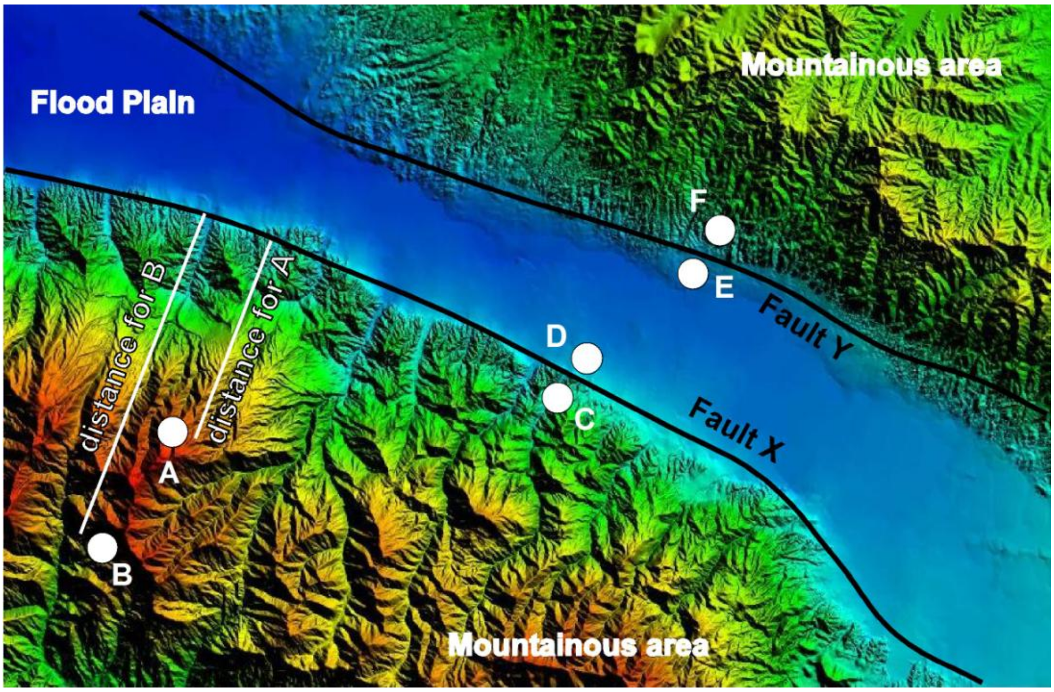


Figure 6.5 The model used for the distance analysis. The figure show two morphological classes (mountainous area and flood plain) separated by fault planes. Note that the coastal area is not shown in the figure.

Although there are four settlements in mountainous area, their distance to the fault line is not the same. For all settlements in the mountainous area, the distance to the flood plain; and for the settlements in the flood plain the distance to mountainous area is measured. To avoid the confusion the "nearest distance" is measured for all settlements. For example, for the settlement C and D, the distance to Fault X; and for the settlements E and F the distance to Fault Y is measured. Coastal settlements have a much simpler measurement which is the shortest distance to the shoreline within a buffer zone of 5 km. A total of three distance sets are measured:

1) Distance to shoreline for coastal settlements,
2) Distance to flood plain for mountainous settlements, and
3) Distance to mountainous area for flood plain settlement.

Each measurement set is repeated for both modern and ancient settlements, resulting in a total of six analyses. The results of these analyses are given in the histograms in Figure 6.6. The distances greater than 4.5 km for the ancient, and 7 km for the modern settlements are not shown in the diagrams. The numbers of the settlements in these intervals are very small and can be neglected.

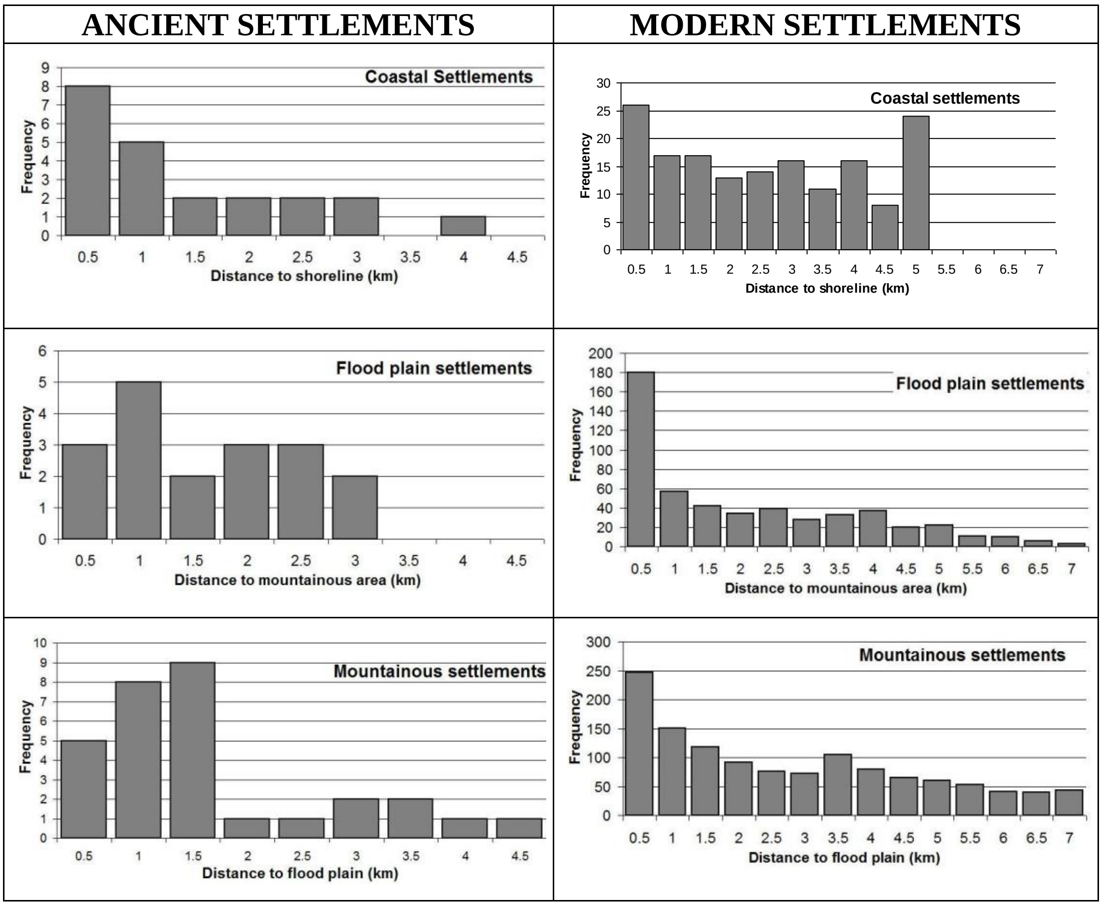


Figure 6.6 Histograms showing the distances to morphological classes for ancient and modern settlements.

The distances given in the histograms are reorganized and plotted in Figure 6.7 on a hypothetical profile across all morphological classes. A buffer zone of 2 km is added to the boundary between flood plain and mountainous area. This zone is defined as “fault zone” because one of the assumptions in this study is that the boundary between these two classes corresponds to an active fault. Since the size of a settlement can be defined in terms of a few km2, the width of this zone is assumed as 2 km. Therefore the settlements in this distance are considered to be located within the fault zone.

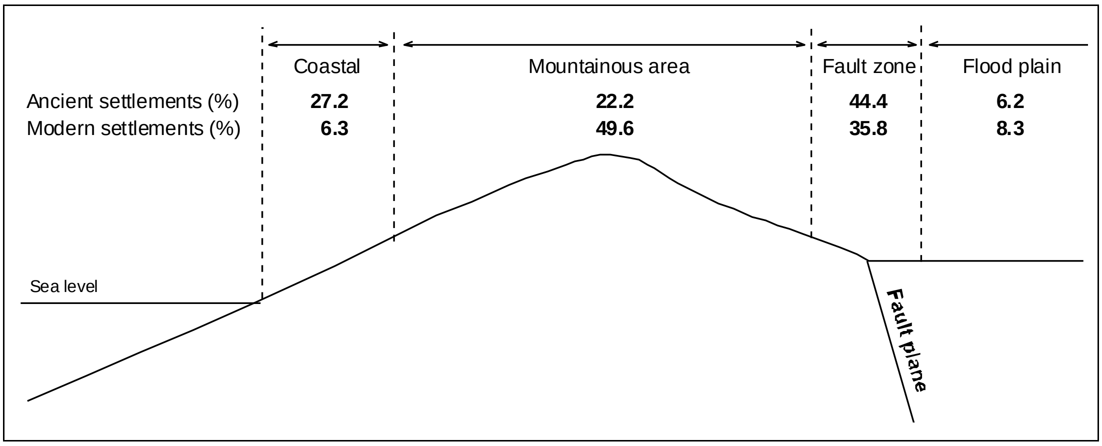


Figure 6.7 Distribution of the ancient and modern settlements within the morphological classes with a particular emphasis on the "fault zone" assumed between floods plain and mountainous areas.

Using the percentages of the settlements in the diagram following observations can be made:

- Almost one-forth of ancient settlements (27.2. %) are located within the coastal areas. There is a remarkable decline in the percentage of the modern settlements (6.3 %) in the same class. It should be remembered that the "new" modern settlement are not used in this study. The reason for this rapid change is out of the scope of this study and will not be discussed here.

- Mountains areas have percentages of 22.2 and 49.6 for ancient and modern settlements, respectively. This class has the biggest aerial coverage and large concentration of settlement can be expected. However the value particularly for ancient settlements is relatively low indicating that high regions with a large distance from shoreline and/or flood plain are not preferred. The increase in the percentage for the modern settlements indicates a gradual shift in time from low to high areas.

- Concentration of the settlements within the "fault zone" is the most critical matter for this study. About half of the ancient and one-third of the modern settlements are located in this zone. Therefore, although this area is a narrow zone (4 km wide), there is a large of concentration in this zone. This is an observation that supports the assumption for the relationship between the settlement site and the fault zone.

- Flood plains have the lowest percentage of settlements (6.2 % for the ancient and 8.3 % for the modern settlements) with a slight increase from ancient to modern times.

The distance between the settlements is another parameter to be investigated. If the settlements are not uniformly distributed in the area, this means in certain areas they are closely spaced and might provide useful information. For this reason the distances between the settlements are investigated for both the ancient and modern settlements. To do this, the coordinates of them are used. A program is written in BASIC language to calculate the distances for each set of data using their coordinates. The distances calculated are the plan-view (shortest) distances, therefore, any topographic factor is not considered. The program inputs the X and Y coordinates of each record and finds the nearest (minimum distance) ancient city for three sets:

1) ancient city to ancient settlement
2) modern city to modern settlement, and
3) ancient city to modern settlement.

The results of the analyses are given in the histograms in Figure 6.8 for three sets of calculation. A summary of the statistics for these data is given in Table 6.1

Table 6.1 Basic statistics of the distances between the settlements

	Frequency	**Min distance (m)**	**Max distance (m)**	**Mean (m)**
Ancient to Ancient	81	2759	47300	14969
Modern to Modern	81	163	6969	2127
Ancient to Modern	2569	12	35213	2342

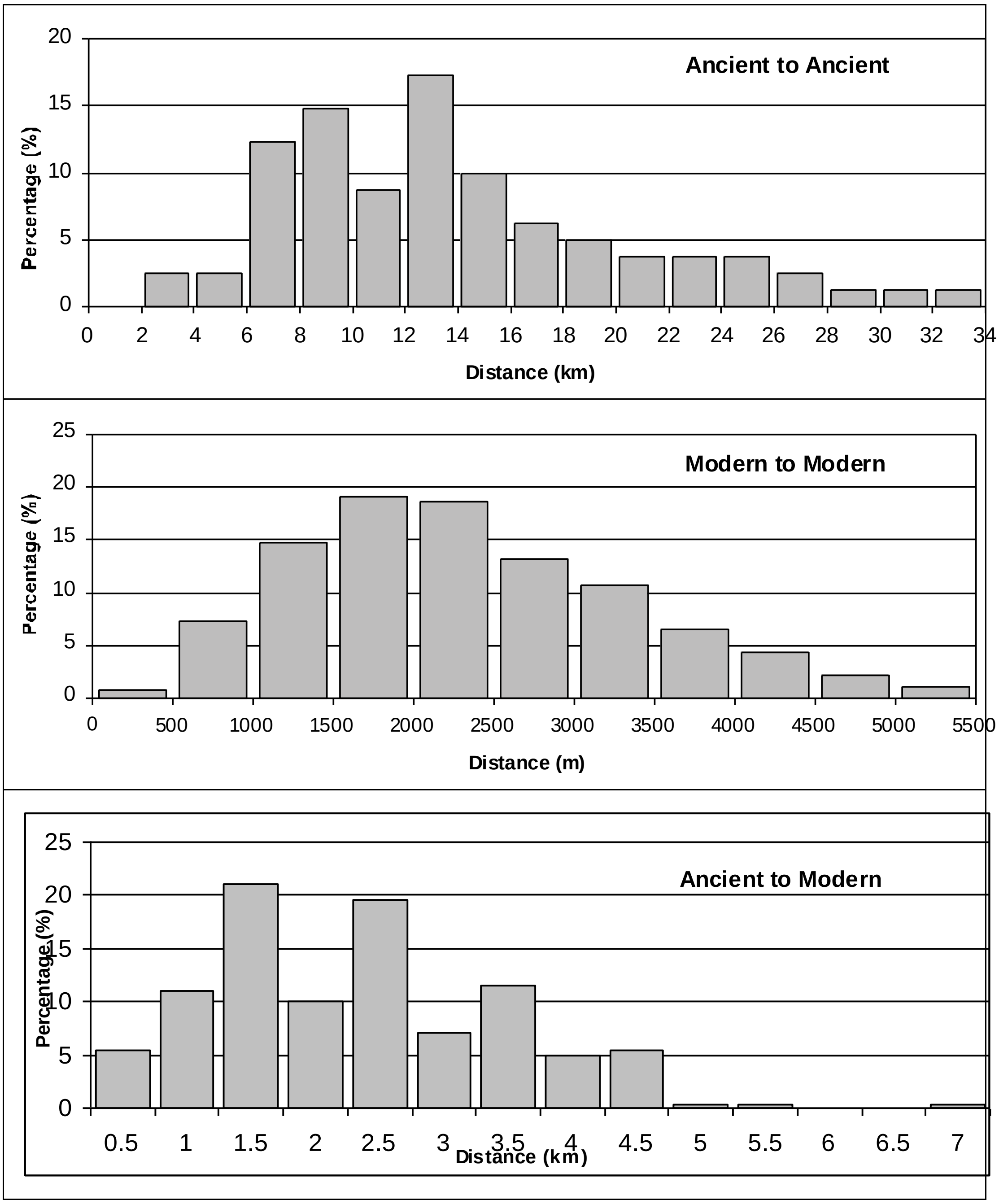


Figure 6.8 Histograms showing the distances between ancient to ancient

The mean distance between two ancient settlements is 14969 m with a maximum concentration of 12-14 km. Although the maximum distance is about 47 km, the values greater tan 34 km are not shown in the histogram. The distance range of 6-16 km has the maximum concentration in the region.

The mean distance between two modern settlements is 2127 m which corresponds to almost the maximum concentration in the histogram. The maximum distance on the other hand is 6969 m which is quite a low value in comparison with the ancient distances. This may indicate that most of the area is already occupied and there is almost no remote and isolated settlement during the modern times. The values greater than 5500 m are not shown in the histogram.

The third histogram shows the distances between ancient settlements and the nearest modern settlement. Total number of the measurements is therefore 81 which is the number of ancient settlements. The reason in finding this distance is to test if there is a modern settlement nearby an ancient settlement. The results indicate that the mean distance is 2342 m with a maximum concentration at 1-1.5 km interval. n two modern settlements is 2342 m. The mean distance between an ancient city and the closest modern settlement is 2127 m. Considering the size of any ancient or modern settlement, these values suggest that most of the ancient cities are in the close vicinity of present settlements. Therefore, the location of the ancient settlements is still attractive in the modern times.

Settlement distances might be affected by the morphological characteristics of the area. To test this relationship, the settlements are grouped according to different distances and plotted over the morphological classes. The results of this analysis are shown in Figure 6.9. The threshold values for the distances are selected using the histograms in Figure 6.8.

Ancient cities are divided into two groups as 1) distances less than 15 km and 2) greater than 15 km. As seen in the figure most of the first group settlements are located either within the coastal areas or at the margins of the flood plains. The second group settlements, on the other hand, are concentrated in the interior parts of the mountainous areas.

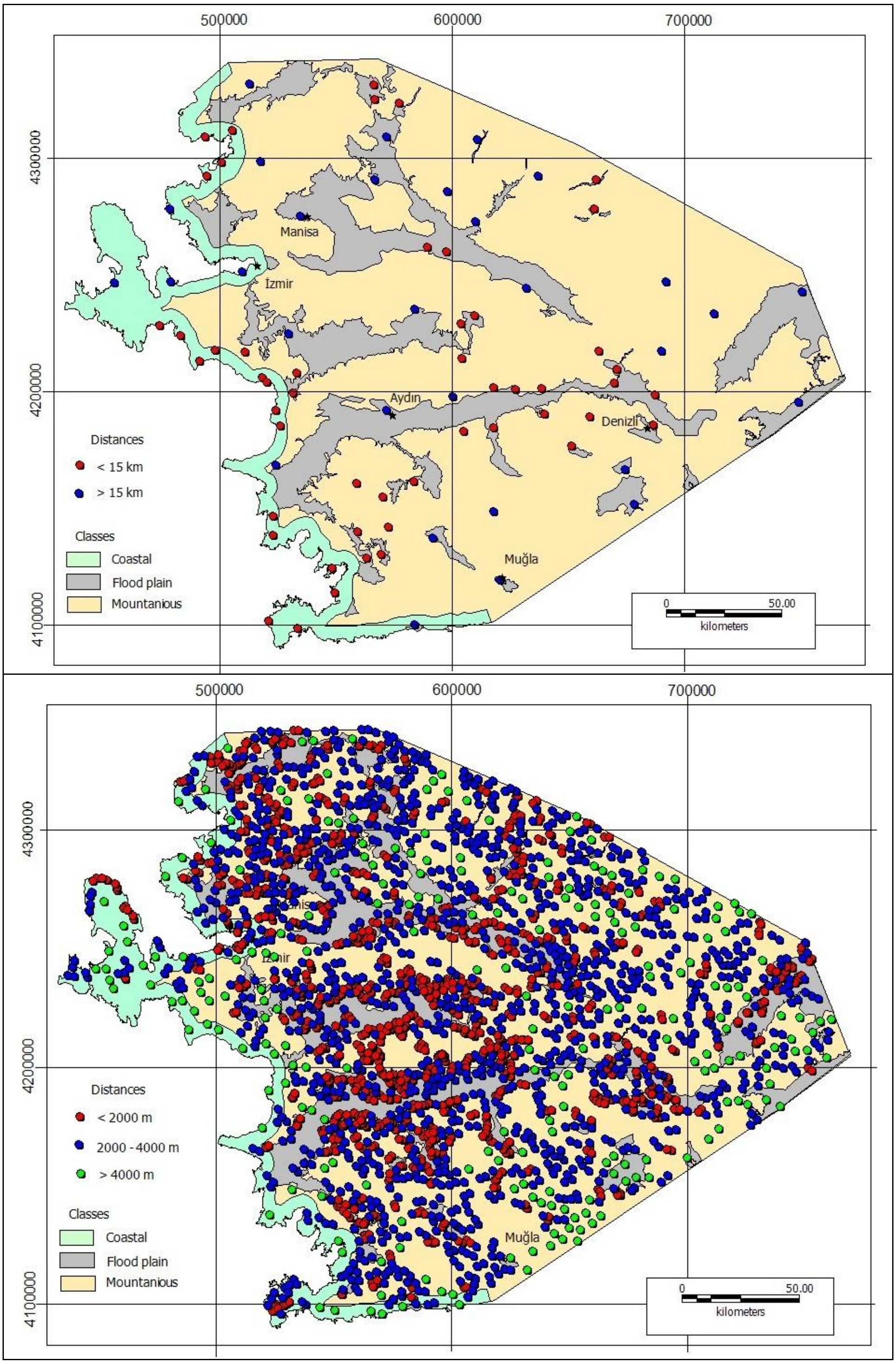


Figure 6.9 Distribution of the settlements according to their distances. Top: Ancient settlements, Bottom: Modern settlements.

The modern settlements are divided into three groups since the number of the settlements is considerably large. The threshold values are taken as the distance 1) less than 2000 m, 2) between 2000 and 4000 m, and 3) greater than 4000. The result indicates that, first of all, the coastal areas are not so much affective for the modern settlements. Secondly, a dense concentration of closely spaced settlements is obvious along the margins of the flood plains.

6.4 Density Analysis

The purpose of the density analysis is to find the maximum and minimum concentrations of the ancient and modern settlements within the study area. These concentrations will be used to evaluate the relationship between the densely located regions and morphology classes which, in turn, will infer the fault locations.

The population data does not exist for the ancient settlement. Therefore, for ancient settlements only the density of the settlements is analyzed. For the modern settlements, on the other hand, the population data for the year 1965 is available. Therefore, for the modern settlements two diagrams are prepared one for settlements and the other for the population of the settlements. The second diagram can be used to infer the "site catchment capacity" of specific areas which might be important for this study and will be discussed later.

During the preparation of the density diagrams, the grid interval is selected as 500 m with a search radius of 10 km. Contour diagrams are prepared from these grid-frequencies and illustrated over the morphological classes of the area. Density of ancient settlements indicates two maximum concentrations in the coastal regions south of İzmir and west of Muğla (Figure 6.10). As far as the flood plains are considered, the section between Aydın and Denizli is emphasized by a dense settlement that corresponds to the eastern parts of the Büyük Menderes graben.

Two density maps are prepared for the modern settlements. The second one which is based on the population has two major problems that negatively affect the quality of the analysis. These problems are: 1) for 154 settlements the population data is missed and has zero values in the database. This problem might be due to the change in the administrative status of the settlement since 1965, 2) some large settlements such as cities have very large values that mask other population data in the list. The affect of these two problems are illustrated in the histograms in Figure 6.11. The top histogram shows the raw data in which 95 % of the population is between 0 and 500.

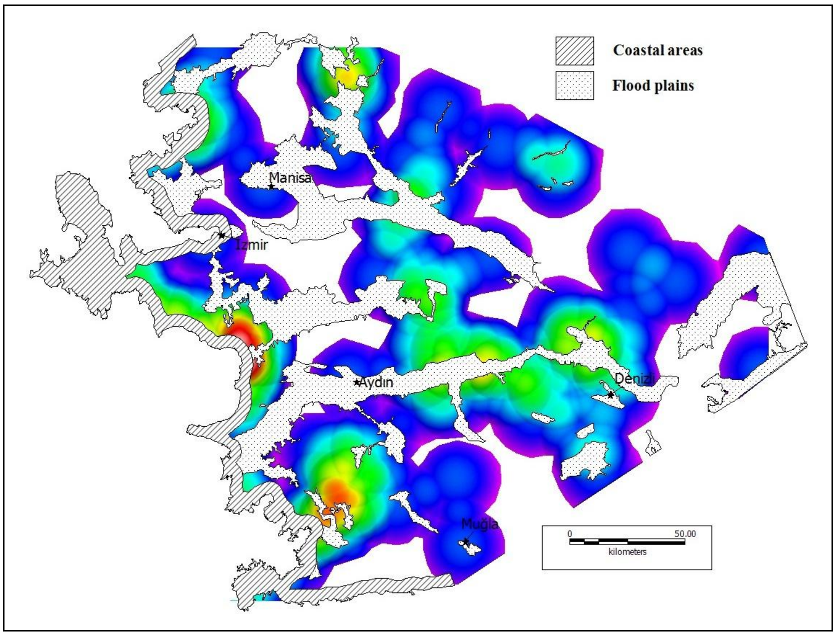


Figure 6.10 Density map of ancient settlements

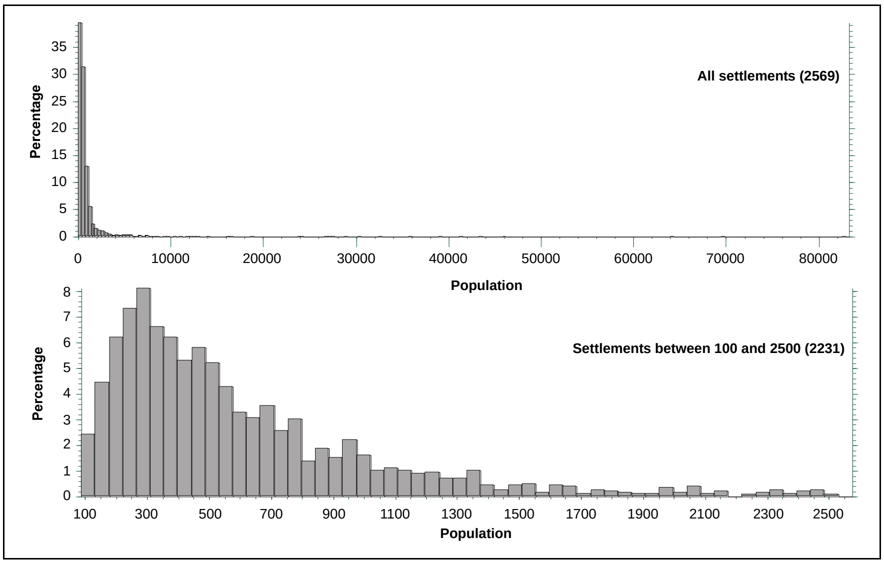


Figure 6.11 Histograms of the raw population data (top) and the population between 100 and 2500 (bottom).

To overcome this problem the population data is truncated for both zero values and very large settlements. The settlements less than 100 (total number of 205) and more than 2500 (total number of 143) are deleted from the database. The resultant histogram is shown in the bottom histogram in Figure 6.11. Total number of settlements used in this analysis is 2231 with a mean population of 600.

The density map for only settlements shows concentrations in five regions (Figure 6.11 top diagram). These areas are close vicinity of Aydın, vicinity of Denizli, east of Denizli, west of Muğla, and north of Manisa. The first three regions are located over the Büyük Menderes graben and its extension towards the east. In this sense, the analysis is consistent with the one for ancient settlements. The main difference, however, is the concentrations along the coastline. The modern density maps suggest a drop in the coastal settlements except the peninsula west of İzmir.

The density plot with populations of the modern settlements (Figure 6.12 bottom diagram) displays major differences from the previous one. These differences are as follows:

- Some mountainous areas with high concentrations for settlements have very low concentrations in the population analysis. Two best examples are

N of Manisa and NE part of the study are (east of Manisa). Interpretation of this fact is that, in these areas there are several small settlements.

- Almost all flood plains have high concentrations for the population analysis. All maximum densities are either within or at the margin of the flood plains. Gediz graben (east of Manisa) is the best example which is almost totally within red-colored high concentration. Two flood plain oriented in NW-SW direction west of Muğla are good examples of smaller size flood plains. The difference between two density plots for the modern settlements indicates that the modern settlements nearby a flood plain are much populated than the settlements in mountainous areas.

- There is a difference in the coastal settlements as well indicating that the coastal settlements are more populated than others.

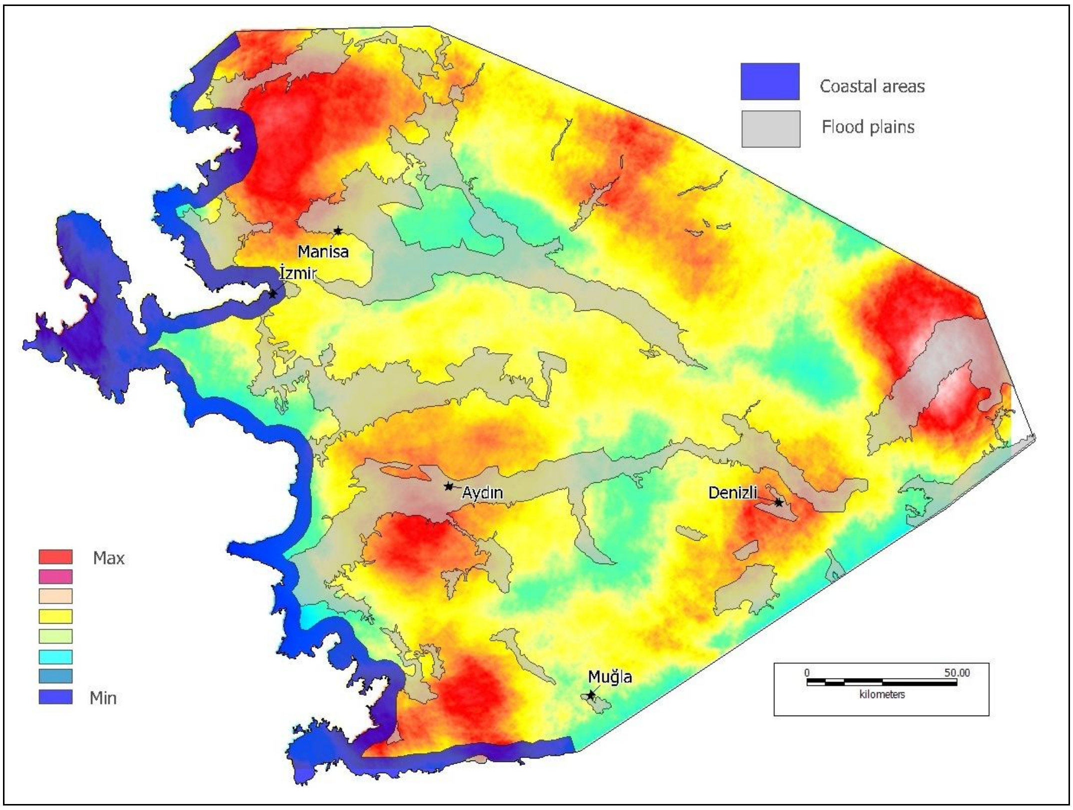


Figure 6.12 Density map of the modern settlements. Top: only settlements; Bottom: populations of the settlements.

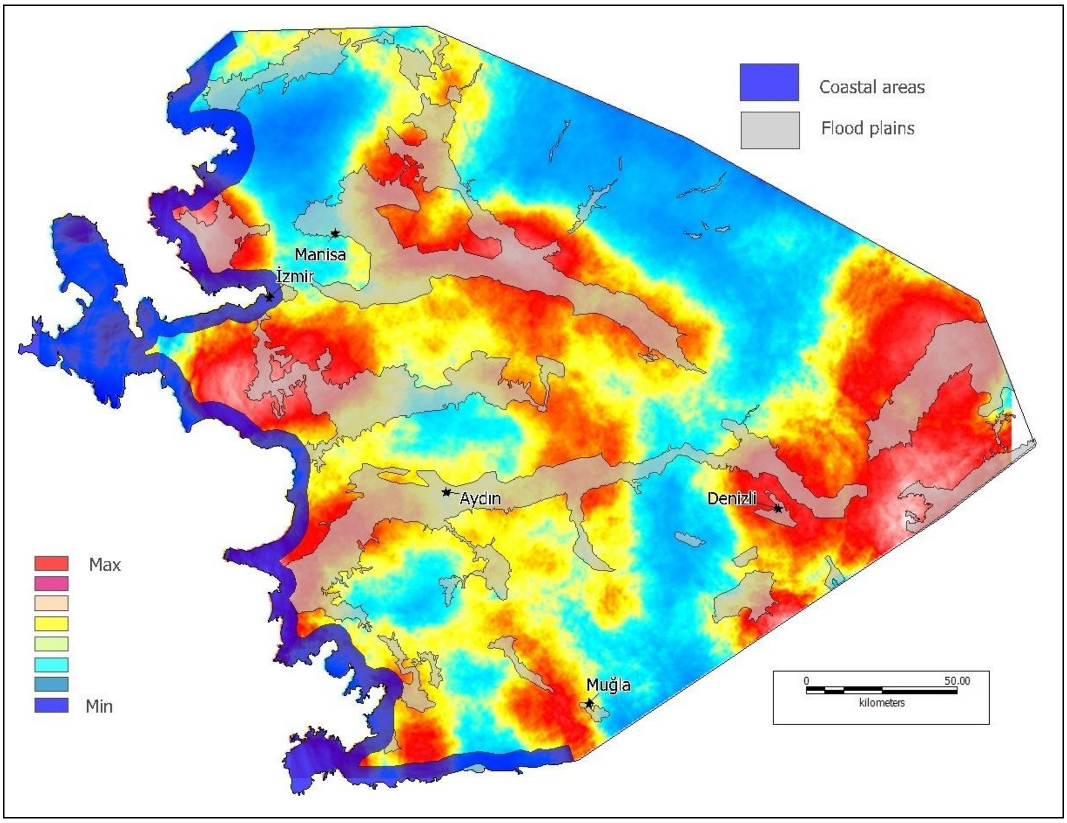


Figure 6.12 (Continued)

6.5 Rock Type Analysis

This analysis seeks a relationship between the rock type and the location of the settlements. Geological map modified for this study is explained in previous chapter. A total of seven rock categories are defined considering their age and lithological characteristics. To investigate the relationship between the rock type and the settlement site, firstly the percentage of settlements in each rock type is determined. Then the percentage of the rock categories over the whole area is calculated. The difference between these two values is plotted as a histogram. Positive numbers in the histogram indicate that the percentage of the settlement is greater than the percentage of this rock type; therefore, this rock type is preferred to be settled. If the value is negative than this rock is avoided.

The data for the ancient settlements is given in Table 6.2. The last column in this table is plotted as a histogram in Figure 6.13 which is the result of this analysis.

Following observations can be made for the relationship between ancient settlements and the rock types:

- The most striking value is 13.2 % for the recent alluvium indicating that this roc type is the most preferred one. Recent alluvium is the youngest unit (Quaternary) observed along the major stream channels. Most of the streams channels in the study area are represented by graben floors.

- The second largest number is -9.1 for metamorphic rocks which is the most avoided rock category. Most of the metamorphic rocks are observed in the high regions which are elevated by faults in the form of horsts. The density of settlements in these regions is low as known from the previous density analysis.

- Other rock categories have plus or minus values close to zero. Because of their small values although a preference or avoidance can not be claimed, it should ne noted that Late Miocene-Pliocene clastics are relatively preferred and Miocene clastics carbonated are avoided.

Table 6.2 Percentages over the ancient settlements and the rock categories

Rock Category		Ancient City		Whole Area	Difference
No	**Rock Name**	**Frequency**	**%**	**%**	**%**
1	Recent alluvium (Quaternary)	30	37.0	23.9	13.2
2	Continental clastics (Late Miocene-Pliocene)	8	9.9	6.6	3.5
3	Clastics & carbonates (Miocene)	11	13.6	18.5	-4.8
4	Igneous rocks (Oligocene-Quaternary)	7	8.6	7.6	1.0
5	Clastics & carbonates (Paleozoic-Eocene)	1	1.2	3.8	-3.1
6	Ophiolites (Jurassic-Cretaceous)	5	6.2	6.8	-0.5
7	Metamorphic rocks (Precambrian-Cretaceous)	19	23.5	32.7	-9.1

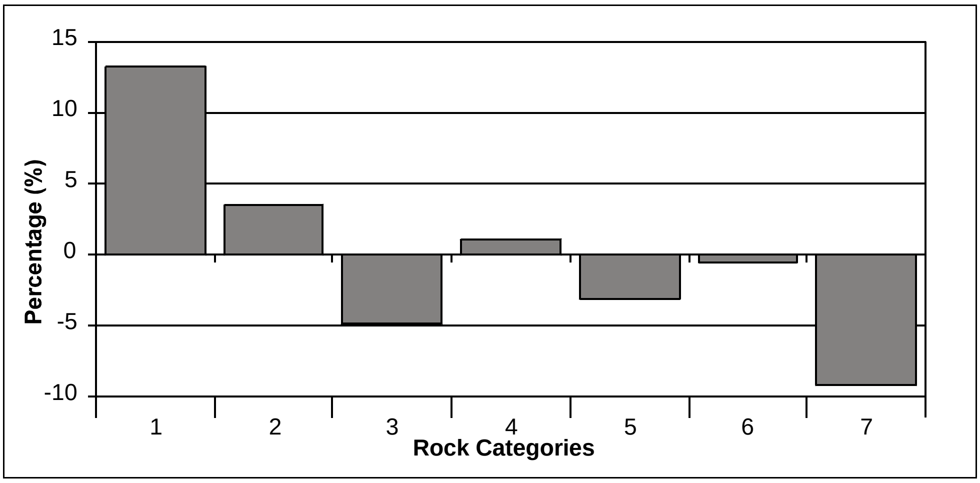


Figure 6.13 Histogram showing the difference between the percentages of the ancient settlements and the rock categories in the area.

The results for the modern settlements are shown in Table 6.3 and Figure 6.14. The results are very similar to the ancient settlement results with minor differences. The main difference is the decrease in the absolute values of both positive and negative percentages. The maximum absolute value for preferred class is 5.8 % and maximum negative value is 3.2 %. This decrease suggests that the settlements extend to all over the area in time and there are not much "barren" regions.Quaternary alluvial deposits are again the most favorable rock types in the modern times. The oldest two rock types (ophiolites and metamorphic rocks) are the most avoided lithologies.

Table 6.3 Percentages over the modern settlements and the rock categories

Rock Category		Modern City		Whole Area %	Difference %
No	**Rock Name**	**Frequency**	**%**		
1	Recent alluvium (Quaternary)	763	29.73	23.9	5.8
2	Continental clastics (Late Miocene-Pliocene)	125	4.86	6.6	-1.8
3	Clastics & carbonates (Miocene)	487	18.95	18.5	0.4
4	Igneous rocks (Oligocene-Quaternary)	245	9.53	7.6	1.9
5	Clastics & carbonates (Paleozoic-Eocene)	59	2.29	3.8	-1.5
6	Ophiolites (Jurassic-Cretaceous)	91	3.54	6.8	-3.2
7	Metamorphic rocks (Precambrian-Cretaceous)	799	31.1	32.7	-1.6

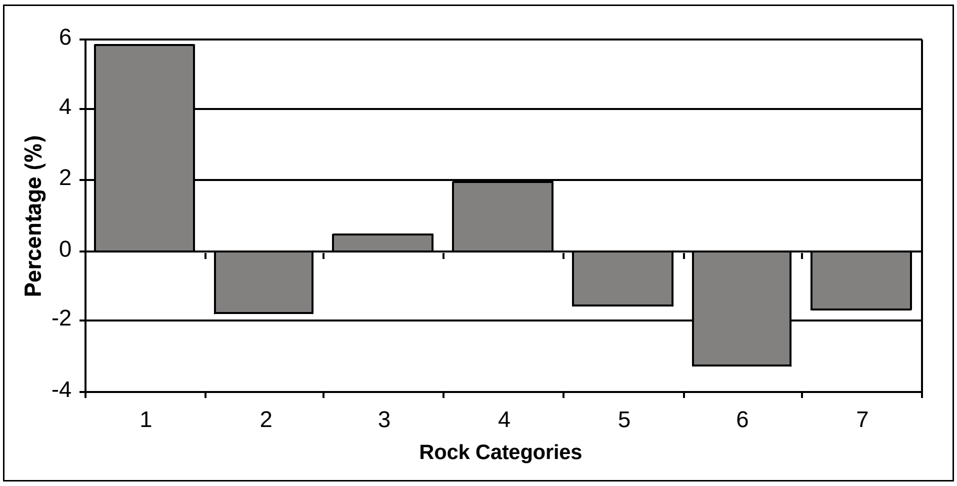


Figure 6.14 Histogram showing the difference between the percentages of the modern settlements and the rock categories in the area.

6.6 Seismic Analysis

Since the earthquakes are formed along the active faults, the distribution of the earthquakes should have a spatial relationship with the fault lines. For this purpose the earthquakes known in the area for the last century are used to infer the location of the fault lines. The seismic data is introduced and briefly explained in the previous chapter. Information about the earthquakes within the study area is given in Table 6.4. Total number of the earthquakes used is 6082. The density map of the earthquakes is prepared with a grid spacing of 500 m and search radius of 10 km. The resultant map is given in Figure 6.15.

Table 6.4 Earthquakes used in the analysis

Magnitude	**Frequency**
3.0 – 3.9	5682
4.0 – 4.9	327
5.0 – 5.9	64
6.0 – 6.9	9

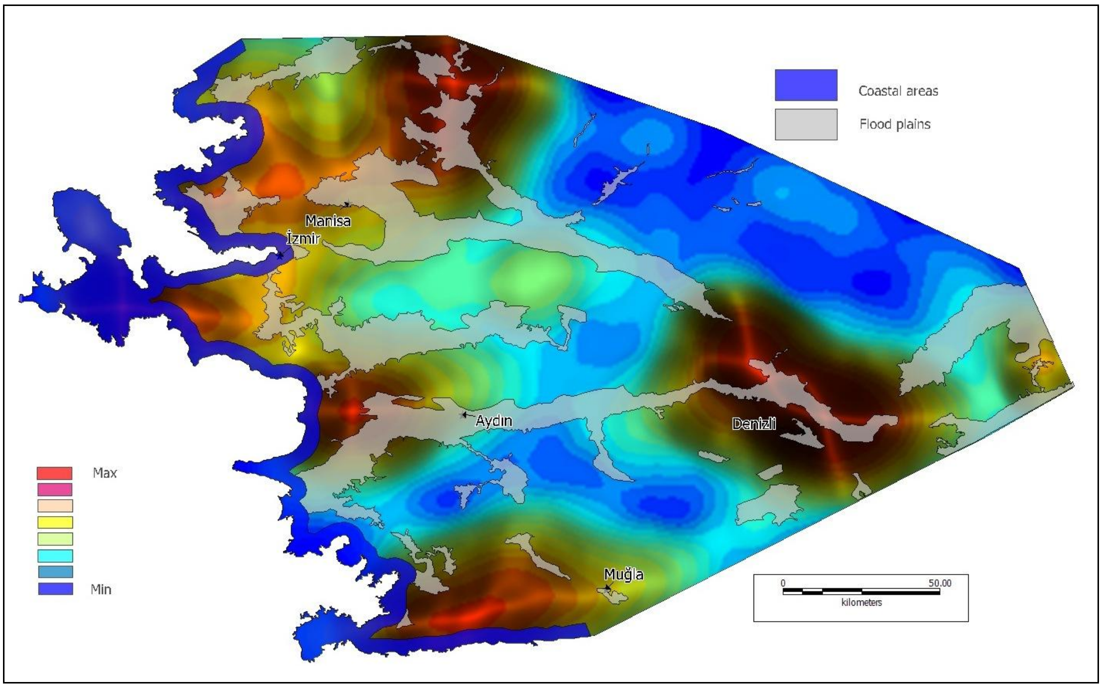


Figure 6.15 Density map of the earthquakes occurred within the study area in the last century (magnitude 3 and larger)

It is difficult to infer the fault lines from such density maps because of two reasons: 1) Seismic data used here belongs to a relatively short time span and may not correspond to all activities in the region. Some active faults, for example, might not produced earthquake in this period and may lead to wrong interpretation, 2) density maps produce spatial regions which are mostly circular or elliptical whereas the fault lines are linear structures. Therefore, the interpretation of the fault line might be problematic. In spite of these problems, density of seismic data can produce valuable information is carefully dealt.

According to the density map generated from the earthquakes in the area, maximum concentrations of the earthquakes are consistent with the morphological classes (Figure 6.15). Almost all maximum densities correspond to the flood plains. Concentrations around Denizli, west of Muğla, west of Aydın, NE of Manisa confirm this relationship. The minimum concentrations all over the area correspond to mountainous regions which are interiors of horst structures. There area, however, some low areas which are expected to be high. The central part of the Büyük Menderes graben (between Aydın and Denizli) and eastern extensions of Küçük Menders and Gediz grabens (east of İzmir) are typical examples. The reason for this low concentration might be due to the lack of seismic data for this period.

CHAPTER VII

CASE STUDIES

The analyses performed in the previous chapter quantify some relationship between certain physical parameters such as geology and topography and the settlement sites. The results of these analyses, however, point to only some statistical conclusions and do not refer to any particular event or relationship in the area. Therefore, in this chapter rather than generalization of the relationship between the earthquakes (active faults) and the settlements, the direct effect of this relationship will be investigated in certain areas. The purpose in this chapter is to illustrate the effect of the earthquakes in the history of the settlements in selected areas.

The main difficulty in the selection of the case areas is the lack of data in the region. For a reliable investigation, two sets of information are necessary: 1) seismic events in the area, 2) active faults of the area. If any of these data is missed, the case presented here will be theoretical. For that reason the case areas selected based on the literature that provide information on both the ancient earthquakes and the active faults mapped in the region.

A total of six sites are determined for which the information is available for both data sources. Since the margins of the flood plains are assumed to correspond to the fault planes, a special attention is given to select the areas located at the margins of the "grabens" (Figure 7.1). Two sites are on the western and eastern tips of Büyük Menderes Grabens. The western case area is located to the west of Aydin and includes some of the well documented ancient sites as Miletos, Priene, Magnesia ad Meander and Ephesus. The eastern site on the other hand is around Denizli city and includes Hierapolis and Laodikeia. Three sites in the Gediz graben are located to the east, central and western parts of the graben each containing one site, namely, Philadelphia, Sardis and Magnesia. The last case area is Stranokeia around Muğla.

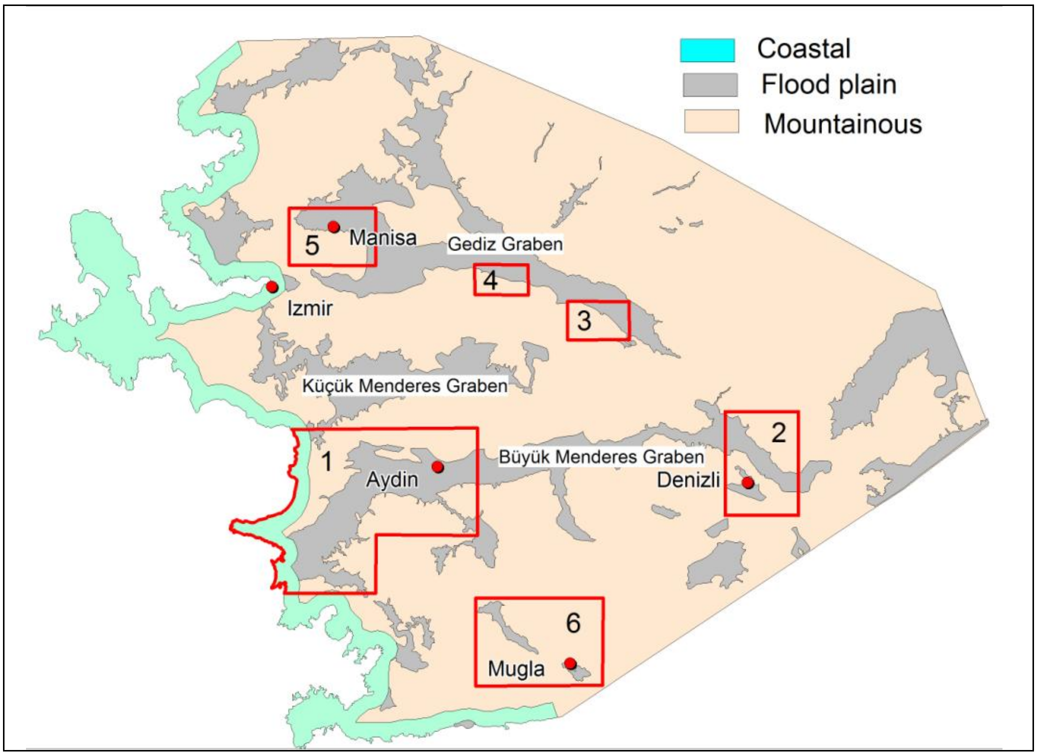


Figure 7.1 Location map of the case study areas

7.1 Aydın Area

Aydın area is on the western termination of the Buyuk Menderes graben (ancient Meander Valley) which is one of the most tectonically active regions of the Western Anatolia. This region had many earthquakes during the history and the intensity of seismicity is heavily concentrated in this as can be supported by the earthquakes occurred last century (Figure 6.14). The region contains many important ancient cities such as Priene, Miletos, Ephesus and Magnesia ad Meander located on the active faults. Today this region is heavily populated with big cities, towns and villages around Buyuk Menderes graben (Figure, 6.12 & 7.2).

Morphology of the area is given in Figure 7.2 together with ancient and modern settlements. The flood plain is easily recognizable by smooth texture of blue color suggesting almost a flat topography. This plain corresponds to the alluvial deposits of Büyük Menderes river. The boundary between this plain and the highlands specified by a sudden change in the texture matches with the active faults. A simplified geological map showing the faults in the area is given in Figure 7.3.

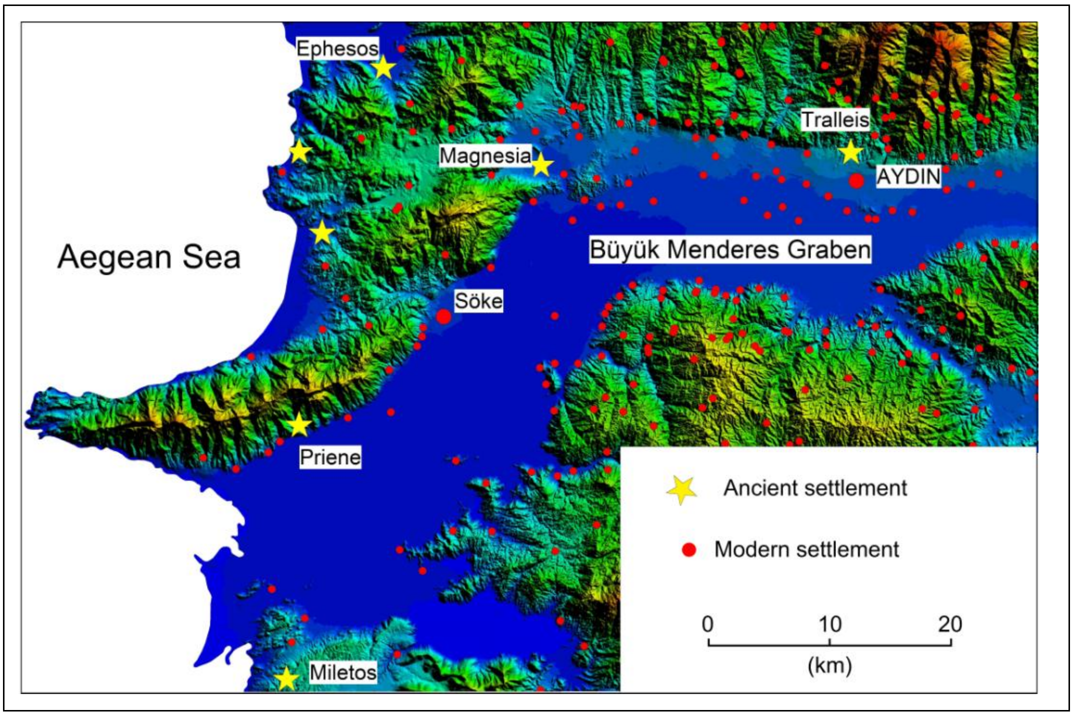


Figure 7.2 Morphology of the area west of Aydın with ancient and modern cities

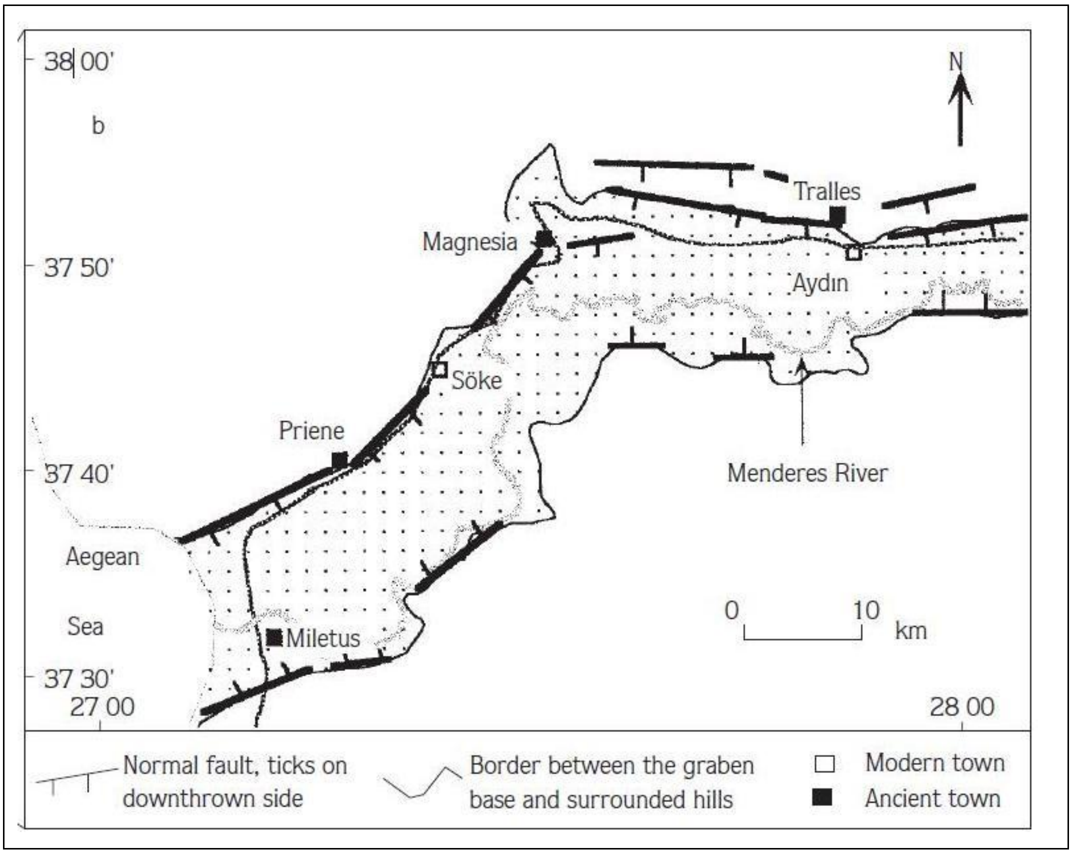


Figure 7.3 Simplified geological map of the area (Altunel, 1998)

The faults in Figure 7.3 run parallel to the boundary of the alluvial plain and the highlands that are defined as "flood plain" and "mountainous" classes in this study, respectively. Although some faults are not continuous and drawn as separate segments, the control of the faults on the formation of morphological classes is obvious. Both ancient and modern settlements are concentrated along the boundary of these two classes.

According to the studies carried out in the flood plain deposits of the Büyük Menderes graben, most of this part of the graben was occupied by sea in the ancient times (Brückner, 1998, 2000, 2002; Brückner et al, 2001). Position of suggested ancient shoreline is given in Figure 7.4. Accordingly, some of the ancient sites located within the flood plain were coastal settlements in the past. This is one of the reasons for the abandonment of some settlements in the region if not destroyed by an earthquake,

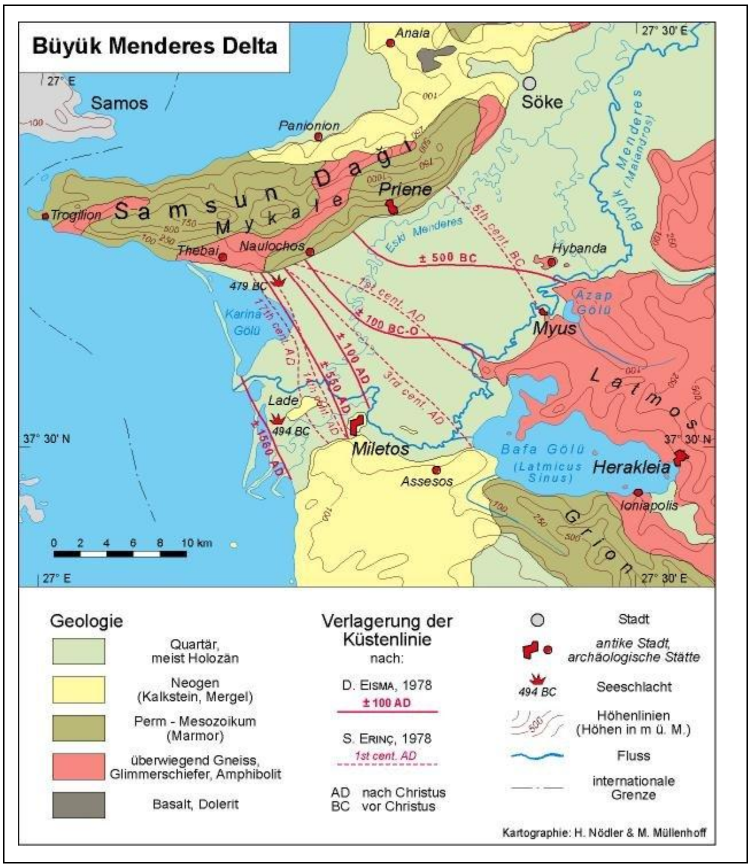


Figure 7.4 Variation of the shoreline in the Büyük Menderes delta in the ancient times (Brückner, 1998)

Priene: The ancient city of Priene was first founded about 8 km in the east of the present coastline on the alluvial plain of Büyük Menderes river. The city, however, was gradually buried under the alluvium because of the silting up within the flood plain (Brückner, 1998, 2000, 2002, Brückner et al, 2001). For this reason, the city was rebuilt around 350s BC over the highland (fault scarp) next to the original site. One of the reasons for the silting up in this area is the activity of the faults resulting in a gradual subsidence at the graben floor.

Priene has a rectangular plan. The main settlement was located under a deep hill (Figure 7.5). The city has nearly 1.46 km2 area. Figure 7.6 shows the aspect, elevation and slope values for Priene prepared from 85 pixels. The aspect histograms show that nearly 80 % of the city is facing south and 20 % to southeast. The elevation values show that the city is located at an elevation interval of 0 to

150 m. Slope histograms show a bimodal distribution with two peaks at 2-5 and 9-12 degrees intevals the former having a larger concentration. All histograms (aspect, elevation and slope) show that Priene was situated on an area that obey the preferred values of the whole ancient cities.

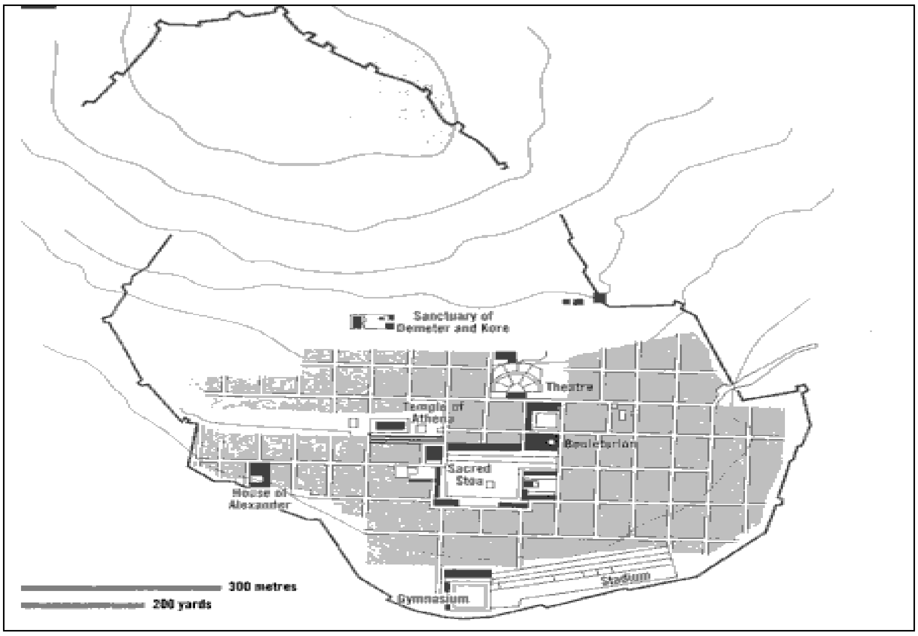


Figure 7.5 City Plan of Priene (Facaros and Pauls, 2000)

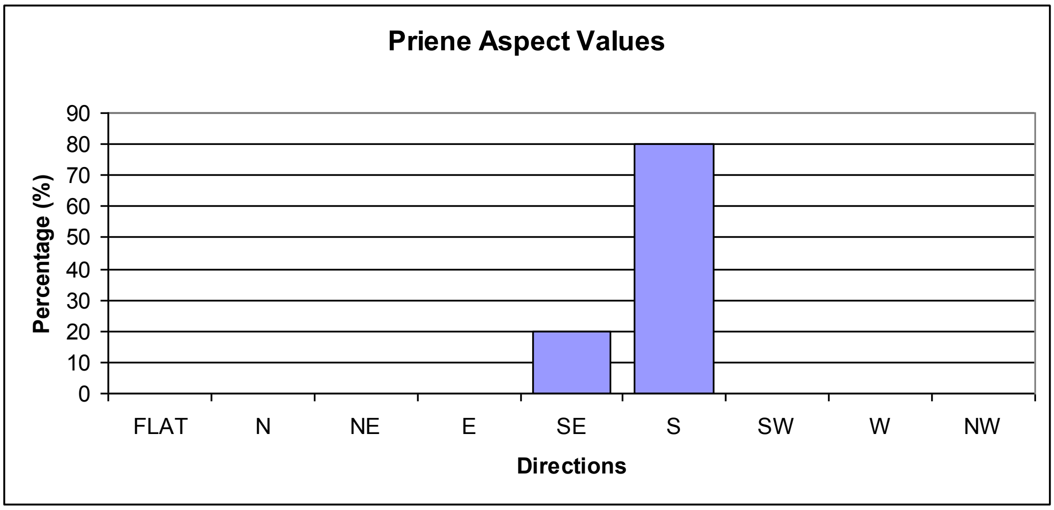
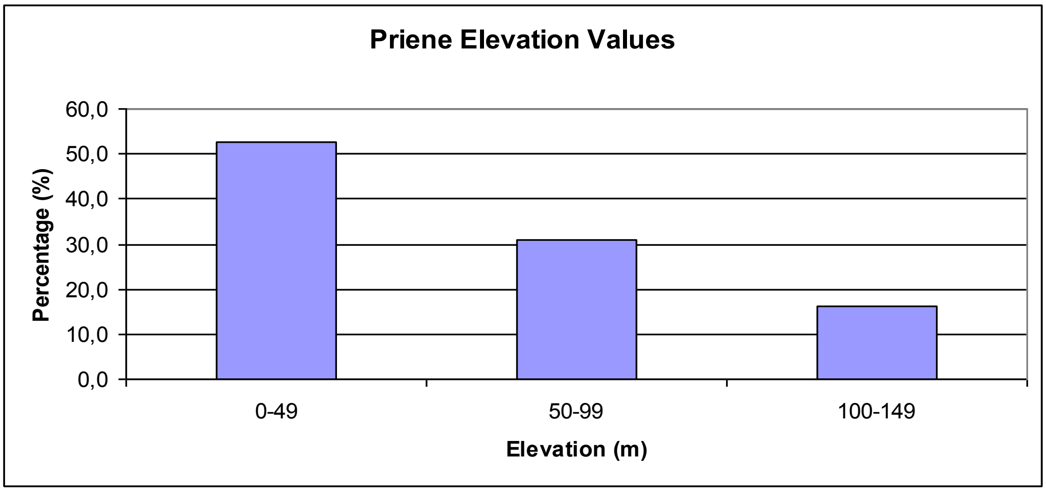


Figure 7.6 Aspect, Elevation and Slope values for Priene



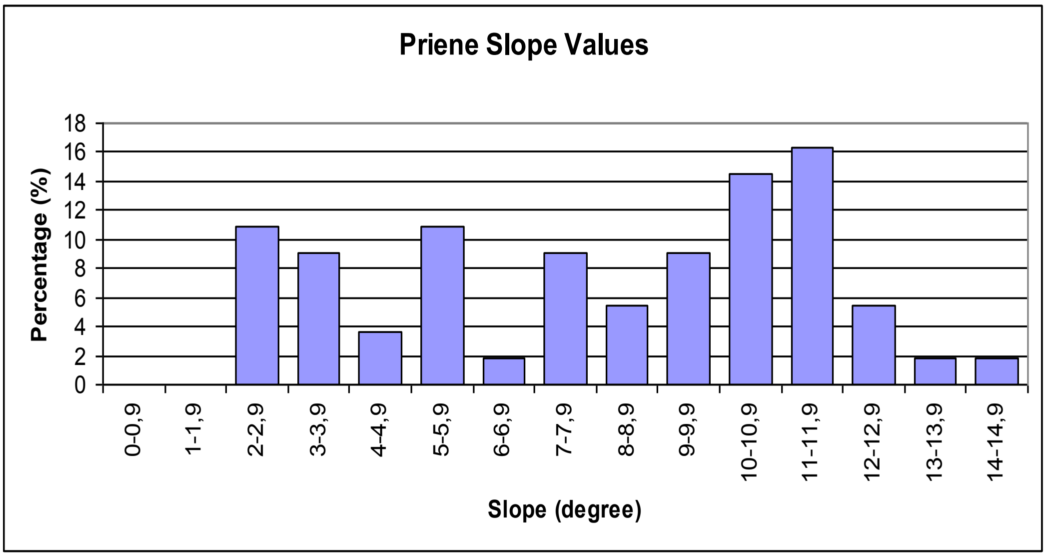


Figure 7.6 (Continued)

Priene has lots of past earthquakes that were observed by Altunel (1998). The evidences are 1) Sacred Stoa in the city was harmed (Figure 7.7) 2) stair blocks of Sacred Stoa were tilted (Figure 7.8). Agora, the theatre, street walls, and water resorvoirs were damaged at various times (Altunel, 1998).

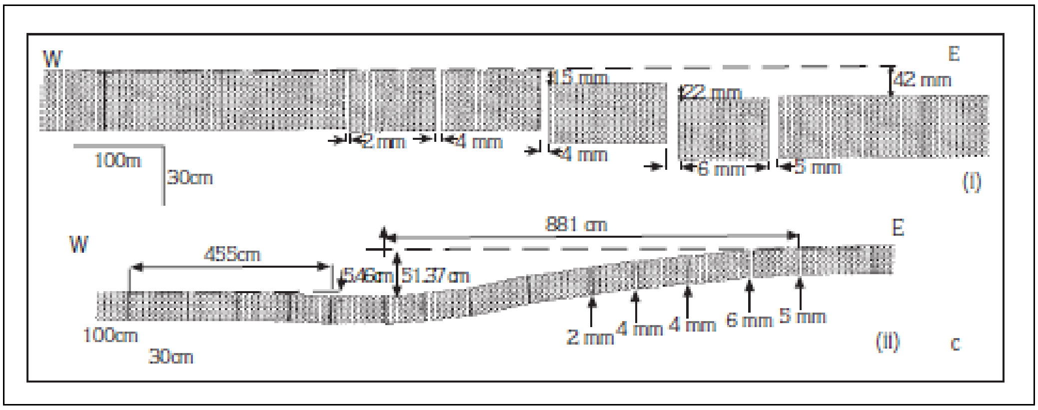


Figure 7.7 The offset measurements in Sacred Stoa in Priene (Altunel, 1998)

A general view of the city is given in Figure 7.9 with numerous collapsed columns. The active fault plane is located along the southern margin of the city (Figure 7.10)

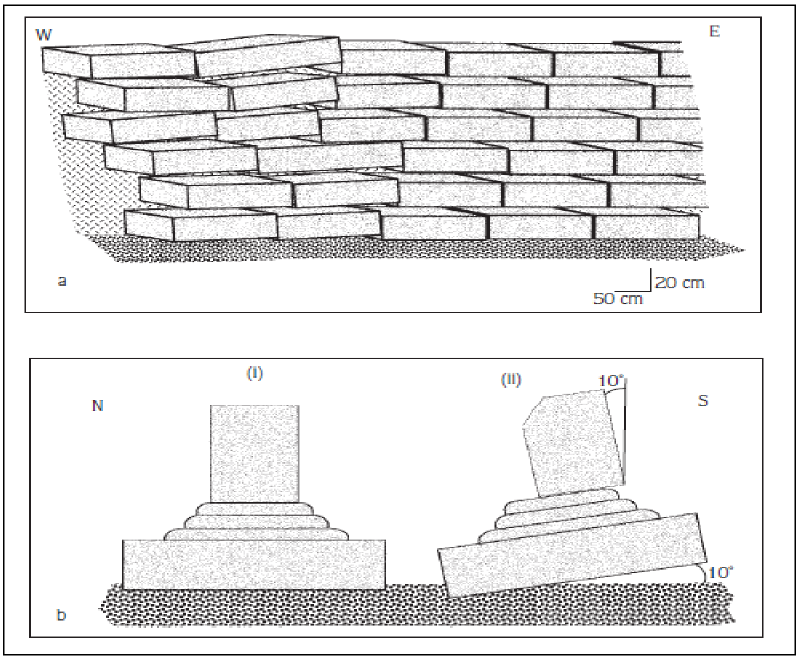


Figure 7.8 Earthquake traces on the block stones of a semicircular building and two adjacent columns (Altunel, 1998)

Figure 7.9 A view of the Priene ancient city showing the collapsed columns

Figure 7.10 A view of Büyük Menderes flood plain taken from southern margin of the city. The view is towards SW. Aegean sea can be seen at the far background.

Ephesus: Ephesus is situated a few km SW of Selcuk, İzmir (Figure 7.2) near to Aegean Sea. It is geologically located at the southern margin of Küçük Menderes graben. Similar to Priene, it was a coastal settlement in the ancient times and an important port. Because of the silting up in the graben floor, the city was gradually isolated from the shoreline that shifted westward for about 5 km (Figure 7.11).

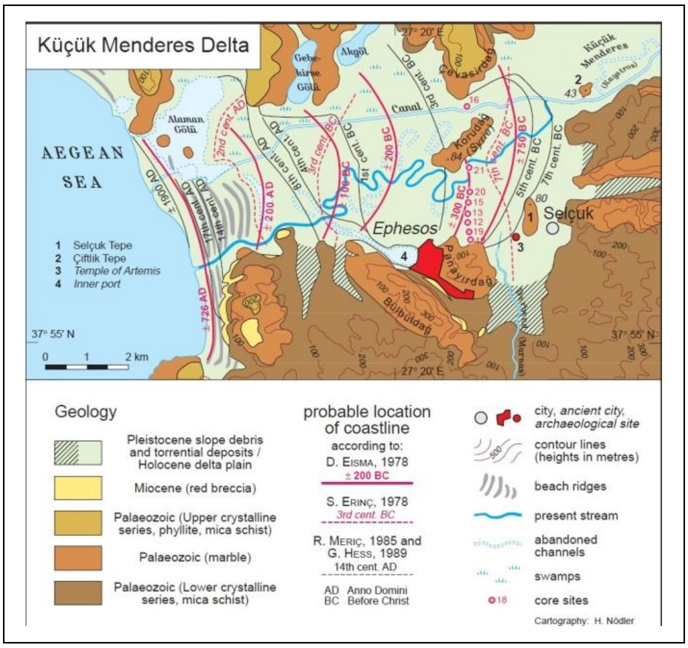


Figure 7.11 Shoreline variations around Küçük Menderes delta (Brückner, 1998)

Figure 7.12 shows the city plan of Ephesus. The city has nearly 2.63 km2 area. Figure 7.13 shows the aspect, elevation and slope values for Ephesus prepared from 144 pixels. The aspect values indicate two dominant concentrations; one at E-SE and the other at N-NW directions, the former one with higher concentration. The elevation values show that the city is buits in a range of 0 to 150 m. According to histograms the lower elevations have higher concentrations. Slope histogram shows that the city has a highest peak around 0-1 degrees in the range of 0 to 12 degrees. All histograms (aspect, elevation and slope) show that the Ephesus is situated on an area that obey the preferred values of the whole ancient cities.

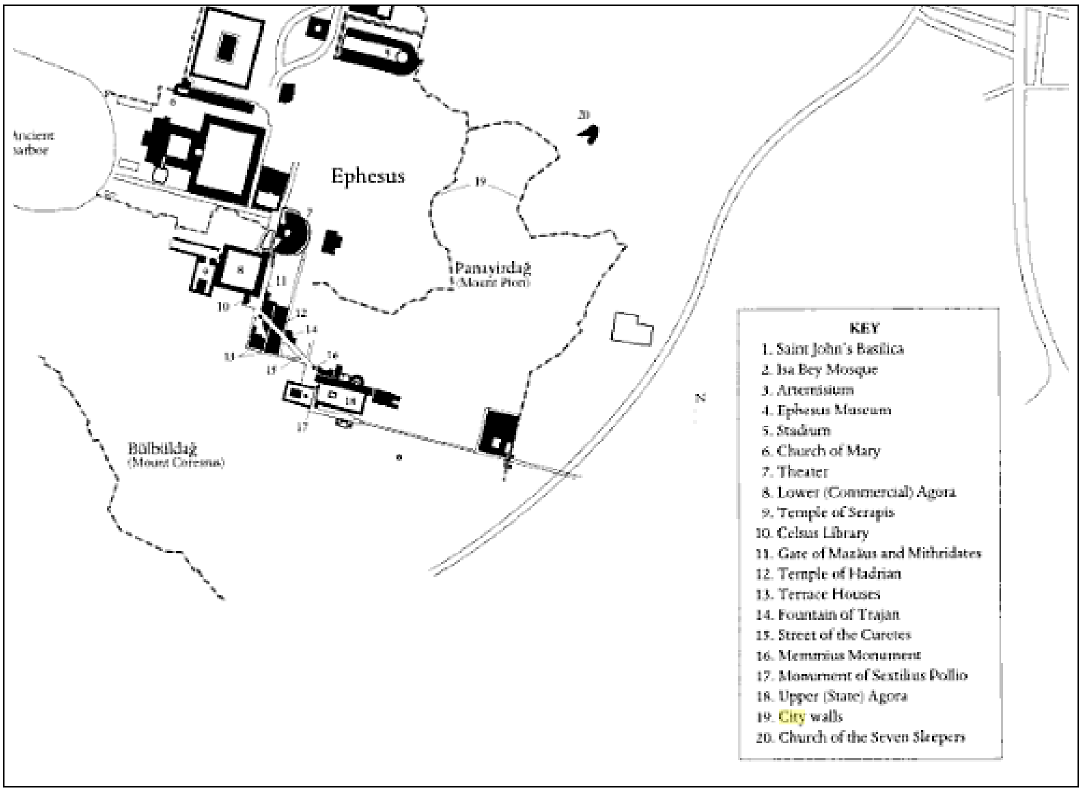


Figure 7.12 City plan of Ephesus (Torre, 1997)

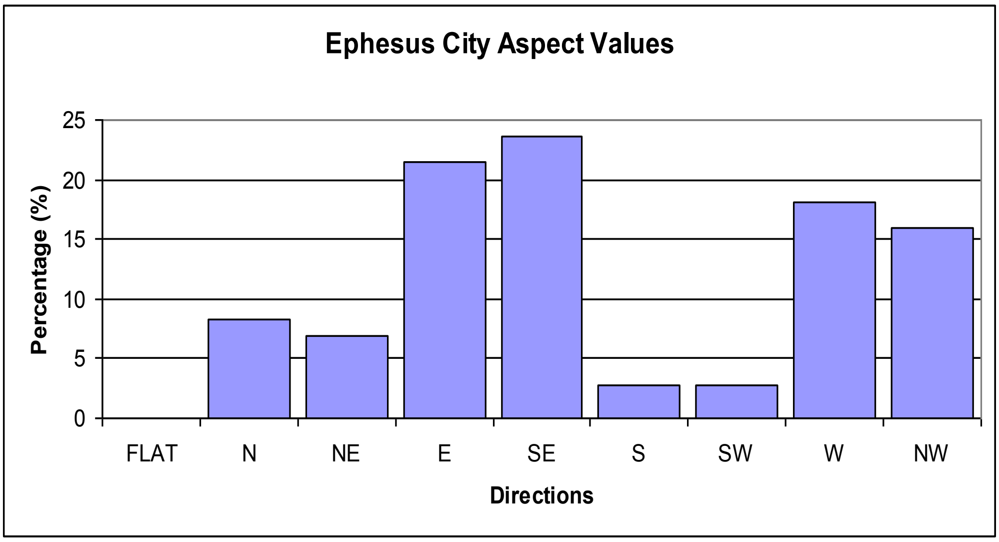
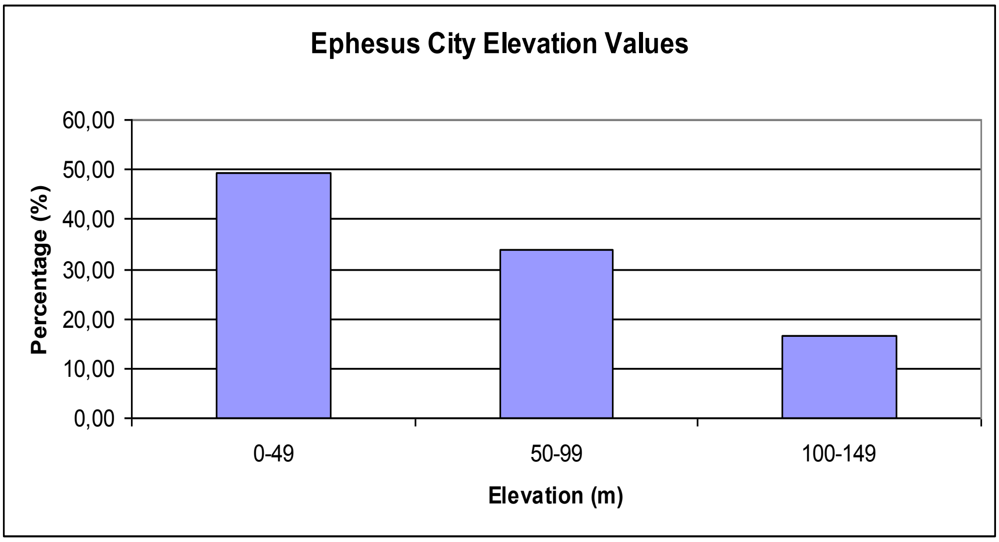


Figure 7.13 Aspect, Elevation and Slope values for Ephesus



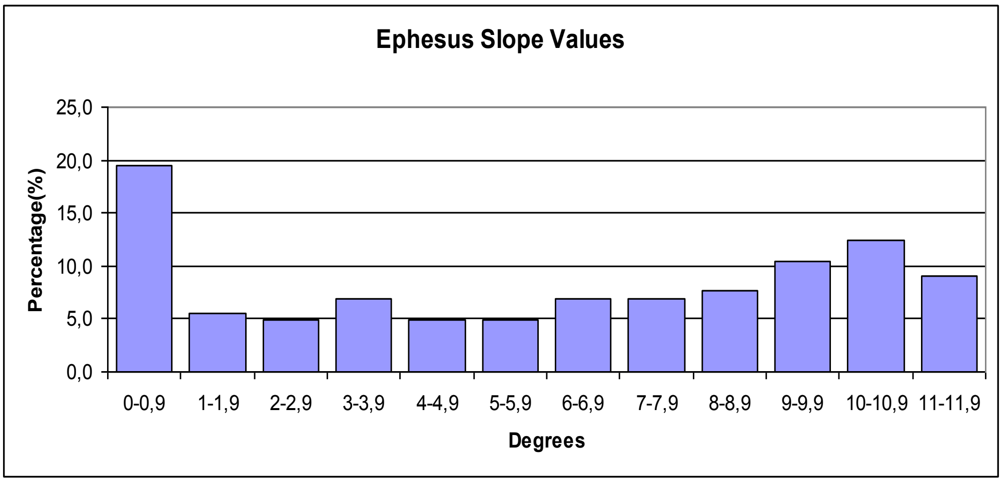


Figure 7.13 (Continued)

Being located in the vicinity of active faults many serious earthquakes struck Ephesus. The city is located just below the fault scarp known as "Ephesos fault" (Dumont et al., 1979) (Figures 7.14 and 7.15). Studies carried out on the slip-lineation data on the fault scarp by Dumont et al. (1979) indicate presence out five successive earthquakes during Plio-Quaternary.

Figure 7.14 A general view of the residence area of Ephesus built over the downthrown block of the fault known as “Ephesus fault”.

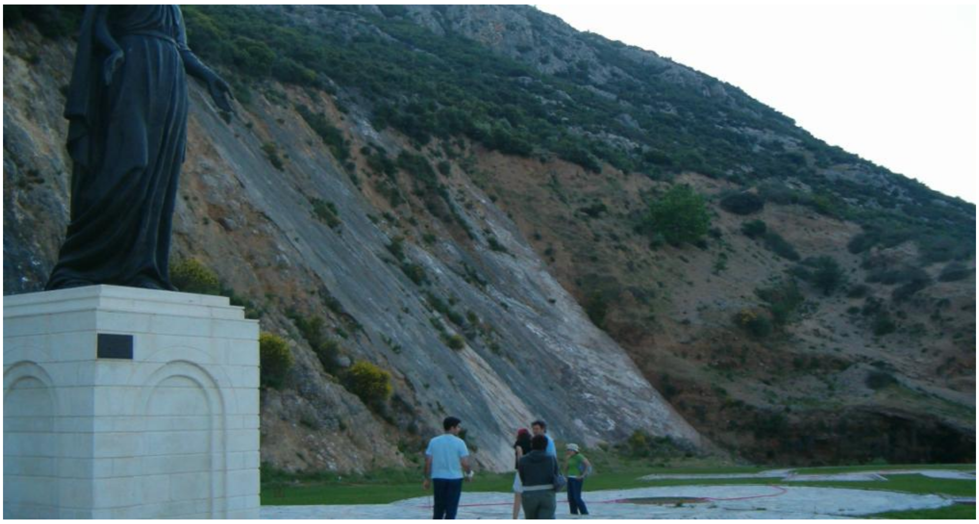


Figure 7.15 A view of the scarp of the Ephesus fault exposed to the surface.

There are several historical earthquakes that struck the city. Many buildings were ruined (Foss, 2010). In 23 BC an earthquake struck the city. Roman Empire restored the city. In 17 AD Ephesus was devastated again by an earthquake.

Emperor Tiberius rebuilt the city. In 262 AD a major earthquake struck Ephesus again.
In the 4 th century, Ephesus was ruined again like other cities. Main buildings such as agora, columns, great theatre were destroyed (Flensted-Jensen, 1994). The city was again partially destroyed later by an earthquake in 614 AD.

All the past earthquakes show that Ephesus was ruined many times and rebuilt again. The city moved from coastal to interior part. This was because of the alluvial deposition, not earthquakes.

Miletos: Miletos today is located on the southern margin of the Büyük Menderes graben at the boundary between the alluvial flood plain and mountainous area (Figure 7.3). In the historical times, however, the city was built at the tip of a peninsula and was a coastal settlement (Figure 7.4). It was later isolated from the sea due to the silting up (Brückner, 1998). Miletos is now nine kilometers distant from the sea (Flensted-Jensen, 1994).

Miletos has a triangular-shape plan (Figure 7.16). The city has nearly 1.045 km2 area. Figure 7.17 shows the aspect, elevation and slope values for Miletos prepared from 60 pixels. The aspect values show that nearly 43 % of the city faces southeast and 14 % east. The other directions were less than 14 %. The elevation values show that city has is located between 0 and 50 m elevation. Slope histograms indicate that the city is located on a flat surface. Histograms suggest that the city has morphologia parameters preferred values for most ancient cities.

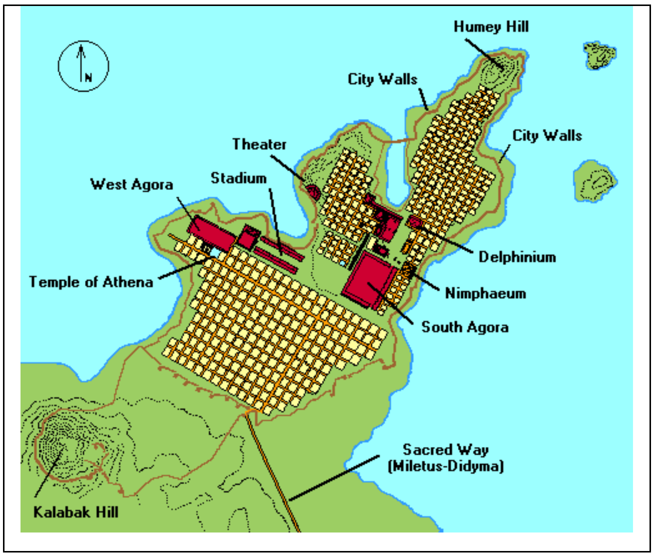
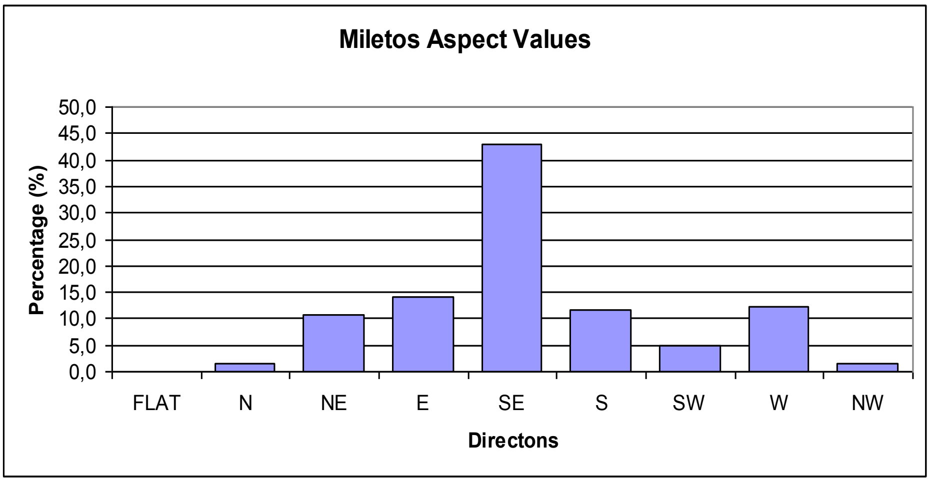


Figure 7.16 City plan of Miletos (Rasmussen, 1969)



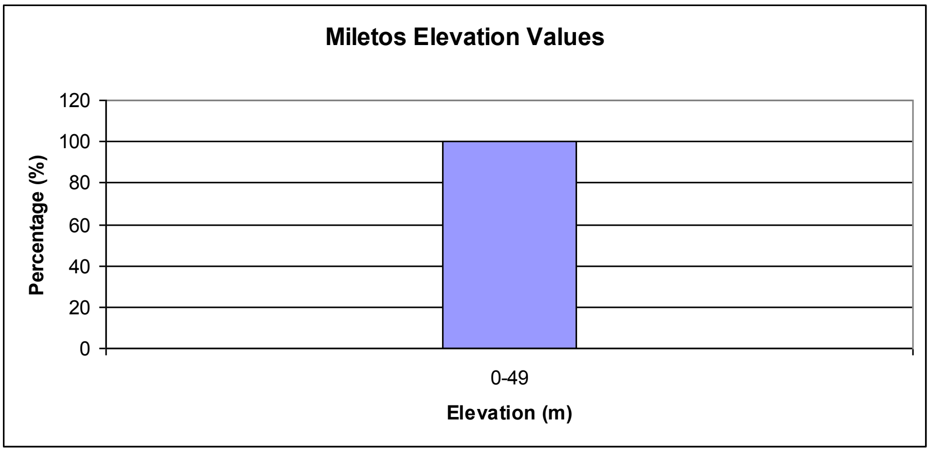


Figure 7.17 Aspect, Elevation and Slope values for Miletos

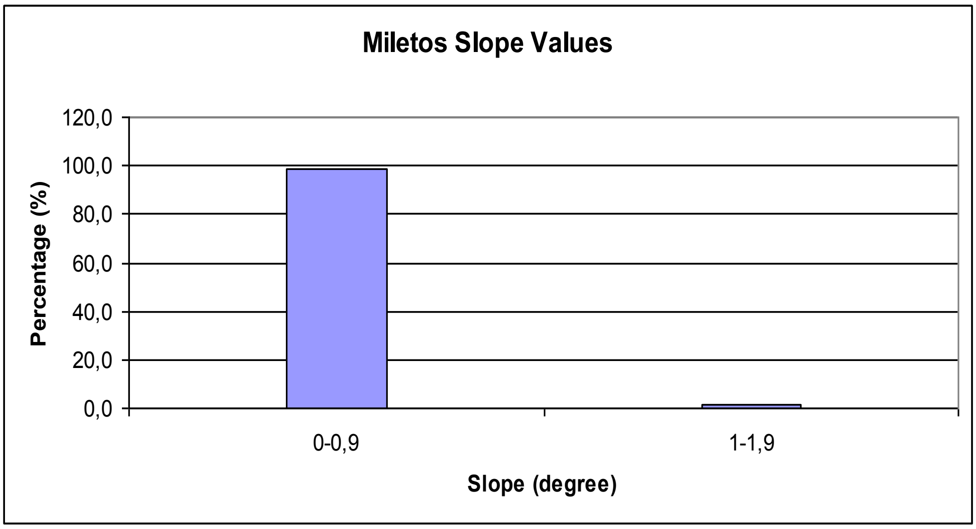


Figure 7.17 (continued)

Miletos was destroyed by earthquakes several times. In 47 AD, the earthquake hit the city and the stones fell from near cliffs and the city was covered by alluvial. Later in the tenth and eleventh centuries AD the city was destructed again by a heavy earthquakes (Jensen, 2000). The city theatre and fortress were destroyed (Gorman, 2001).

Magnesia ad Meander: This ancient city is located on the northern margin of Büyük Menderes graben between Tralleis and Priene (Figure 7.3). It might be a coastal settlement in ancient times which is not proved today yet.

Figure 7.18 shows the plan of Magnesia ad Meander. The city has nearly 1.22 km2 area. Figure 7.19 shows the aspect, elevation and slope values of Magnesia ad Maender prepared from 70 pixels. The aspect values show that nearly 50 % of the city looks to North and 50 % of the city looks to Northeast. The other directions have zero values. The elevation values show that city has 50 m height. Slope histograms show that the city has a 3-4 degree inclination. All histograms (except the aspect values , elevation and slope) show that the Magnesia ad Maender was situated on an area that obey the preferred values of the whole ancient cities.

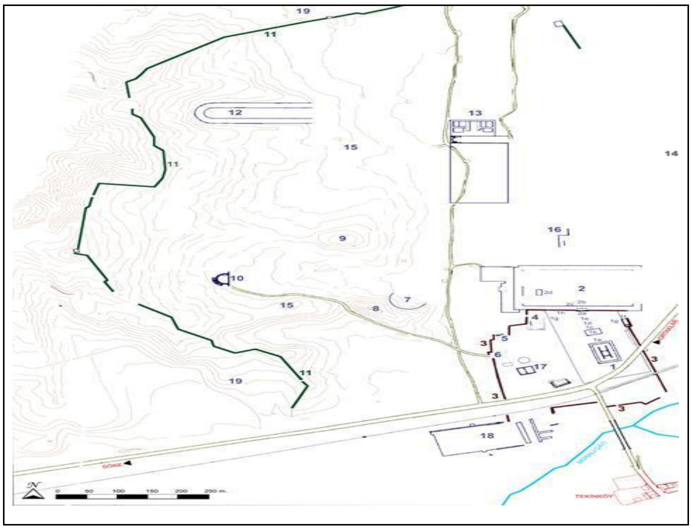


Figure 7.18 City plan of Magnesia ad Maendrum (Mitchiner, 1978)

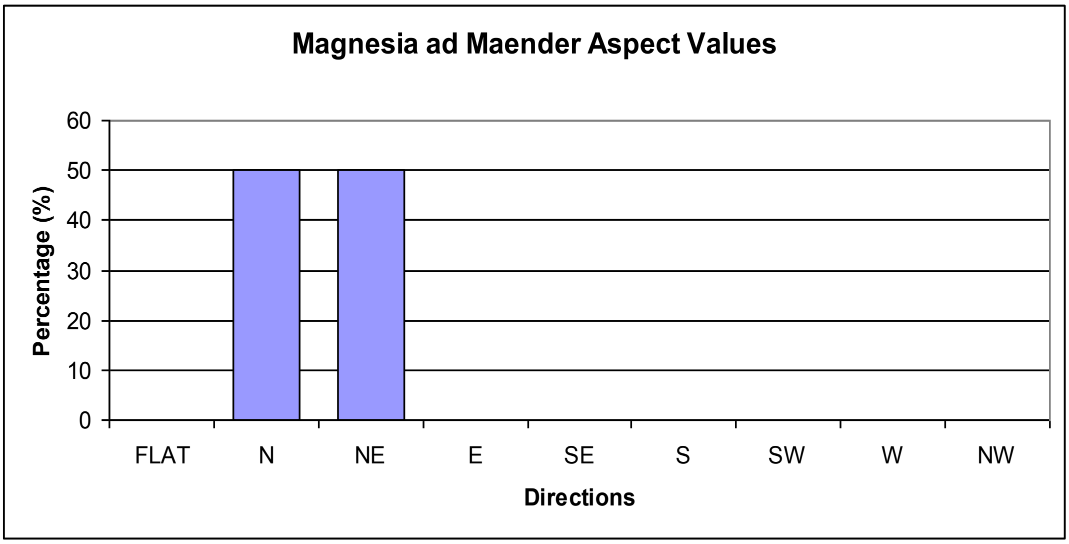
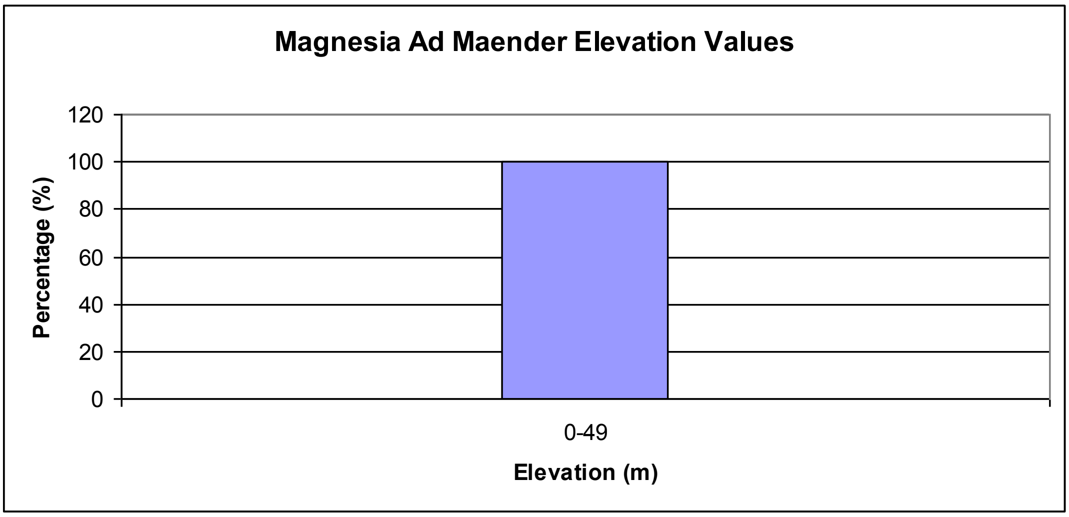


Figure 7.19 Aspect, Elevation and Slope values for Magnesia ad Maender



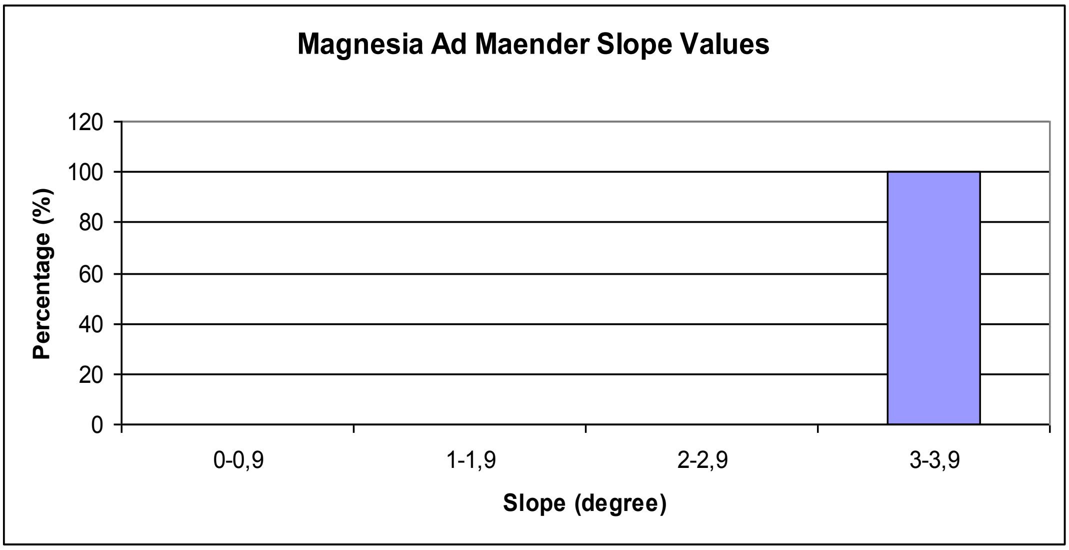


Figure 7.19 (continued)

There are several destructive earthquakes already identified (Bingöl, 2007). The city was destroyed by an earthquake in 17 A.D. and reconstructed by Tiberius (Cancik et al. 2006). Roman philosopher Seneca described this earthquake as total collapse of twelve Asia Minor cities at the same time.

7.2 Denizli Area

Denizli area involves the eastern tip of Büyük Menderes flood plain where a narrow graben is developed in NW-SE direction (Figure 7.20). The reasons for the selection of this area are: 1) The active fault of this area are mapped and illustrated in “Active Fault Map of Turkey” by MTA, and 2) Two well-nown ancient cities, namely, Hierapolis and Laodikeia are located in this region.

The morphology of the area is illustrated in Figure 7.20 (left) characterized by a flat graben floor bounded by steep topography on both margins. All these margins correspond to active faults that strike parallel to the elongation of the graben. Numerous closely spaced, parallel fault segments (Figure 7.20, right) are mapped in the area. Spatial distribution of both ancient and modern settlements shows a relationship between the fault lines and the settlements.

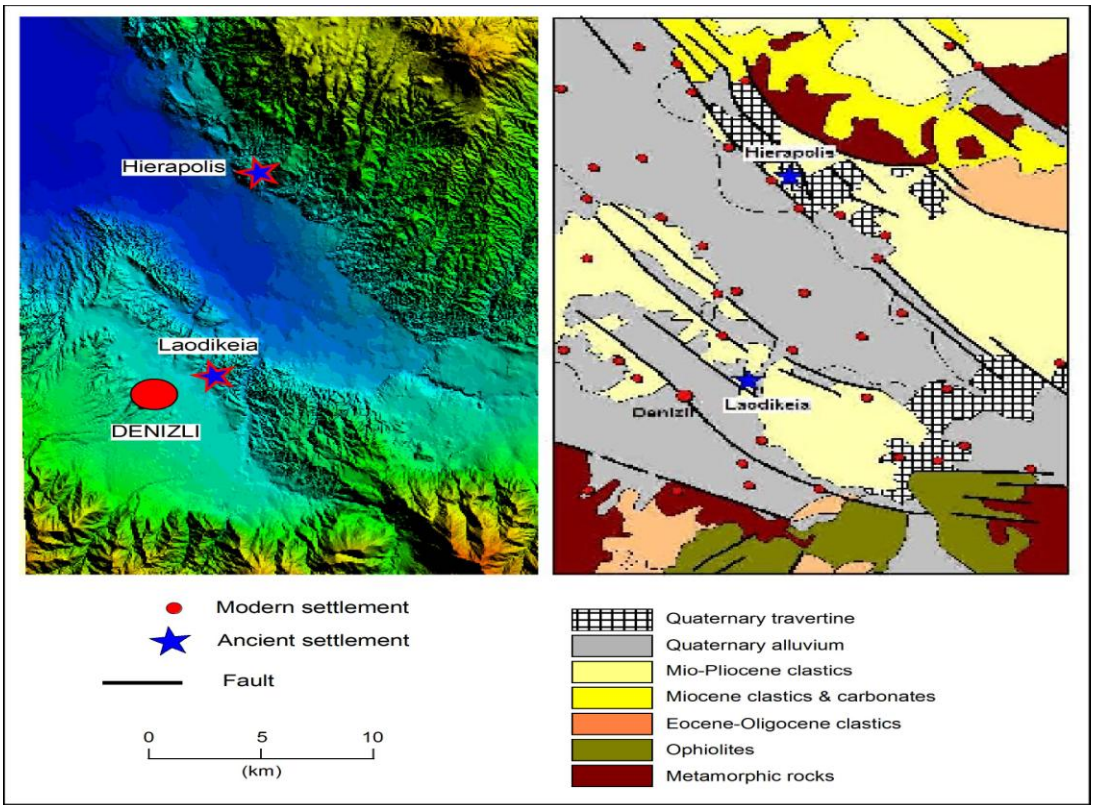


Figure 7.20 Morphology and geology of the area around Denizli with ancient cities of Hierapolis and Laodikeia

Hierapolis: The city is built very close to an active fault on the northern margin of the graben (Figure 7.23). There are several hot springs in the area that reach to the surface along the fault planes (Figure 7.24). These springs might be the main reason for the selection of the site. Travertine is a common product of the precipitation of carbonaceous material at the surface. Geological map of the area shows that the deposition of travertine is not confined just to Hierapolis but covers large areas in the region (Figure 7.20).

Figure 7.21 shows the Hierapolis city plan. The city has nearly 2.55 km2 area. Figure 7.22 shows the aspect, elevation and slope values for Hierapolis prepared from 134 pixels. The aspect values indicate that the city is totally facing S-SW direction. According to elevation histogram, the city is located between 350 and 450 meters with higher concentration in the 350-400 m interval. Slope histograms indicate that the city is situated mostly at a surface with slope values of 4 to 6 degrees. All histograms (aspect, elevation and slope) show that Hierapolis is situated on an area that obey the preferred values of the whole ancient cities.

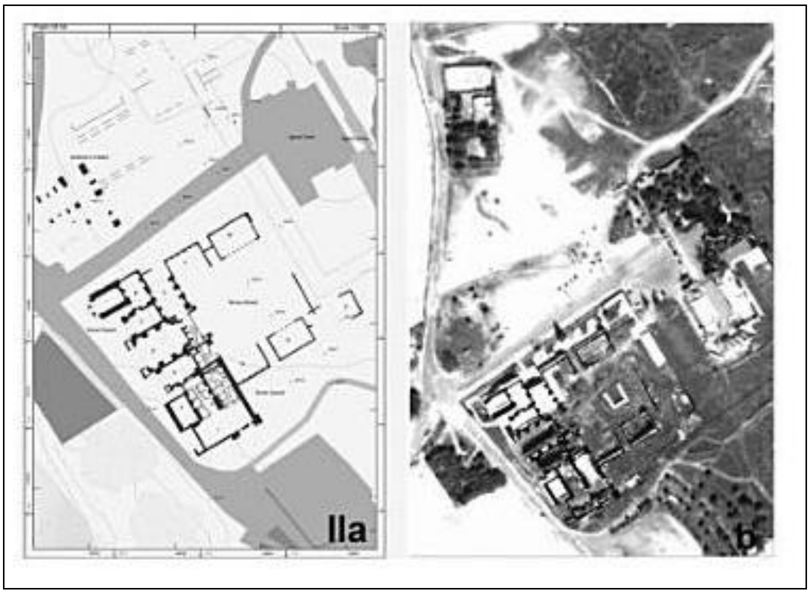
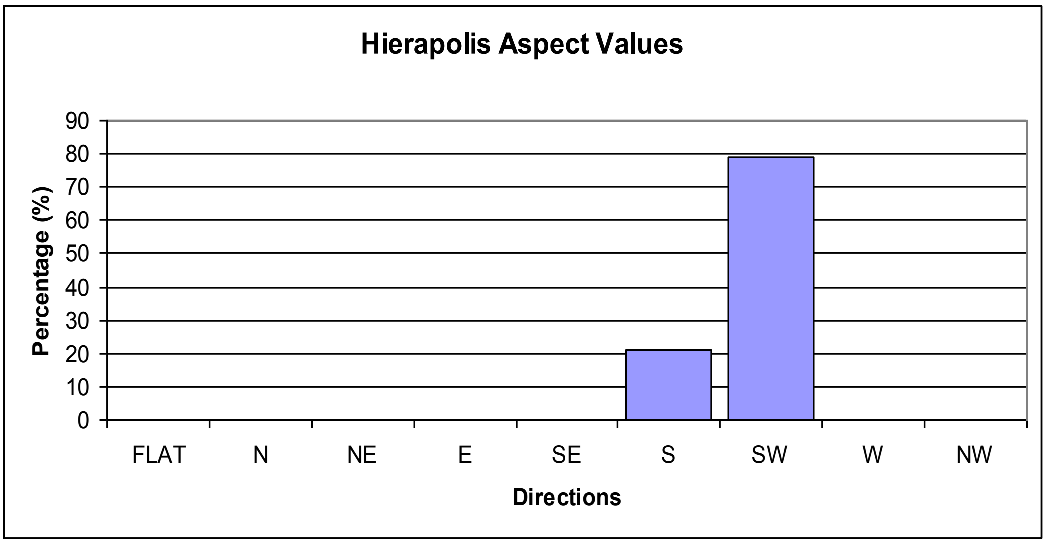
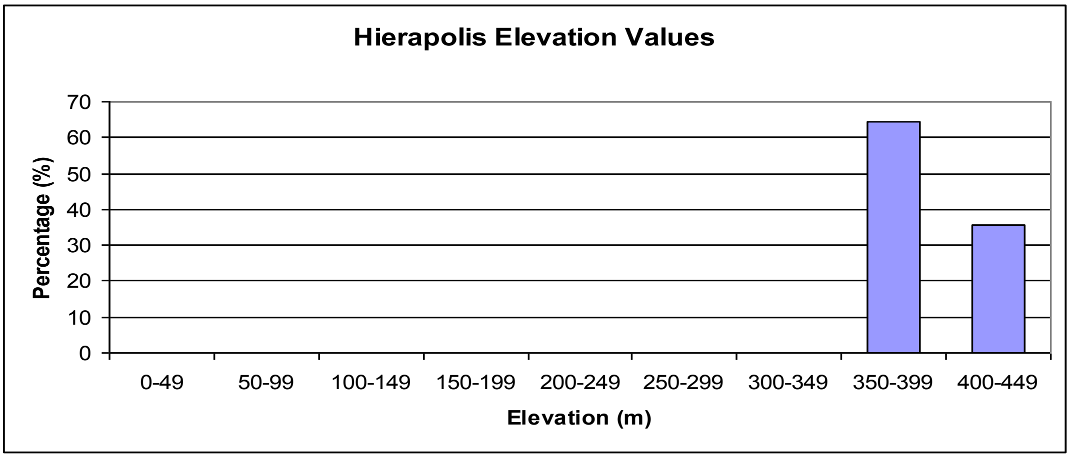


Figure 7.21 City plan of Hierapolis (Ferrari, 1998)





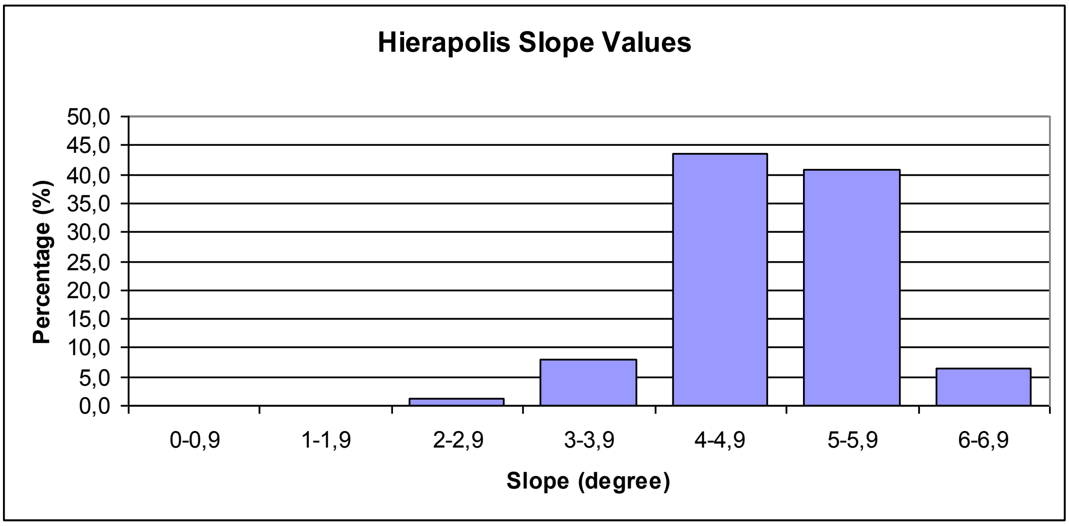


Figure 7.22 Aspect, Elevation and Slope values for Hierapolis

The city was devastated many times because of the earthquakes. The traces of ancient cities can be seen many parts of ruins today (Figure 7.25).

Figure 7.23 A general view of the graben viewed from Hierapolis. The white material in the foreground is travertine deposited by the thermal waters.

Figure 7.24 A view of the fault scarp north of Hierapolis.

Figure 7.25 A view of ruins in Hieraopolis

Hancock and Altunel (1997) mentions earthquake damaged the city in 60 AD earthquake. The city was rebuilt. Figure 7.26 shows the traces of the earthquakes. Roman freshwater channel, Roman and Byzantine walls were deformed. Many monuments tilted. The maximum damage can be generally seen adjacent to the fault that passes through the centre of the city.

At the 3rd century AD the city was ruined by an earthquake. The 494 AD earthquake struck the city again with other nearby cities such as Laodicea and Tripolis (Ritti et al, 2007).

Archaeological research by the team of F.D'Andria and Italian Mission in Turkey has brought some earthquakes traces on the city in the late antique and Byzantine periods. There were numerous large lesions and split Stone in the Byzantine wall. The Byzantine fortified (North) wall collapsed by this earthquake and many pottery dumps were found at the foot of the wall (Altunel, 1997).

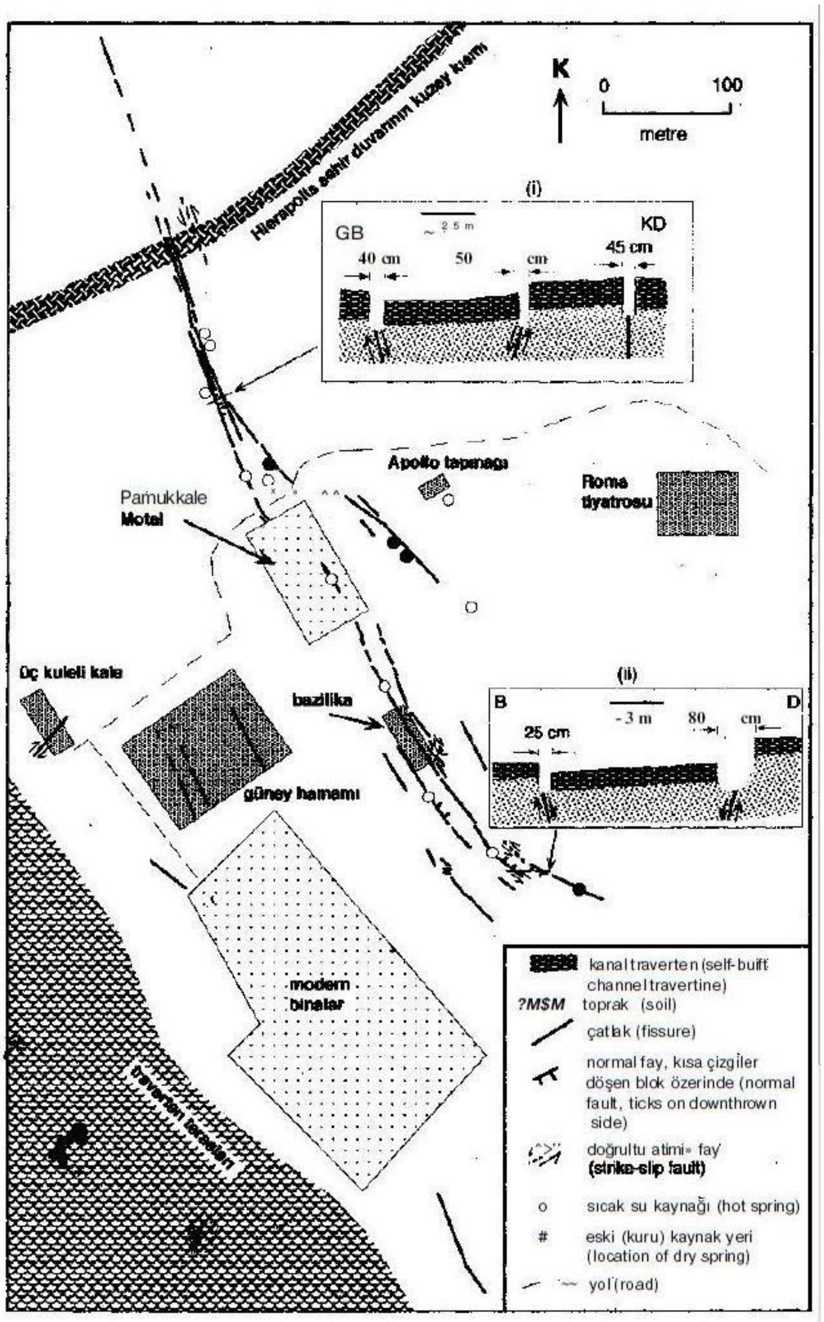


Figure 7.26 Details of the damage caused by earthquake within the city center in Hierapolis (Altunel, 1997).

Laodicea: Laodicea is located towards the southern margin of the graben. The fault pattern mapped in the area suggests that there is a small horst within the graben towards the southern margin (Figure 7.20) and the city is located over this horst (Figure 7.27). It is about 10 km to the south of Hierapolis.

Figure 7.27 A general view of the graben from Laodicea which is situated on a small horst at the southern part of the graben.

Laodicea has a rectangular plan (Figure 7.28). The city has nearly 1.47 km2 area. Figure 7.29 shows the aspect, elevation and slope values of Laodicea prepared from 87 pixels. The aspect values indicate that the city has an inclination to Northwest. The city is located at an elevation between 250-300 m. Slope histograms show that the city has a highest peak around 1-2 degrees and 0-1, 3-4 and 2-3 degrees are other slope values of Laodicea. All histograms (aspect, elevation and slope) show that Laodicea is situated on a preferred area that obey the whole ancient cities.

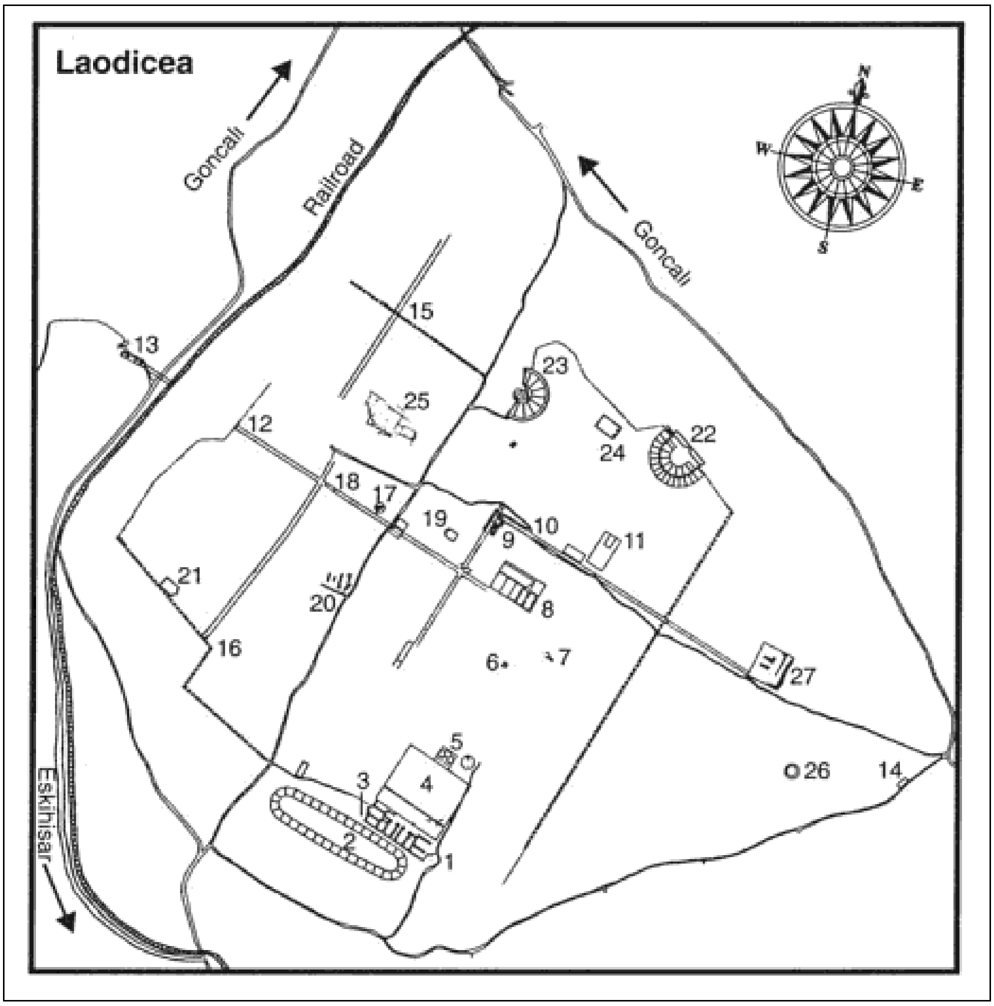


Figure 7.28 City plan of Laodicea (Fant and Reddish., 2000)

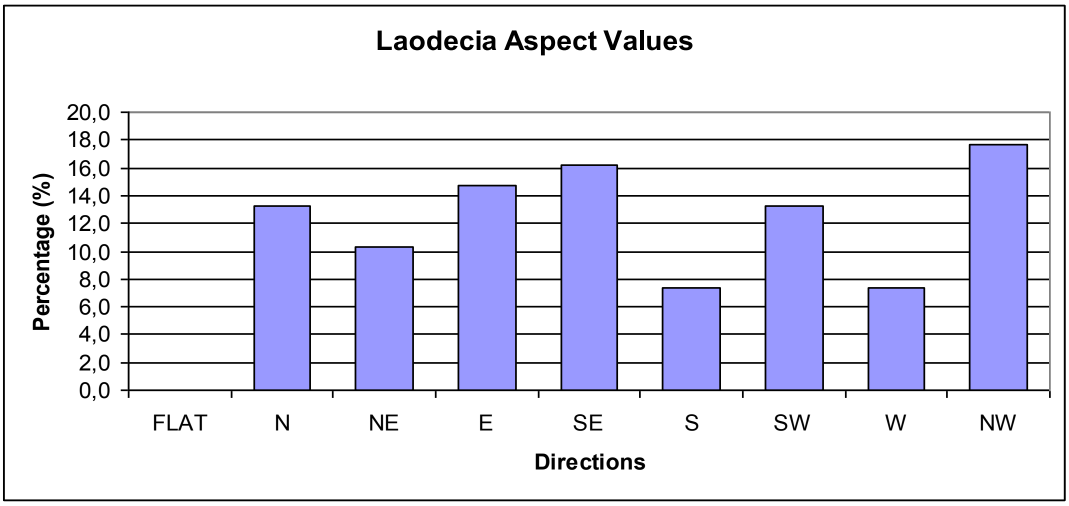
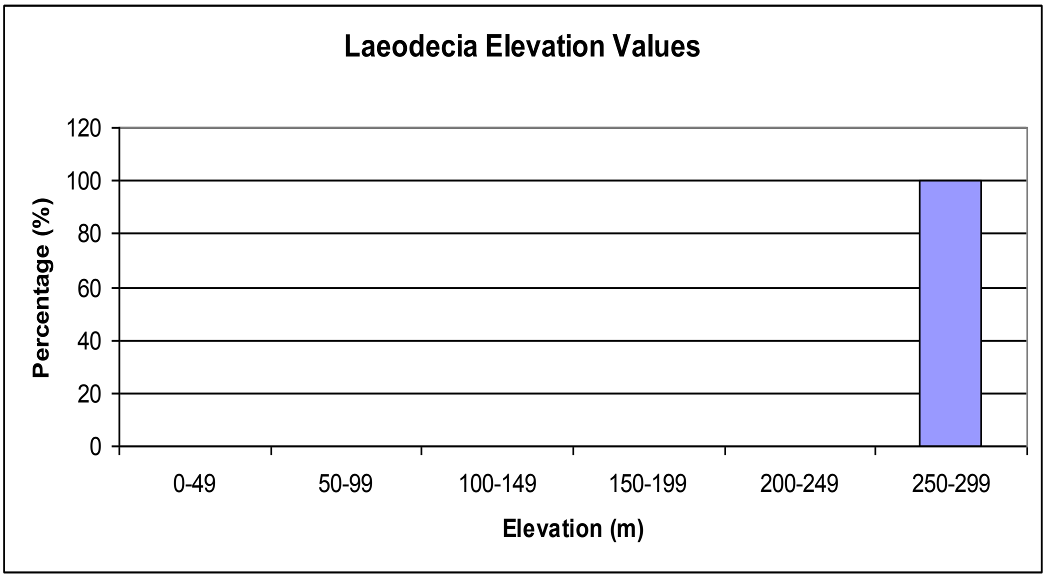


Figure 7.29 Aspect, Elevation and Slope values for Laodicea



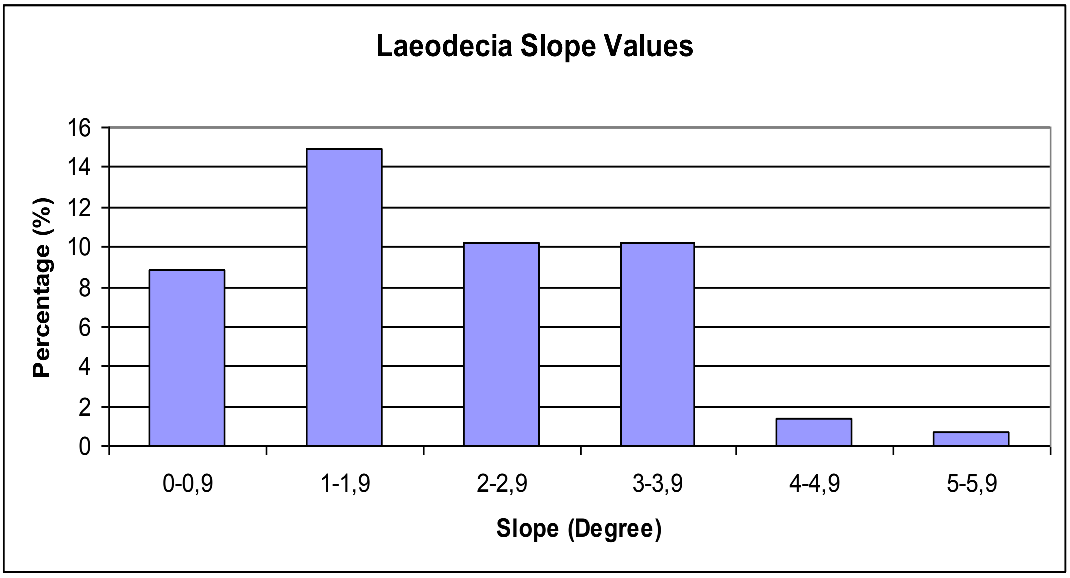


Figure 7.29 (Continued)

The ancient city was suffered from earthquakes many times (Figures 7.30 and 7.31).

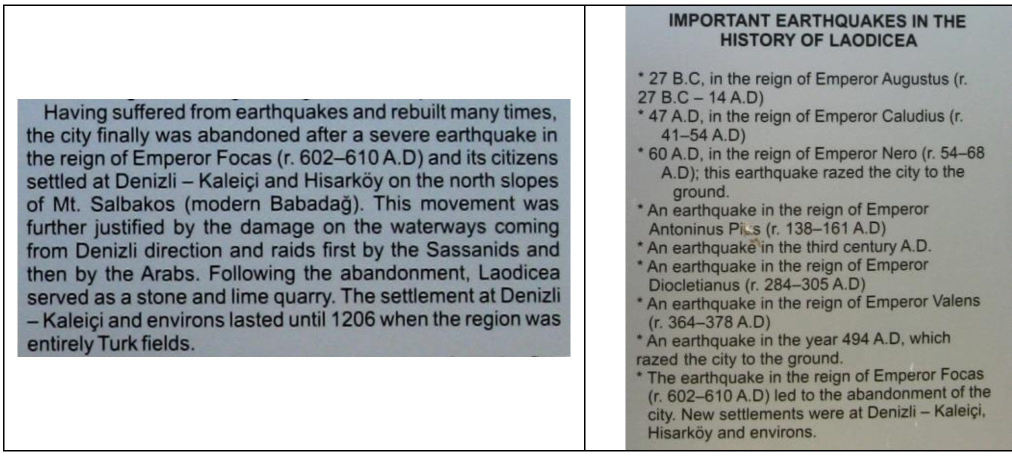


Figure 7.30 Signboards in Laodicea set up by Denizli municipality showing the information related to earthquakes

Figure 7.31 A view of the ruins of Laodicea

Ancient historian Strabo mentioned in his writing about rebuilding work at Laodicea at 27 BC after earthquakes. The city was rebuilt by a financial help of Emperor. He also pointed out that the hot water spout out after the earthquake. An inscription was found in Samos Island that mentioned an earthquake that affected Laodicea in 47 AD.

Roman historian Tacitus, mentioned in his Annals, an earthquake at Laodicea at 60 AD. Although other Roman cities like Hieropolis were donated by the Roman emperor after the earthquake, Laodikeia was reconstructed by the help of inhabitants of the city itself. The city was rebuilt from its own resources, without any help from Rome. Roman historian Eusebius also mentioned an earthquake occurred in 64 AD

The city was hit by a heavy earthquake in 194 AD. After this earthquake the city has never recovered. The city rebuilt at the same location.

7.3 Alaşehir (Philadelphia)

Alaşehir is located on the southern margin of Gediz graben region (Figure 7.32). This modern city is built over the ancient Philadelphia which was one of the important settlements of its time. The earthquakes of the last century indicate that density seismicity is heavily concentrated in the region (Figure 6.14). Geological map of the area suggest the presence of several closely spaced, parallel active faults (Çiftçi and Bozkurt, 2009, 2010). The main fault (MGBF in Figure 7.33) is a continuous fault defining the southern limit of the graben. This fault is only a few km from Alaşehir (and Philadelphia) and can be considered the main source of the earthquakes. Travertine is deposits at different places along this fault.

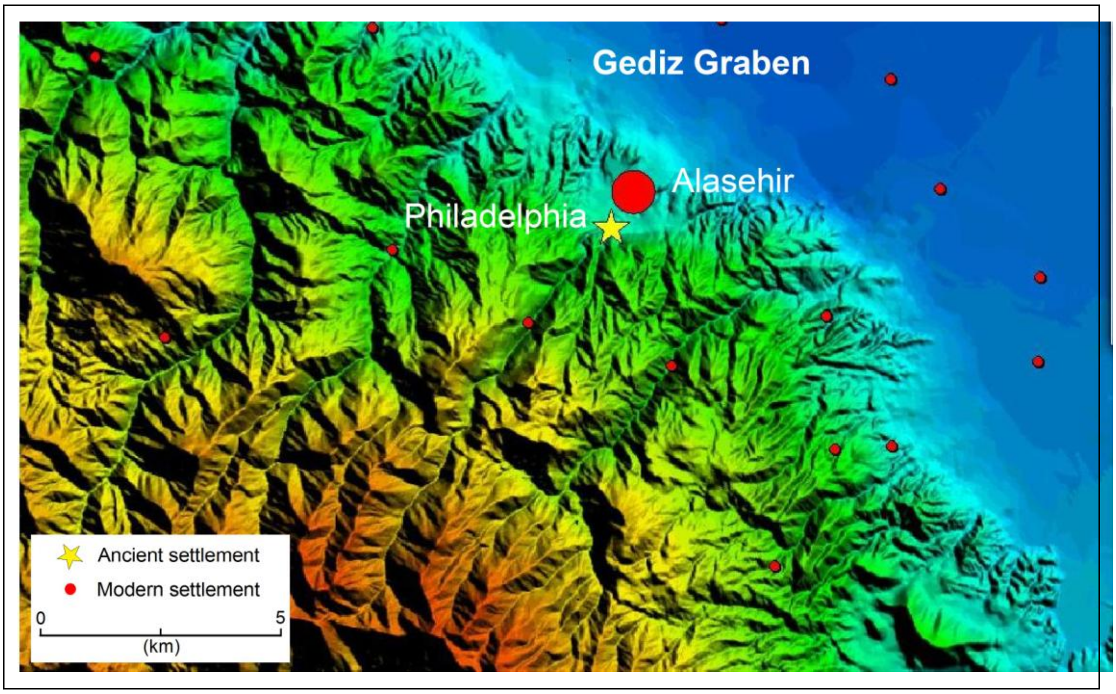


Figure 7.32 Morphology of Alaşehir area located on the southern margin of Gediz graben

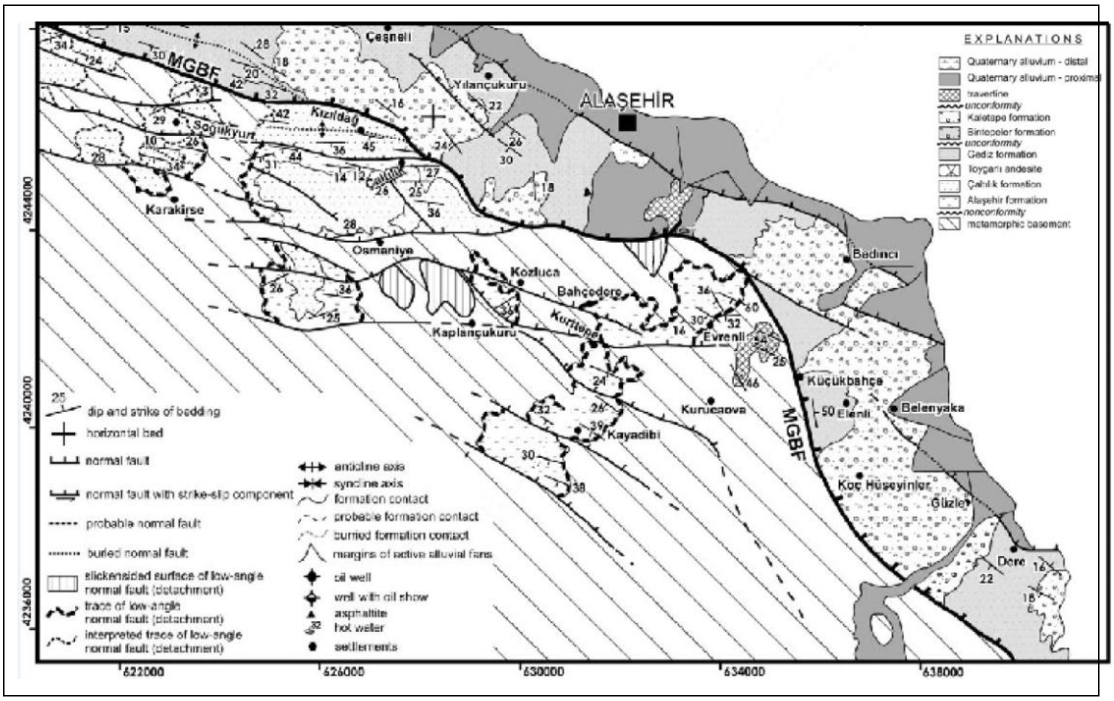


Figure 7.33 Location of Philadelphia

Both Alaşehir and Philadelphia are built at the slopes of the fault scarp (Figure 7.34). The ancient city of Philadelphia lie buried underneath Alaşehir and some remains have been uncovered on the ancient acropolis of the city. There are only little foundation stones and a few Roman columns (Figure 7.35).

Figure 7.34 View of Alaşehir and Gediz graben from top of the hills viewing northwest.

Figure 7.35 A view of the remains of the church of Philadelphia in Alaşehir.

The city has nearly 2.03 km2 area (Figure 7.36). Figure 7.37 shows the aspect, elevation and slope values of the Philadelphia prepared from 96 pixels. The city faces mainly to Northeast . The elevation of Philadelphia is between 250-300 m. Slope values of the city are 1-2, 3-4 and 4-5 degrees as the same percentage.

Figure 7.36 City Plan of Philadelphia (from Google Earth)

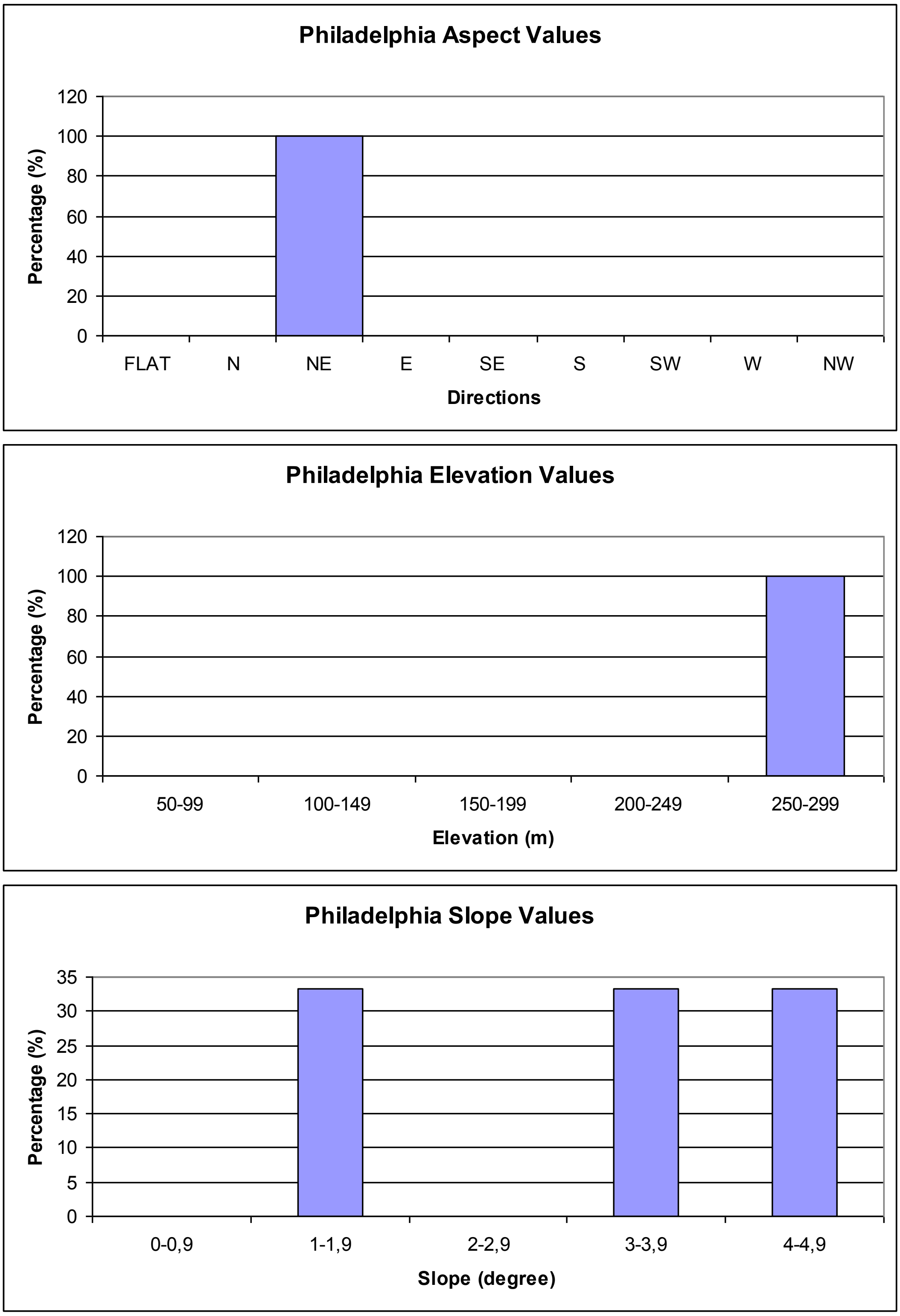


Figure 7.37 Aspect, Elevation and Slope values for Philadelphia

In 17 AD Philadelphia was struck by earthquakes and the city was ruined completely. Strabo mentioned this event in his writings. Meriç (1991), who excavated in the city, claimed that the foundations at the base of the church supported the church against to earthquakes.

7.4 Sardis

Sardis is located on the southern margin of the central part of Gediz graben west of Salihli (Manisa) (Figure 7.38). Geological map of the area clearly indicate that (Figure 7.39) there are several, closely spaced faults passing very close to the ancient city. Since the city lies on the downthrown block of the faults, it is gradually covered by alluvium derived from the upthrown block as the faults are activated (Figure 7.40). Therefore, today the ancient city is mostly buried under the alluvium.

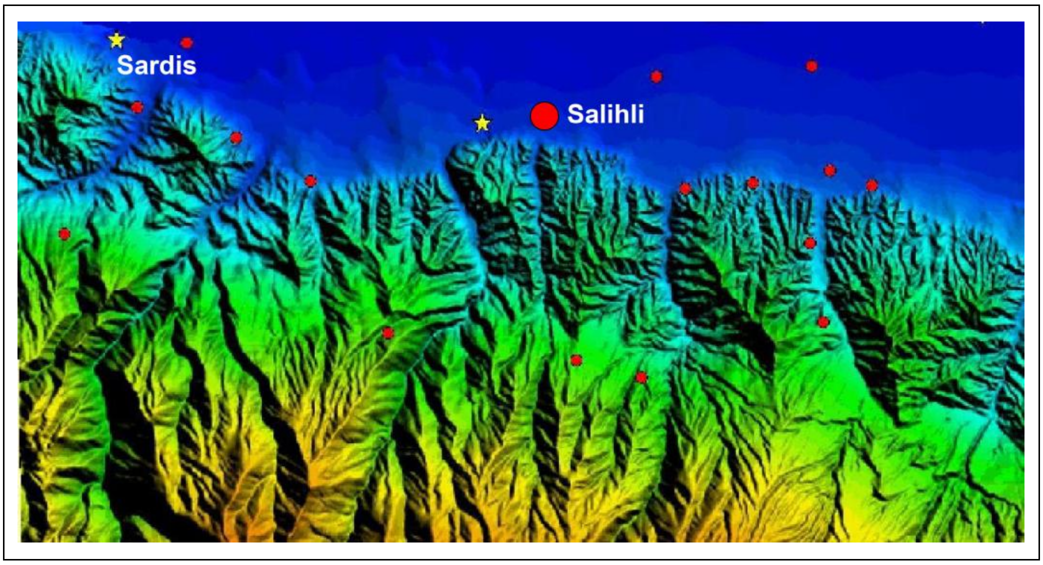


Figure 7.38 Morhology of Sardis-Salihli areas

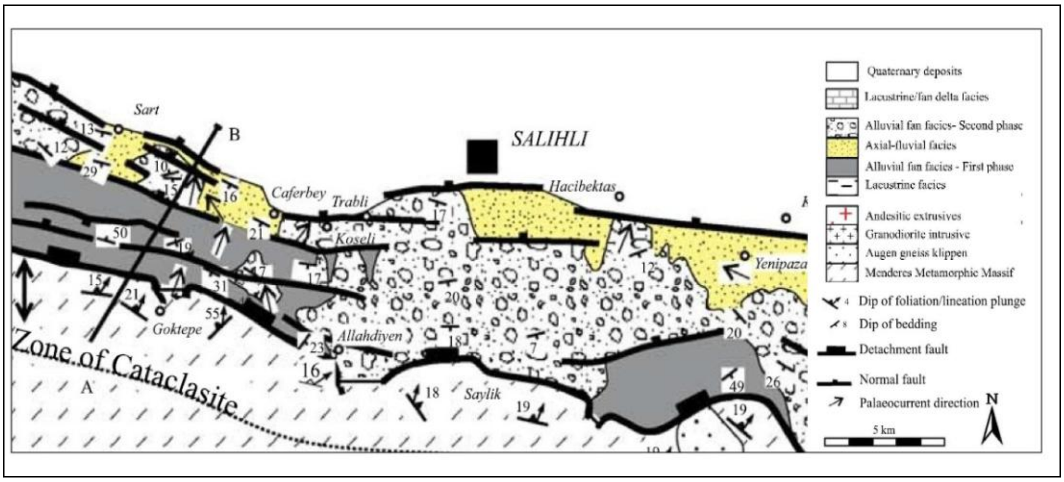


Figure 7.39 Geological map of the Sardis-Salihli area. (Sart in the figure is the Turkish equivalent of Sardis).

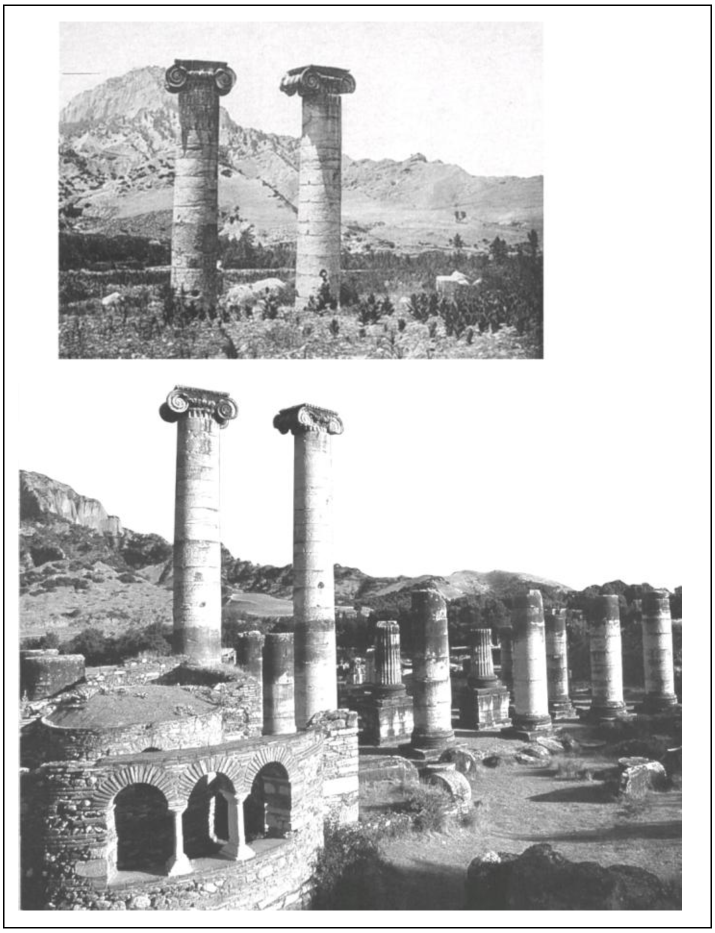


Figure 7.40 A view of the Sardis before (top) and after (bottom) excavations indicating a thick alluvial cover burying the city.

Sardis has a rectangular plan (Figure 7.41).The city has nearly 1.4 km2 area. Figure 7.42 shows the aspect, elevation and slope values of the Sardes prepared 80 pixels. The aspect values show that nearly 60 % of the city looks to North. NE and NW are the other dominant directions. The elevation values indicate that some parts of the city have 100-150 m elevation as 38 percentage and some parts have an elevation between 150-200 m as 31 percentage. Slope histograms show that the city has 1-17 degrees slope values. However the main peak was observed at 6-7 degrees.

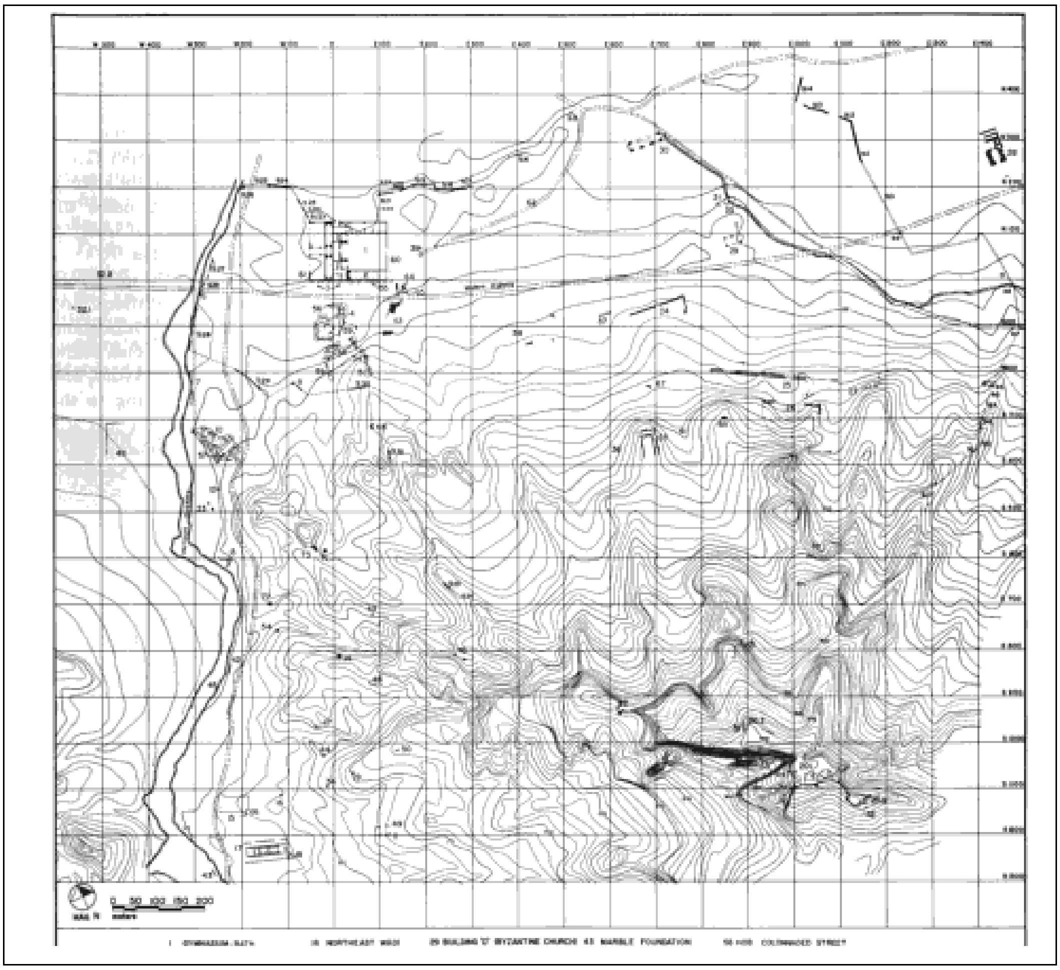


Figure 7.41 City plan of Sardis (Graber, 1998)

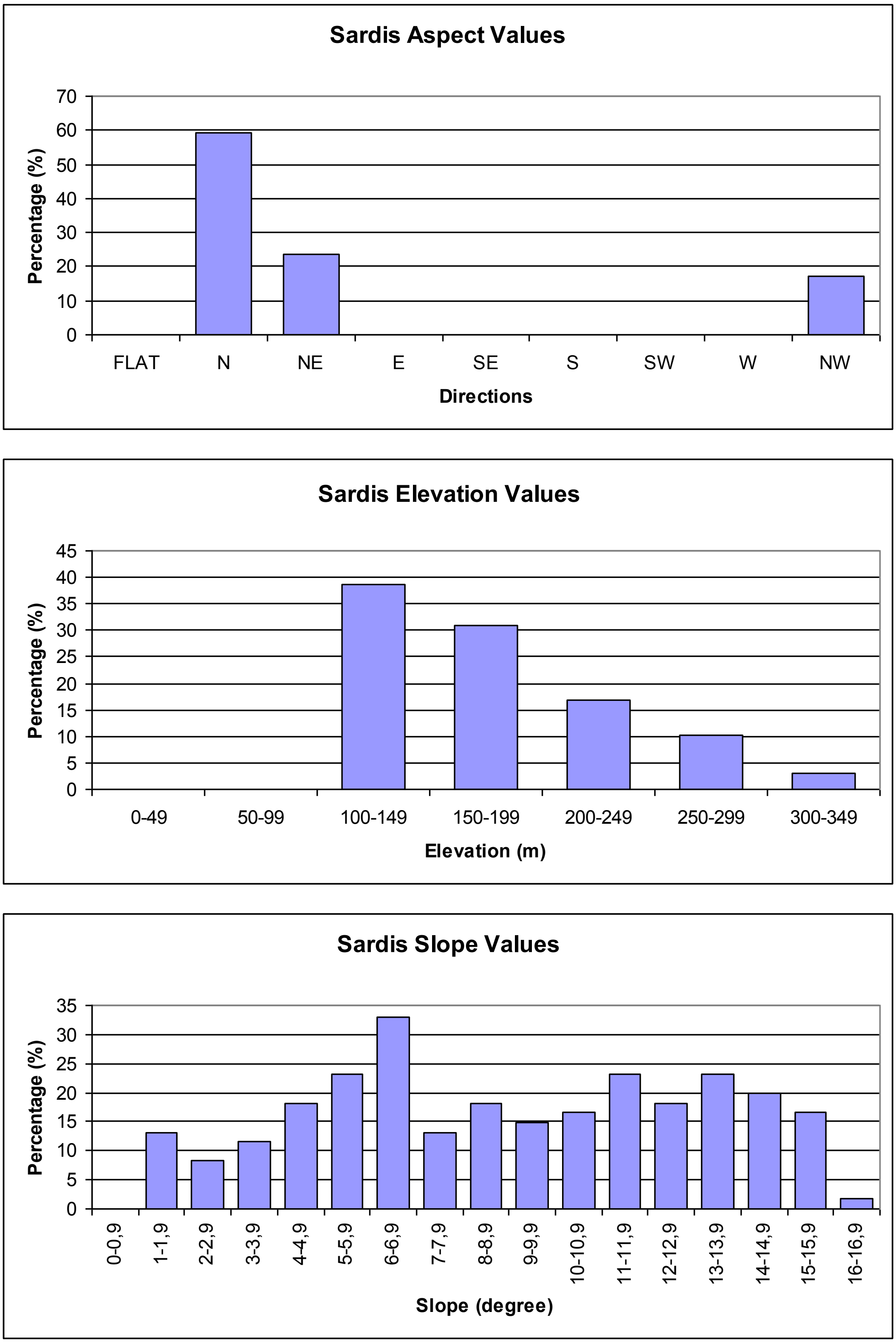


Figure 7.42 Aspect, Elevation and Slope values for Sardis

In 17 AD Sardes was struck by a devastating earthquake. The city later was rebuilt by Emperor.

7.5. Manisa (Magnesia)

Manisa is located on the southern part of Gediz graben (Figure 7.43). Geological map of the area clearly indicate that (Figure 7.44) there are several, closely spaced faults passing very close to the ancient city. Since the city lies on the downthrown block of the faults, it is gradually covered by alluvium derived from the upthrown block as the faults are activated. Therefore, Magnesia is under the today's Manisa city and in ancient times city was called as Magnesia ad Sipylum. Today the ancient city is mostly buried under the alluvium. Since the ancient city in the under the city, no morphological histograms prepared.

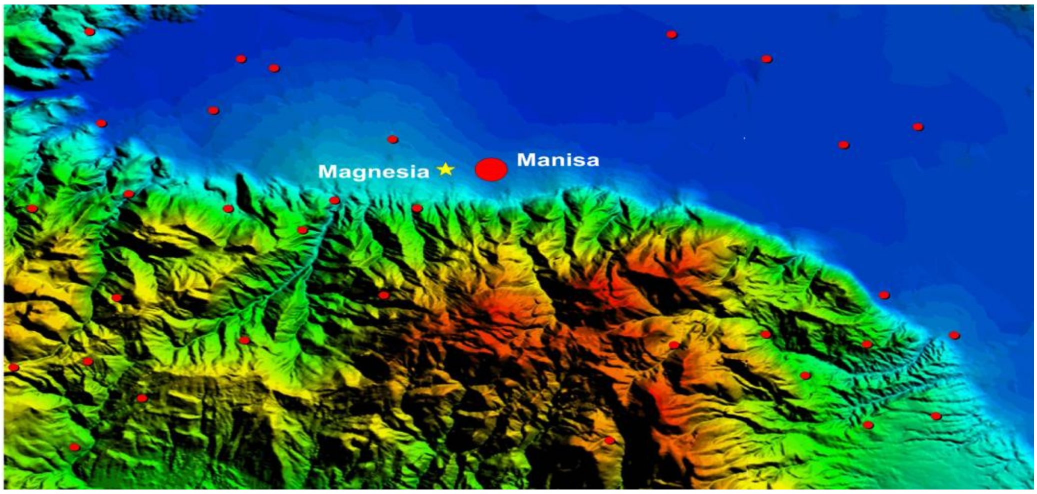


Figure 7.43 Morphological map of the Manisa area

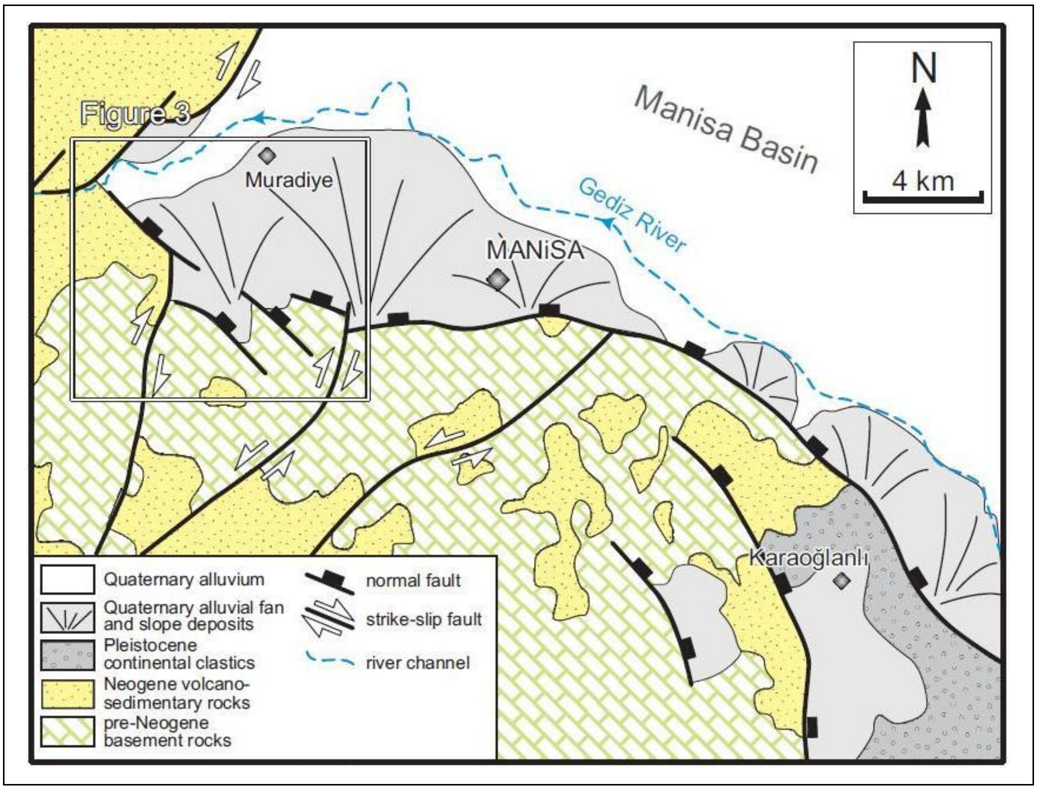


Figure 7.44 Geological map of the Manisa area

7.6 Muğla Area

Muğla is situated on a flood plan where a narrow graben is developed in NW-SE direction (Figure 7.45). Three well-known ancient cities, namely, Stratonikeia, Lagina and Mobolla are located in this region.

The morphology of the area is illustrated in (Figure 7.45) characterized by a flat graben floor bounded by steep topography on both margins. All these margins involve active faults. All these faults are parallel to the elongation of the graben (Figure 7.46).

Morphological characteristics of Stratonikeia, Lagina and Mobolla have similar values. All settlements are quantified as showing features of “preferred” landforms based on the analysis of 81 ancient settlements.

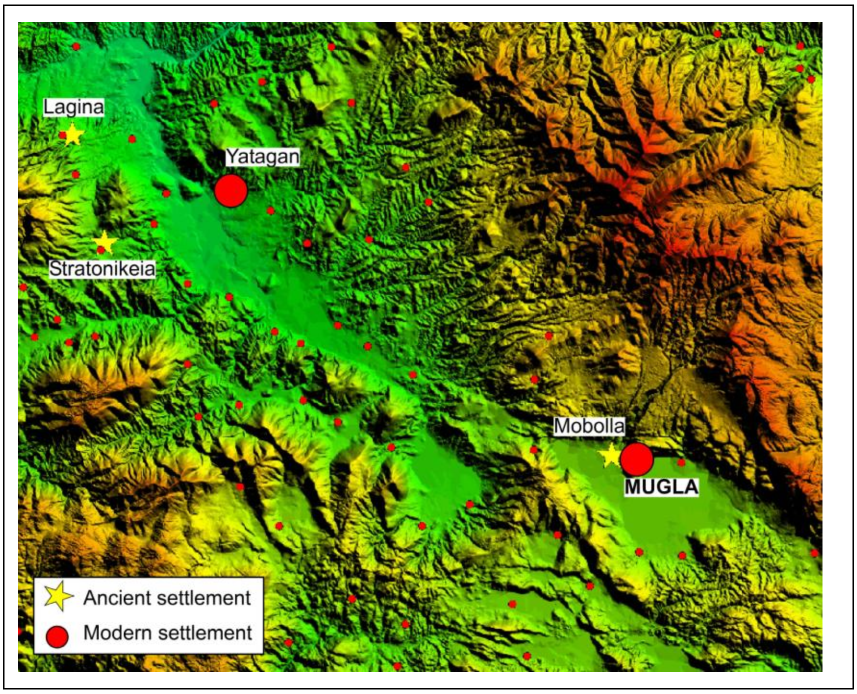


Figure 7.45 Morphology of Muğla Area

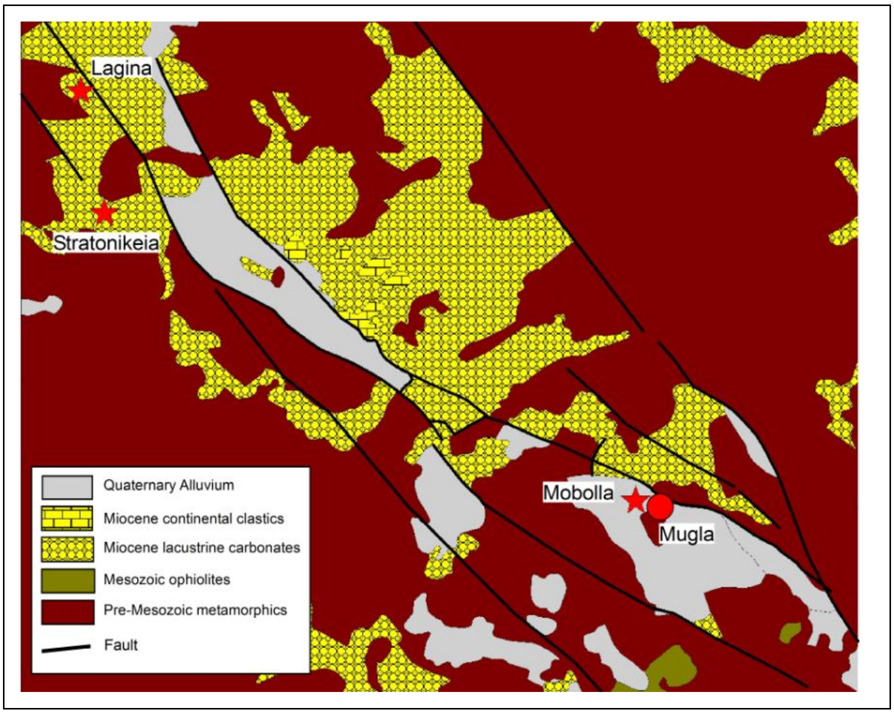


Figure 7.46 Geology of the area around Muğla with ancient cities of Mobolla, Lagina and Stratonikeia

Stratonikeia: The city is located very close to an active fault on the northern margin of the graben (Figure 7.46). The city devastated many times because of the earthquakes. However, the most devastated earthquake hit the city in 140 AD. That earthquake ruined the city.

Figure 7.47 shows the city plan of Stratonikeia. The ancient city has nearly 0.49 km2 area. Figure 7.48 shows the aspect, elevation and slope values of the city prepared from 36 pixels. Stratonikeia is located on a surface mainly South, Southeast, South directions. The elevation values indicate that city mainly situated on an area of 500-550 m. elevation. The slope vales show that the main inclination is at 4-5 degrees.

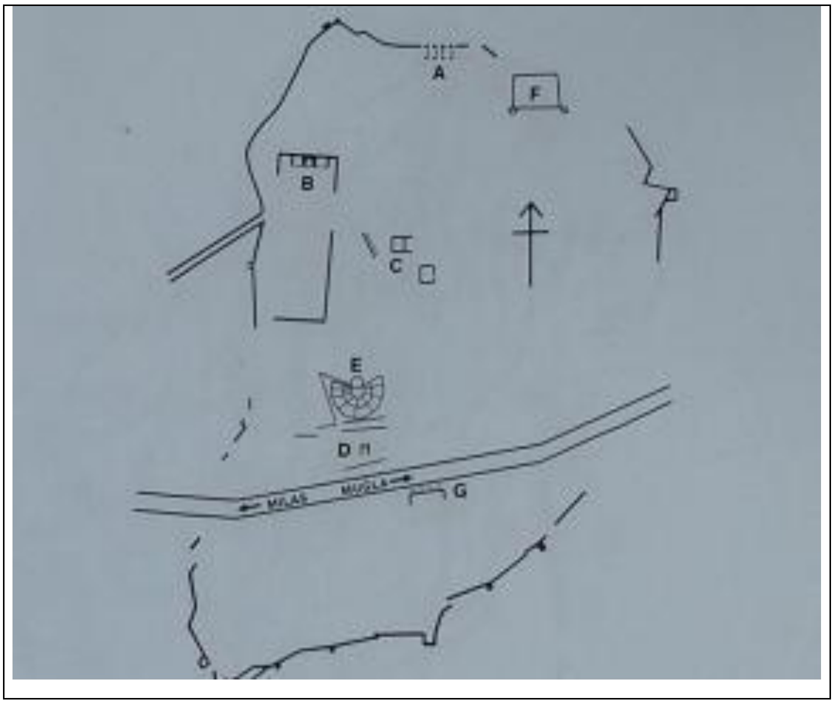


Figure 7.47 City plan of Stratonikeia (Hakkert, 2005)

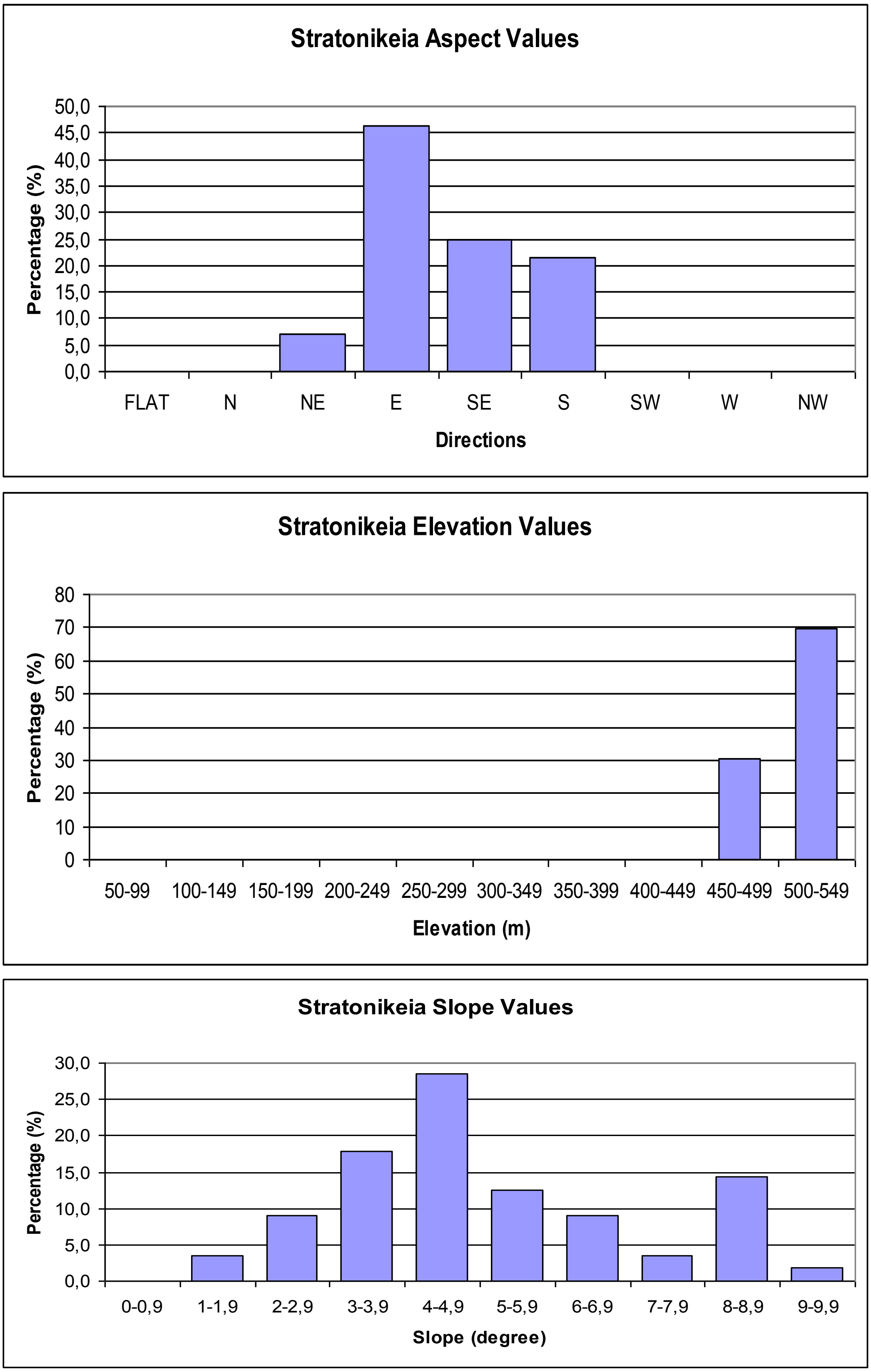


Figure 7.48 Aspect, Elevation and Slope values for Stratonikeia

CHAPTER VIII

ACTIVE FAULTS AND SETTLEMENTS

Since the main purpose of this study is to investigate the relationship between active faults and settlement location, an “active fault map” of the area is one of the essential inputs of the study. However, during the period the thesis was organized and prepared such a data was not available. Although MTA has a project that aims to compile the active fault map of Turkey since 1987, this map is not complete and is still under the progress.

Only recently, some active fault maps are published by MTA at 1/250.000 scale that also covers the study area. After these maps are published, one alternative was to modify the methodology of the thesis and use these fault maps. Accordingly, morphological classes which are used as indication of active faults in this thesis would be replaced by the faults. However, a careful investigation of the active fault map indicates that some faults are not correctly mapped and that these maps still need to be modified. For example,only a few faults are drawn in the vicinity of Küçük Menderes graben, which is believed to be more than this according various previous investigations. For this reason, these faults are decided not to replace the morphological classes but to be used for testing the accuracy of the results obtained in this study.

An example of the analog copy of the active faults is introduced in the DATA chapter. These maps are scanned and registered individually. Then all the maps are mosaiced to get one single map. This map is then clipped out using the boundary of the study area. All the faults in this map are digitized and stored as a separate layer. The resultant active fault map is shown in Figure 8.1

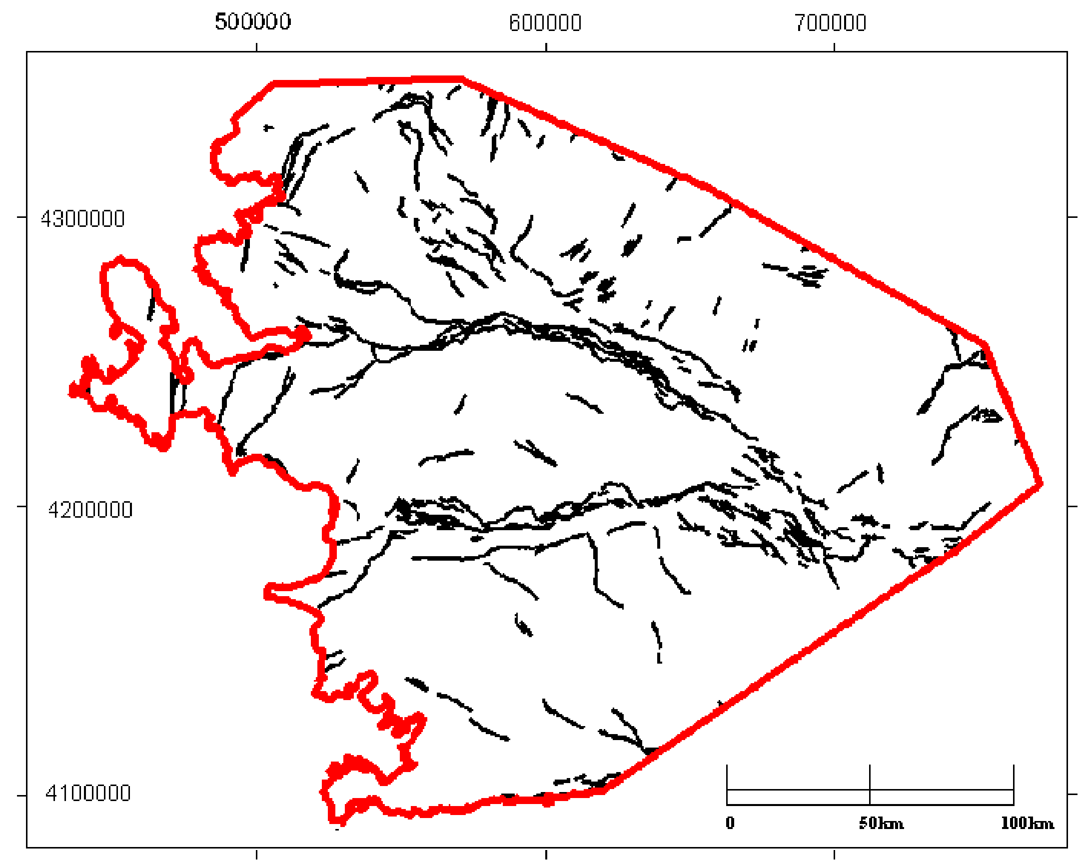


Figure 8.1 Fault map of the study area

Testing accuracy of the results is made in two steps. The first step is to see if the fault lines coincide the "flood plain" boundaries or not. This is the main assumption used in this study based on the fact that flood plains are recent structures formed by the activity of the faults. The second step is quantify and compare the distances of settlements (both ancient and modern) to the fault lines and to the "flood plain" boundaries. The second step, in a way, is a justification of the first step.

For the first step, the fault map and the morphological classes are combined in one map (Figure 8.2). Grey areas in this figure correspond to the "flood plain", the white areas to "mountainous areas" and the blue strip is the 5 km coastal buffer zone explained in previous chapters.

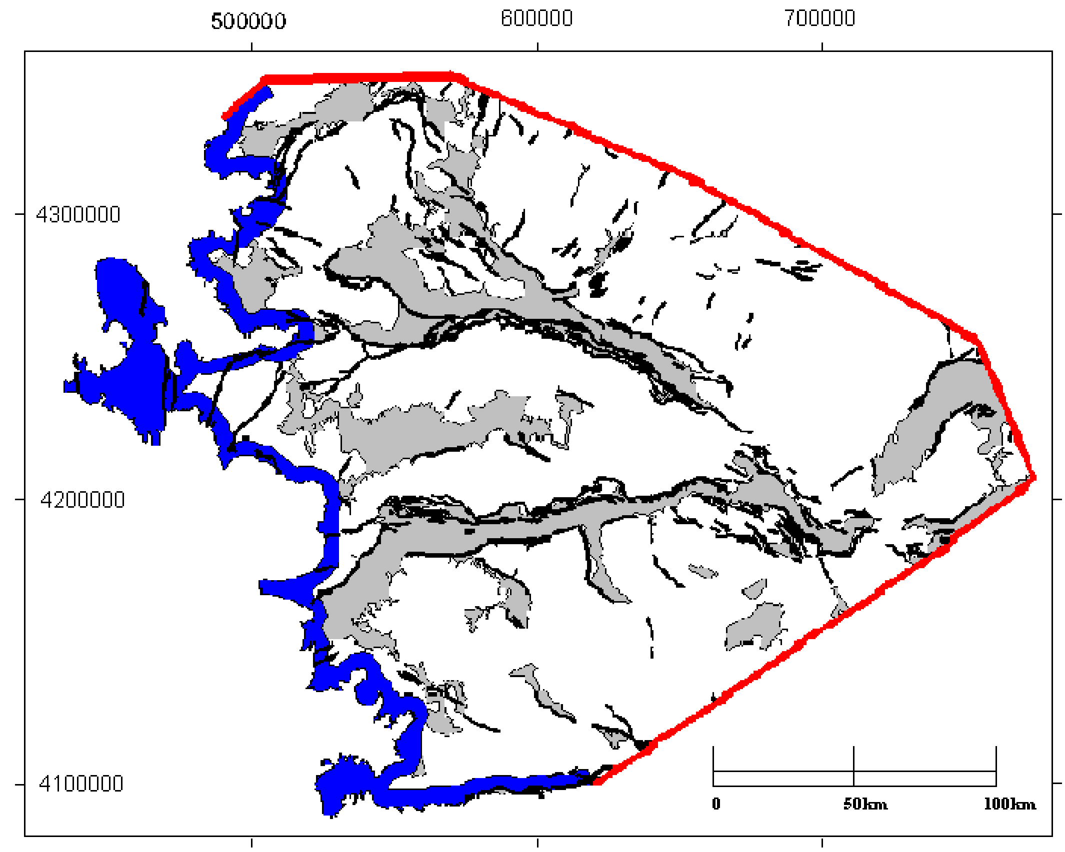


Figure 8.2 Morphological classes and fault lines in the study area

Asssen in the figure, most of the active faults are clearly concentrated at the flood plain boundary. This is overemphasized particularly in both northern and southern margins of Büyük Menderes and Gediz grabens. In Küçük Menderes graben, however only a few fault lines are identified. Most of other smaller flood plains are also associated with active faults as observed in the eastern (Denizli area), south-western (Mugla area) and northwestern parts of the area. With the exception of Küçük Menderes Graben, there is no major flood plain which is not associated with active faults. Therefore, the assumption that the floods plains are bounded by active faults is a true assumption.

For the second test, the distances of the settlements to the faults lines are measured. To do this first of all, the coastal settlements are excluded as done in the analysis chapter. Secondly,a buffer zone of 2 km was considered along the fault lines.

The distances to the fault planes are measured for both ancient and modern settlements. The results are shown in the histograms in Figure 8.3. Among the ancient settlements, 22 are located with a distance of 0 to 1.5 km wcich correspond to 36.6 % of the ancient settlements (21 coastal settlements are excluded). The pattern of the modern settlements, on the other hand, represents a more interesting relationship. The maximum concentration of the modern settlements is observed within a distance of 0 to 0.5 km which suddenly drops and consistently reduced away from the fault plane. The percentage of the modern settlement in the buffer zone is 32. 8 %.

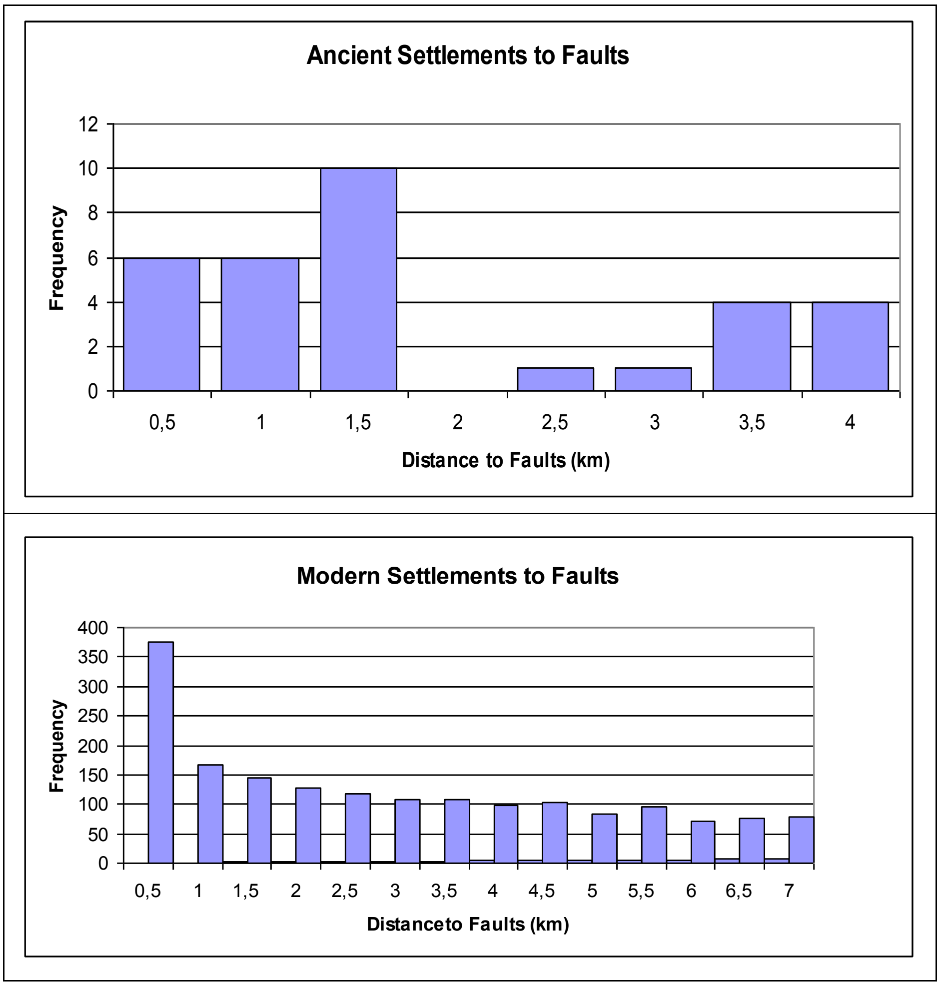


Figure 8.3 Ancient and modern settlements distances to the active faults (22 coastal settlements are excluded)

Table 8.1 shows the comparison of the results of the distances to the fault plane (first column) and to the flood plain boundary (second column). Accordingly,36.6 % of the ancient and 32.8 % of the modern settlements are built next to the fault lines. Percentages shown in the second column (to flood plains) are transferred from Chapter 6.

The results for two methods indicate that the percentages of both ancient and modern settlements dropped for some amount consistently. This might be due to two reasons: 1) all margins of the floods plains are not fault controlled, or 2) along some margins of the flood plains certain fault lines are not identified. Considering the scope of this study there is no way to justify this problem.

Table 8.1 Comparison of ancient and modern settlements distances found by two methods

	Percentage using active fault	Percentage using morphological classes
Ancient Settlements	36.6	44.4
Modern Settlements	32.8	35.8

The spatial relationship between the seismic data and the fault line may also give valuable information because the earthquakes are generated along the active faults. To test this relationship the seismic data are plotted together with the fault lines (Figure 8.4). The earthquakes shown in this figere belong to the last century and have magnitude equal to or graeter than 3 as explained in DATA chapter.

As seen in the figure, there is an obvious relationship between the earthquakes and the fault lines. At certain locations this relationship is over emphasized. These localities are: vicinity of Denizli where Büyük Menderes and Küçük Menderes grabens join, northeastern part of the area (Izmir and vicinity) and the southern part of the area (vicinity of Mugla). It should kept in the mind that the seismic data belong to only one century period and some parts of the regions could not be well monitored.

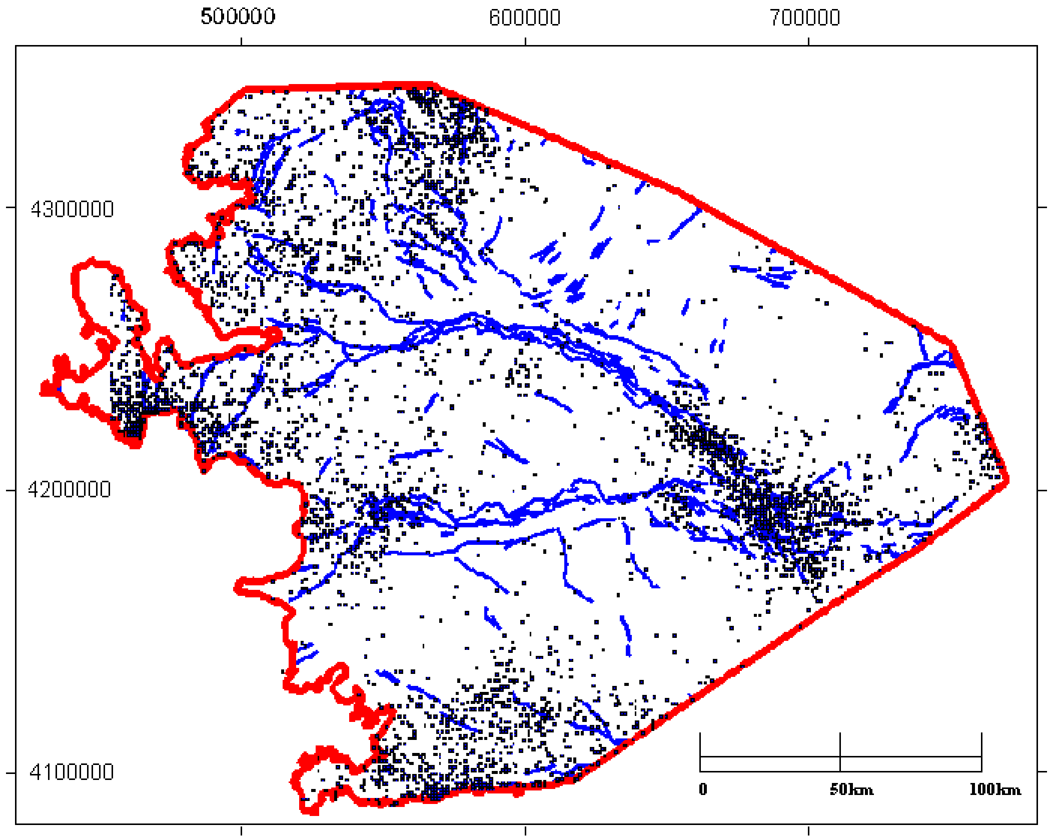


Figure 8.4 Fauts and earthquake distributions in the study area

CHAPTER IX

DISCUSSION AND CONCLUSIONS

Roman and Greek period ancient cities are examined in this study within the context of their location near to the active faults with certain physical parameters. Physical parameters considered in this study are three morphological features (elevation, slope and aspect), rock type and seismicity. The thesis started to evaluate the location of ancient settlements in relation to these parameters. Modern settlements are also used to examine the change occurred during the time. This chapter contains three sections. In the first section, the methodology is disussed. In the second section, the quality of data used in this study and their effect of the results will be discussed. In the last section, the interpretation of the results obtained in this thesis will be discussed.

9.1 Methodology

The methodology of the study is based on investigation of the location of settlements in relation to the active fault lines. However, since there is not a complete and reliable active fault map for the region, this relationship is investigated indirectly using the boundaries of the floods plain which are assumed to coinside the fault lines.

The methodology is composed of four major steps. The first step is the creation of the database. Quality (and quantitiy) of the data will be discussed in the next section. Using the database prepared from the input data the second and the third steps are performed separately.

The second step (Chapter6) involves a set of analysis carried out at regional scale in order to understand the location of the settlement in relation to fault lines together with other possible factors. These analyses produce resultswhich can be interpreted only statistically. However, each specific analysis is believed to contribute to the settlement pattern in the region. For example, the density diagrams of the settlement overlaid on the morphological classes gives a broad idea on the selection of the settlement site.

In the third step (Chapter 7) of the methodology, certain selected areas are tested for their earthquake potential as case studies. Earthquakes that occur in these areas are compiled from the literature and interpreted by detailed geological maps with a particular emphasis on the active faults mapped in the area. This step is believed to demonstrate the relationship between the settlement locations and active fault planes.

The last step (Chapter 8) tends to test the accuracy of the results using active fault map recently published by MTA. Since the map is still in the progress and not completed it is not used as the main input data in the study.

Integration of the various steps of the methodology is believed to answer the assumtion raised in this study: The people were not aware the fault line which produced suitable landform and therefore settled insistently in the close vicinity of the earthquake-producing fault lines.

9.2 Quality of Data

The data sets used in this study are introduced in Chapter 5. It is obvious that the quality of the data affects the accuracy of the results. For this reason, a special attention is given during the compilation of the data.

Ancient settlements: The most important input data is the catalogue of the ancient settlements. There are severals problems faced during the compilation of this dataset. First of all there is not a complete list of ancient settlements for this region although it is one of the best studied parts of Turkey. Several catalogues have inconsistencies in their lists. Ancient settlements identified by Tubinger Atlas des Vorderen Orients are used in this study, which is believed to be the best.

Location of the settlements is another problem faced during the creation of this database. The locations of the settlements are given in small-scale maps that could lead to erratic reading. Some known ancient settlements are identified on 1/25.000 scale topographic maps are are accurately recorded while some others assigned a coordinate with an error range of few kms

Population of the ancient settlements could not be used in this study because of the lack of data. Although this data is available for settlements in the region, populations of the most of the settlements are unknown.

History of the ancient settlements, particularly the earthquakes occurred approximately the settlements is an essential for this study. For most of the settlements, particularly for those not excavated, this data is missing. For this reason, the case studies are performed in limited areas where data is available.

Only a limited time (Greek and Roman) settlements are selected for two reasons: 1) This period settlements are relatively well known and more studied, 2) The response of the people to earthquakes would be more meaningful for a certain period of civilization.

Modern settlements: The reason for including the modern settlements in this study is to test the tradition in the selection of settlement location from past to present. Modern settlements used in this study exclude the recent settlements (later than 1975), touristic sites and highland settlements (yayla). Coordinates of all settlements are read from topographic maps.

Topographic data: Topographic data used in this study is SRTM files provided by NASA which has a modified pixel size of 100 m. Therefore, each pixel in this study corresponds to an area of 10000 m2. This resolution is optimum for this study considering the size of the study area. Total number of pixels used in the study is 925688. All topographic and morphologic datasets are derived from this data. These are essentially: 1) Elevation, slope and aspect values of the area as well as the ancient and modern settlements, 2) morphological classes (flood plain and mountainous areas)

Rock type data: Rock type data is provided from MTA and reorganized in this study. The initial map contained more than 100 individiual rock types, which were reduced to 7 related classes. In fact, the most important rock unit in the database is the Quaternary alluvium, which is deposited within the flood plains. Other units, however, are also tested in relation to their elevation to understand if any rock type is preferred as settlement site. Testing the accuracy of this dataset is not practical and possible in this study.

Seismic data: The study area is known for its recent tectonic acivity. Earthquakes of different magnitude occur in the area continuously. Since the earthquakes occur along the active faults, the earthquakes of the last century are obtained to have an idea on the distribution of the earthquakes. Particularly the spatial relationship beteen the earthquakes and the flood plain boundaries is very important for this study. However, it should be kept in the mind that, the earthquakes of such a short period may not accurately reflect the nature of this distribution.

9.3 Interpretation of Results

This thesis based on the hypothesis that there is a genetic relationship between the earthquake producing active faults and the location of the settlement. Three main assumptions used in the study are:

- Active faults can shape the earth and produce a suitable landform to settle.
- Ancient people built their settlements close to the active faults.
- Ancient people did not recognize the “fault line”

First these assumtions will be tested and than the main hypthesis will be discussed using the results obtained in the thesis.

The first hypthesis is correct as indicated by the relationship between the morphological classes and the fault lines. The margins of the flood plains coincide with the fault lines. Therefore, the fault lines define the boundary between the flat alluvial plains and steep mountain fronts. This line therefore corresponds to a sudden slope change in the area at the edge of fertile agricultural fields. Another positive factor is that, the groundwater reaches the surface along these fault planes. Therefore the, vicinity of the faultline is an attractive site for the settlement.

The second hypothesis is quantified by the percentages of the settlements located close to the fault. Both distance analysis and density analysis indicate that the concentration of the settlements near the fault line is high.

The third assumption is justified using the data compiled from literature on the recognition of the earthquakes. Almost all parts of the world, ancient people attributed the occurrence of earthquake on different beliefs. None of these beliefs considers a “distance” to a physical structure (fault line). Accordingly, earthquake can occur anyway. Although there are some documents for Greek period scholars trying to understand the reason, all theories are far behind the recognition of a fault line.

Since the people are not aware of the fault line, they did not change the location of their settlement after earthquakes. This is approved by many ancient settlements insistently built at the same location after it is seriously or totally damaged.

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APPENDIX A

ANCIENT SETTLEMENTS LIST

Settlement	Northing	Easting
Aigai	517168.41	4298440.21
Airai	474000.07	4228000.76
Akrasos	566495.99	4325202.9
Alabanda	583217.84	4161403.28
Alinda	570255.92	4154746.13
Amyzon	558832.41	4160364.78
Anineta	627147.55	4200886.16
Antiocheia	639602.15	4190164.10
Aphrodisia	651336.19	4176654.71
Apollonias	678404.86	4151704.89
Apollonous hieron	663176.49	4217317.39
Attaleia	576960.25	4323779.63
Attouda	659450.96	4189070.41
Aurelioupolis	597373.23	4260038.80
Bargylia	549367.06	4113472.27
Blaundos	692199.58	4246968.78
Brioulla	638716.23	4201363.26
Daldis	597858.09	4285632.52
Didyma	522900.05	4138400.56
Dionysopolis	712718.07	4233444.13
Elaia	505122.35	4311928.54
Ephesus	531286.37	4199280.01

Erythrai	454467.38	4246430.43
Eumeneia	750881.76	4242716.42
Euromos	559358.89	4139958.32
Gordos	610823.01	4308113.33
Halicarnassus	533307.38	4098389.85
Harpasa	617783.96	4184430.24
Herakleia	674423.42	4166346.53
Hierokaisareia	566705.49	4290831.47
Hieraopolis	687246.17	4198555.25
Hydai	563023.67	4128610.12
Hyllarima	617677.90	4148351.66
Hypaipa	583951.88	4235397.08
Keramos	583686.25	4099966.88
Klaros	518100.00	4206000.00
Klazomenai	478564.74	4247145.19
Koloe	603607.64	4228812.99
Kolophon	510768.63	4216760.59
Kyme	494438.1	4292340.44
Labranda	572509.78	4141676.23
Lagina	591456.43	4136971.61
Laodikeia	686691.72	4185737.32
Iasos	548193.05	4124347.67
Lebedos	497600.00	4217600.00
Magnesia	544000.00	4188000.00
Magnesia ad mean.	534708.86	4274976.9
Mastaura	617667.24	4201767.31
Metropolis	529275.08	4224705.13
Miletos	522923.94	4146376.06
Mobolla	620612.34	4119041.12
Mossyna	690153.86	4217313.78

Mylasa	569361.33	4130015.11
Myndos	520827.34	4101502.76
Mynneuses	491000.44	4213000.68
Myrina	500559.53	4298231.26
Notion	520000.86	4204000.87
Nysa	600121.54	4197539.21
Orthosia	605062.98	4182658.12
Palaiapolis	604132.91	4214242.21
Panionion	526000.33	4185000.11
Pergamon	512638.51	4331911.23
Philadelphia	631883.97	4244111.98
Phokaia	478306.60	4278166.07
Phygela	524000.21	4192000.98
Pitane	493409.26	4309311.59
Priene	524008.15	4168358.69
Sanaos	749288.74	4195442.75
Sardis	589381.18	4261933.37
Satala	609856.27	4272749.56
Settai	636861.33	4292222.84
Silandos	662062.35	4290882.06
Smyrna	509623.06	4251068.79
Sratonikeia	566305.19	4331580.26
Tabala	661171.93	4278345.73
Teos	482928.53	4223704.76
Theodosiopolis	609584.65	4232563.98
Thyateira	571845.22	4309132.16
Tralleis	571703.05	4191968.13
Trapezopolis	669918.22	4203470.78
Tripolis	671023.38	4209327.08

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PUBLICATIONS
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BOOKS
Deterioration Problems of Ankara Castle Andesites: Weathering, Case Study, Conservation and Restoration, VDM Verlag Dr. Müller Publising Company, Germany