PLIOCENE-QUATERNARY GEOLOGY OF THE SOMA GRABEN, WESTERN TURKEY

by

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İZMİR

PLIOCENE-QUATERNARY GEOLOGY OF THE SOMA GRABEN, WESTERN TURKEY

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by

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ABSTRACT

The Soma and Bakırçay grabens has been developed on the pre-Miocene basement rocks (İzmir-Ankara zone), Miocene Soma and Deniş Formations comprising of lignite-bearing clastic and carbonate rocks, and Kumköy Formation probably Upper Miocene in age which are successed each other by unconformities. The Kumköy Formation, underlying the deposits of the Soma and Bakırçay grabens by unconformity, is composed of reddish alluvial fan conglomerates, braided river conglomerates and sandstones, fine-grained floodplain deposits and pisolitic/onkolitic carbonate rocks which were deposited in shallow lacustrine developed on this floodplain.

The sedimentary fill of the Soma and Kırkağaç grabens is composed of Quaternary alluvial fan conglomerates with thickness of > 70 m which were deposited as debris flows, Holocene colluvial fan-apron conglomerates accumulated in front of the fault scarps and, laterally equivalent of the colluvial deposits, river deposits of the Bakırçay. The total thickness of both graben-fill is approximately 200-250 m.

The Soma graben is a narrow and long, WSW-ESE trended, less convex toward north and, its southern margin high-dipped active depression. It is divided in the west by Boyalıktepe horst from Bakırçay (Bergama) graben. Dereköy graben located in the south of the Soma graben and its deposits partially preserved. It is limited by Kocatepe horst in the west, Kösedağ horst in the north and Çamlıcadağ horst in the south. The E-W trending Dereköy graben is located in the south of the Soma graben, and its deposits partially preserved. It is limited by Kocatepe horst to the west, Kösedağ horst to the north and Çamlıcadağ horst.

The fault of the Soma and Bakırçay graben systems are with 0,2-21 km long and they are developed mainly WSW, ENE, NE and NW-directions. The most of the faults are active and source of the multi-directional extension. The results of the kinematic analysis of the fault surface measurements from nineteen stations show the oblique-slip normal faults with dextral and sinistral slip components and oblique-slip reversed faults with dextral slip lateral components. The faults control the southern margin of the Soma graben are more dominant, active and younger than the other faults relatively.

The total vertical slip during Quaternary period (1,6 myr) along the faults that control the southern margin of the Soma graben is 575 m. It refers to about 0,36 mm/year of vertical deformation rate in the graben.

Keywords: Quaternary, Pliocene, Soma, Bakırçay, western Turkey, graben, kinematic, active fault

ÖZET

Soma ve Bakırçay (Manisa) grabenleri, birbirinden stratigrafi uyumsuzlukları ile aralanmış Miyosen öncesi temel kayalar (İzmir-Ankara zonu), linyit içeren kırıntılı ve karbonat kayalardan oluşan Miyosen yaşlı Soma ve Deniş Formasyonları ile olasılıkla Geç Pliyosen yaşlı Kumköy Formasyonu üzerinde açınmıştır. Soma ve Bakırçay graben dolgularından uyumsuzlukla aralanan deformasyon geçirmiş Kumköy Formasyonu kırmızımsı renkli alüvyal yelpaze çakıltaşları, örgülü akarsu çakıltaşları ve kumtaşları, ince taneli taşkın düzlüğü çökelleri ve bu taşkın düzlüğünde gelişmiş sığ karbonat gölünde biriktirilmiş pisolitik/ onkolitik karbonat kayalarından oluşur.

Soma ve Bakırçay grabenlerinin tortul dolgusunu, döküntü akmalarıyla biriktirilmiş ve 70 m den fazla kalınlıklı Kuvaterner yaşlı alüvyon yelpazesi çakıltaşları, fay sarplıklarında oluşmuş güncel kolüvyon yelpaze-apron çakıltaşları ve bunlarla yanal geçişli Bakır Çayı'nın güncel akarsu çökellerinden oluşur. Her iki grabendeki tortul dolgunun toplam kalınlığı 200-250 m dir.

Soma grabeni, BGB-DGD gidişli, kuzeye çok az dışbükey, güney kenarı yüksek eğimli bakışımsız aktif bir çöküntüdür. Batıdan Boyalıktepe horstu ile Bakırçay (Bergama) grabeninden ayrılır. Soma grabenin güneyinde, dolgusu kısmen korunmuş, D-B gidişli, kuzeyden Kösedağ horstu, güneyden Çamlıcadağ horstu ile sınırlı Dereköy grabeni bulunur.

Soma ve Bakırçay grabenlerinin kenar fayları 0,2-21 km arası uzunlukta ve başlıca BGB, DKD, KD ve KB gidişlidir. Bu fayların çoğu aktif olup çok yönlü genleşmenin kaynağıdırlar. Ondokuz istasyondan yapılan fay düzlemi ölçümlerinin kinematik analiz sonuçları, sağ yanal atımlı, sol yanal atım, sağ ve sol yanal atım bileşenli verev atımlı normal faylar ile sağ yanal atım bileşenli verev atımlı ters fayları gösterir. Soma grabenini kontrol eden faylar diğer faylara göre daha baskın, daha aktif ve daha gençtir.

Kuvaterner zamanı boyunca Soma grabeninin güney kenarını denetleyen fayların toplam düşey atımı 575 m'dir. Bu grabende yaklaşık olarak yıllık 0,36 mm'lik bir düşey deformasyona karşılık gelir.

Anahtar kelimeler: Kuvaterner, Pliyosen, Soma, Bakırçay, Batı Anadolu, graben, kinematik, aktif fay

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CHAPTER ONE
INTRODUCTION

A considerable part of agriculture fields and living centers in Turkey are on the Quaternary deposits. For this reason, Quaternary researches in these areas will contribute to the construction and development of our country.

Soma and its surroundings are located nearby place of active fault zone. The geological investigation of the faults those have been active before and throughout Quaternary will contribute to the geology and the town planning of the above-mentioned areas.

Plio-Quaternary deposits cover extensive areas in Western Anatolia. However, the geological research of these deposits is restricted. Plio-Quaternary sequence in Soma (Manisa) and surroundings hasn't been studied in detail up to now. Furthermore, there is no study about the relationship between this sequence and the fault zone that cuts across the region in W-E direction.

1.1 STUDY AREA

The Soma region is located in western-northwestern part of Turkey, to the south of Balıkesir and the north of Manisa. The study area lies between the towns of Yağcılı, Bergama and Kırkağaç. Soma, the well-known coal-bearing basin in the western Anatolia, is situated in the eastern part of the study area, and is about 85 km to north of Manisa (Figure 1.1). The area, which mapped on 1/25.000 scale, includes the topographic maps of Balıkesir J18-b_3, J18-c_2, c_3, J19-d_1, d_4, J19-a_4 and covers approximately 500 square kilometers.

Both highway and railway connecting the cities Manisa and Balıkesir pass through the study area in the southeast-northwest direction. There are also a lot of minor and coalmine roads connecting towns and villages. Çamlıcadağ in the south, Kösedağ in the northwest form the high ground of the study area. Bakırçay and Yağcılı rivers form the main drainage system of the study area.

1. 2 PREVIOUS STUDIES

The most of the previous studies in Soma and the surroundings were focused on the stratigraphy of the lignite-bearing Neogene because of its economical potential and the pre-Neogene basement rocks. For this reason there is no detailed investigation of the Plio-Quaternary deposits and their relationship with the active fault zones.

Brinkmann, Fiest, Marr, Nichel, Schlimn & Walter (1970) pointed out that the Soma Mountains had the fault lines running in the NE and NNE directions. Furthermore they interpreted that the tectonics of the Soma Mountains was completed in three stages. They emphasized that present day relief of study area was modified in the Pleistocene and the terraces in Tarhala and Kozanlı may be originated from this period.

Nebert (1978) indicated that the structural evolution and present day tectonomorphic structure of the Soma district were developed in the Pleistocene period. He proposes three sedimentation cycles being separated from one another by an unconformity each other and, the last cycle was realized during the Pleistocene period. In addition he pointed out that the Quaternary sediments around Soma were composed of a Pleistocene layer succession and Holocene alluvium.

Akyürek & Soysal (1982) named the carbonate rocks as the Kırkağaç formation and the clastic rocks as the Kınık formation in the study area.

Figure 1.1 Location map of study area in global and local scale.

Koçyiğit (1984) suggested three tectonic phases for western Turkey and the adjacent areas; Paleotectonic phase, Transitional phase and Neotectonic phase. The Neotectonic phase is extensional tectonic regime-controlled and it represents terrestrial sedimentation, intracontinental volcanism and block faulting. The author pointed out that the region was divided into several blocks with various dimensions, restricted by oblique-slip normal faults in Neotectonic phase and many of them are still active seismically.

Şengör, Görür & Şaroğlu (1985) indicated that the Aegean region had seismic activity more intense than the adjacent areas and the Plio-Quaternary geology presents a very complex tectonic frame. The workers claimed that the tectonic frames of the Aegean and the Eastern Mediterranean were formed as a result of the westward escape of the Anatolian plate with respect to the European plate in the north.

Erçan, Satır, Kreuzer, Türkecan, Günay, Çevikbaş, Ateş & Can (1985) pointed out that the Kula basalt and the Denizli volcanics were originated from the mantle and the other volcanics from the continental crust, or were the mantle products including crustal assimilation. In addition, they interpreted that the upper continental crust thickened in Western Anatolia since the Eocene and the volcanic rocks were occurred by partial melting of the crust.

Akgün, Alişan & Akyol (1986) indicated that the Lower and Middle lignite seams of Neogene sequence in the Soma area contained the Miocene flora. The palynomorph spectra of the flora assemblage represent that the Mediterranean climate was slightly more humid and hot during the deposition of the coal-bearing formations.

Kazancı (1988) pointed out that the fault-controlled alluvial fans were deposited during the Pleistocene-Holocene period in the Burdur Lake Basin of southwestern Turkey similar to the study area.

Stewart & Hancock (1988), in the Corinth Bay and the surrounding region of İzmir in the Aegean Region, indicate that an alternation of the compact breccia sheets and incohesive breccia belts in normal fault zones separating the pre-Neogene carbonate rocks and the Quaternary deposits. In these tectonic zones, there are three types of the tectonic contacts representing tectonic reactivation during the Quaternary period.

Mercier, Sorel & Vergely (1989) pointed out that the kinematics of the faults show three extensional tectonic regimes in the Aegean Region. Tensional directions were in NE-SW and N-S and these were active during the Upper Miocene, the Pliocene-Lower Pleistocene and the Middle Pleistocene-present day, respectively.

Erdoğan (1990) indicated that the rock units of the İzmir-Ankara Zone present an internal structure that consists of the Triassic-Upper Cretaceous platform type carbonate blocky rocks floating in Upper Cretaceous-Paleocene flysch-type matrix.

According to Okay & Siyako (1991) the rock units in the surroundings of Soma and Balıkesir can be divided into the İzmir-Ankara Zone and the Pontide Belt (Sakarya Zone), and they propose a new probable plate margin approximately trending N-S.

According to the paleontological studies of Takashi & Jux (1991) the age of the Soma lignite-bearing sequence is the Miocene.

Paton (1992) pointed out that the geomorphologic patterns of western Turkey were predominantly controlled by active normal faults. On the footwall basement rocks, drainage patterns are developed perpendicular and obliquely and have been cut and moved laterally by the active normal faults. In these areas, the large alluvial fans were formed.

Oral, Reilinger, Toksöz, Barka & Kınık (1983) noted that western Turkey moves southwestward relative to the Eurasian plate. The authors pointed out that the numerical models, showing the deformation of western Turkey, cannot be accounted for by only collusion processes.

According to İnci (1994) the lignite-bearing Neogene sequence in the Soma district was formed by two megasequences, which were known as the Soma formation and Deniş formation, and the Deniş megasequence overlied the Soma megasequence by a depositional unconformity. The author indicated that these sequences were occurred by fluvial/alluvial, shallow lacustrine and lake-margin mud flat environments having similarity to each other.

İnci (1995) noted that the Neogene rock units in the study area were formed by upward-fining two cycles in Miocene and the basal cycle at the bottom deposited in alluvial, lacustrine and swamp lake conditions. The upper cycle developed in alluvial-lacustrine depositional system was formed contemporaneously with calc-alkaline and basaltic volcanism of the Western Anatolia. According to the author, the basin is subdivided into two megasegments by extensional faults and hanging wall segment is overlain by thick Quaternary deposits.

Cohen, Dart, Akyüz & Barka (1995) pointed out that the development of the Büyük Menderes and Gediz grabens of western Turkey during the Miocene throughout the recent extension in the Aegean region. Field evidence shows that extension was primarily accommodated with tilted fault blocks 0.2-0.8 km in width, bounded by planar faults that were modified by antithetic faulting.

Barka (1996) indicated that the Anatolian region was one of the most seismically active parts of Alp-Himalayan system. In Western Anatolia, E-W and WNW-ESE trending rifts and the related normal faults are the dominant Neotectonic features and there are many limestone fault scarps with 50 m in height along the normal faults.

According to İnci (1998), the lignite-bearing Deniş formation or megasequence was effected from syn-sedimentary explosive volcanism and developed volcanoclastic alluvial fans or aprons and volcanic alluvial plain deposits in the formation.

McClusky, Balassanian, Barka, Demir, Ergintav, Georgiev, Gurkan, Hamburger, Hurst, Kahle, Kastens, Kekelidze, King, Kotzev, Lenk, Mahmoud, Mishin, Nadariya, Ouzounis, Paradissis, Peter, Prilepin, Reilinger, Sanli, Seeger, Tealeb, Toksöz and Veis (2000) claimed that the central and southern Aegean was characterized by coherent motion (internal deformation of <2 mm/yr) toward the SW at 30 ± 1 mm/yr relative to Eurasia. The authors indicated that the stations in the SE Aegean deviated significantly from the overall motion of the southern Aegean, showing increasing velocities toward the trench and reaching 10 ± 1 mm/yr relative to the southern Aegean as a whole

1.3 OBJECTIVES

The purpose of this study is to obtain the Plio-Quaternary sequence in the Soma district and to investigate the relationship between this sequence and the fault zone that restrict the grabens and expose the geometry of sequence. This study will contribute to the knowledge about the Western Anatolian Graben Complex.

1.4 METHODS

The study area has been investigated by taking into consideration the Plio-Quaternary deposits and the tectonic lines. The rocks that were overlain by Plio-Quaternary deposits called as the basement rocks in the study arae and the information about them were largely obtained from the previous studies.

An area about 500 km^2 was mapped geologically in 1/25.000 scale. Some places that required to study in detail, were mapped in 1/10.000 or 1/5.000 scales.

Plio-Quaternary deposits have been changed into soil cover due to their low consolidation and these deposits were largely covered by urban areas. Therefore the data has been collected from Plio-Quaternary outcops on the road-cuts, the railway-cuts and the valley bases.

The data for kinematic analysis were collected from well outcropped fault planes and the drawings were prepared in computer.

The textural features of the carbonate rocks were investigated with a polarized microscope.

CHAPTER TWO
GEOLOGICAL SETTING

The Soma coal basin forms a considerable part of the study area and is preserved in a small (approximately 150 square kilometers) intramontane setting (Figure 2.1). This basin is located within the Western Anatolian extensional province (WAEP) (Şengör et al., 1985; Şengör, 1987) characterized by numerous E-W grabens and NNE- trending basins. It is bounded by the Hellenic and Cyprus arcs (HA, CA) in the south and the dextral North Anatolian Fault zone (NAF) to the north (Figure 2.2) (McKenzie, 1972; Le Pichôn & Angelier, 1979; Koçyiğit, 1984; Westaway, 1990; McKenzie & Yılmaz, 1991).

Western Anatolia represents intracontinental extensional type neotectonic regime and the features that are related to this regime. The main structures, modify this region tectonically, are grabens of Edremit, Bakırçay, Gediz, Küçük Menderes, Büyük Menderes and Gökova and the horsts between them. Plio-Quaternary deposits were accumulated in the grabens of Western Anatolia Graben Complex.

Soma basin is surrounded in north by the pre-Neogene rocks of the West Pontide Orogenic Belt, that was called as the Sakarya Zone by Okay & Siyako (1991) in the north. The basin developed on the clastic and carbonate rocks of İzmir-Ankara Zone in the south. Soma basin is a characteristic intramontane basin and developed on the morphotectonic structure that modified by the collision of Anatolia and Sakarya continents in the Late Eocene-Early Miocene period (İnci, 1998a).

The basin formation probably started in the Late-Early Miocene (Takashi & Jux, 1991; İnci, 1998a) and the Neogene sediments from the Early to the Middle Miocene deposited on the NE-trending palaeovalleys (Brinkmann et al., 1970) which were probably fault-controlled developing over the Mesozoic carbonate rocks.

It is commonly claimed that the N-trending basins developed by N-S compression during the Late Paleogene and were filled by the Early Miocene sediments. It is mentioned that these basins were cut by W-E trending grabens which are Tortonian (Late Miocene) and younger in age. It is also claimed that these different-trending basins/grabens has continued to be developed by the effect of N-S extensional regime.

Seyitoğlu & Scott (1991) claimed that the latest Oligocene-Early Miocene extensional tectonics and claimed that the beginning of Ealy Miocene basin formation are related to thinning and spreading of the crust (orogenic collapse model) just after finish shortening related to latest Eocene collision.

Volcanism in the region continued from the Eocene to the Plio-Quaternary in calc-alkaline character and volcanic-originated alluvial sediments deposited in the Soma region (for example; Deniş formation). The products of this volcanism formed volcaniclastic fan deposits that well observed along the northern margin of the basin in the north of Soma and extended between Bergama and Gelenbe (İnci, 1998b).

Neogene sediments in Soma show an extensional tectonic regime that displaying NW-SE, NE-SW and N-S extensional directions which probably have been active in the Early Miocene, Pliocene and Quaternary-present day respectively. The latest extensional tectonic regime was the cause of the formation of W-E trending graben-like basins as Bakırçay Graben. This graben was filled by the Quaternary deposits.

It is claimed that the Late Miocene and younger extensional tectonic regime especially in Western Turkey are related to the W-E trending Bakırçay, Gediz, Küçük and Büyük Menderes grabens which are due to the tectonic escape model. In this model, the Eurasian and Arabian plates were collided across the Bitlis Suture in southeastern Turkey in the Middle Miocene (Şengör et al., 1985). For this reason, Anatolian continent moved into the west along the sinistral strike-slip Eastern Anatolia Fault and right-handed strike-slip Northern Anatolia Fault. Therefore the formation of these grabens is related to N-S extensional regime.

Another model for formation of these grabens is back-arc spreading model. This model explains that the extensional regimes is related to the subduction in the Hellenic arc. The migration of trench system toward the south caused an extensional regime in the present day (Mercier et al., 1989).

As a conclusion, the begining of neotectonism (transition from compressional to extensional regime) in Western Turkey is acceptable as being the Tortonian accroding to these tectonic models.

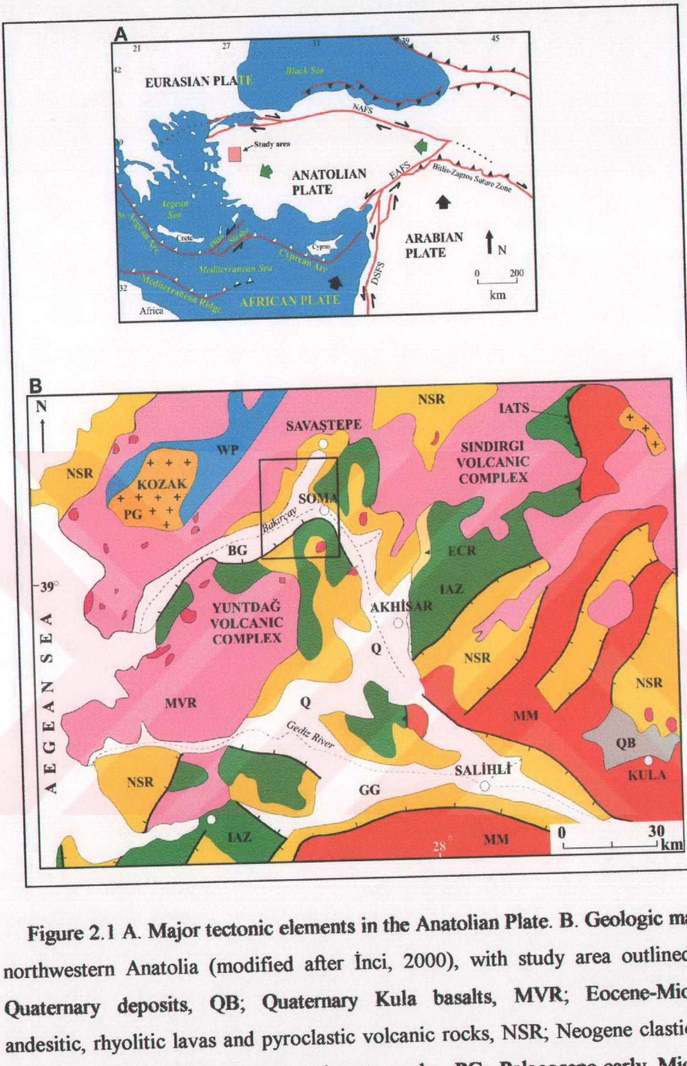


Figure 2.1 A. Major tectonic elements in the Anatolian Plate. B. Geologic map of northwestern Anatolia (modified after İnci, 2000), with study area outlined. Q; Quaternary deposits, QB; Quaternary Kula basalts, MVR; Eocene-Miocene andesitic, rhyolitic lavas and pyroclastic volcanic rocks, NSR; Neogene clastic and carbonate rocks, ECR; Eocene carbonate rocks, PG; Palaeocene-early Miocene granodiorites, IAZ; siliciclastic and carbonate rocks of the Izmir-Ankara zone, WP;Western Pontides, MM; Metamorphic rocks of the Menderes massif, IATS; Izmir-Ankara thrust suture, BG; Bakırçay graben, GG; Gediz graben.

CHAPTER THREE
STRATIGRAHY

3.1 BASEMENT ROCKS

The basement rocks in the study area are composed of the clastic and carbonate rocks of Cretaceous-Paleocene İzmir-Ankara Zone and the lignite-bearing Miocene Soma and Deniş formations (Fig. 3.1). The graben formation has been developed on these rocks.

3.1.1 Pre-Miocene Basement Rocks

3.1.1.1 İzmir-Ankara Zone

This zone that covers extensive areas between Balıkesir and İzmir are made of the Mesozoic flysch-type siliciclastic and carbonate rocks of the İzmir-Ankara zone described by some earlier workers (e.g., Brinkmann, 1972, Güvenç & Konuk, 1981; Şengör et al., 1985; Erdoğan 1990; Okay & Siyako, 1991).

3.1.1.1.1 Clastic Rocks

The matrix consists mainly of grayish-brown colored thin grained sandstone, poor siliceous shale, mudstone and turbiditic conglomerates. It represents the characteristics of flysch facies in lateral and vertical directions and strongly deformed. Submarine mafic volcanic rocks are observed as transitive with flysch matrix. Primary bed structures of the rock units are broken down with tectonism. The age of flysch is Maestrihtien-Paleocene.

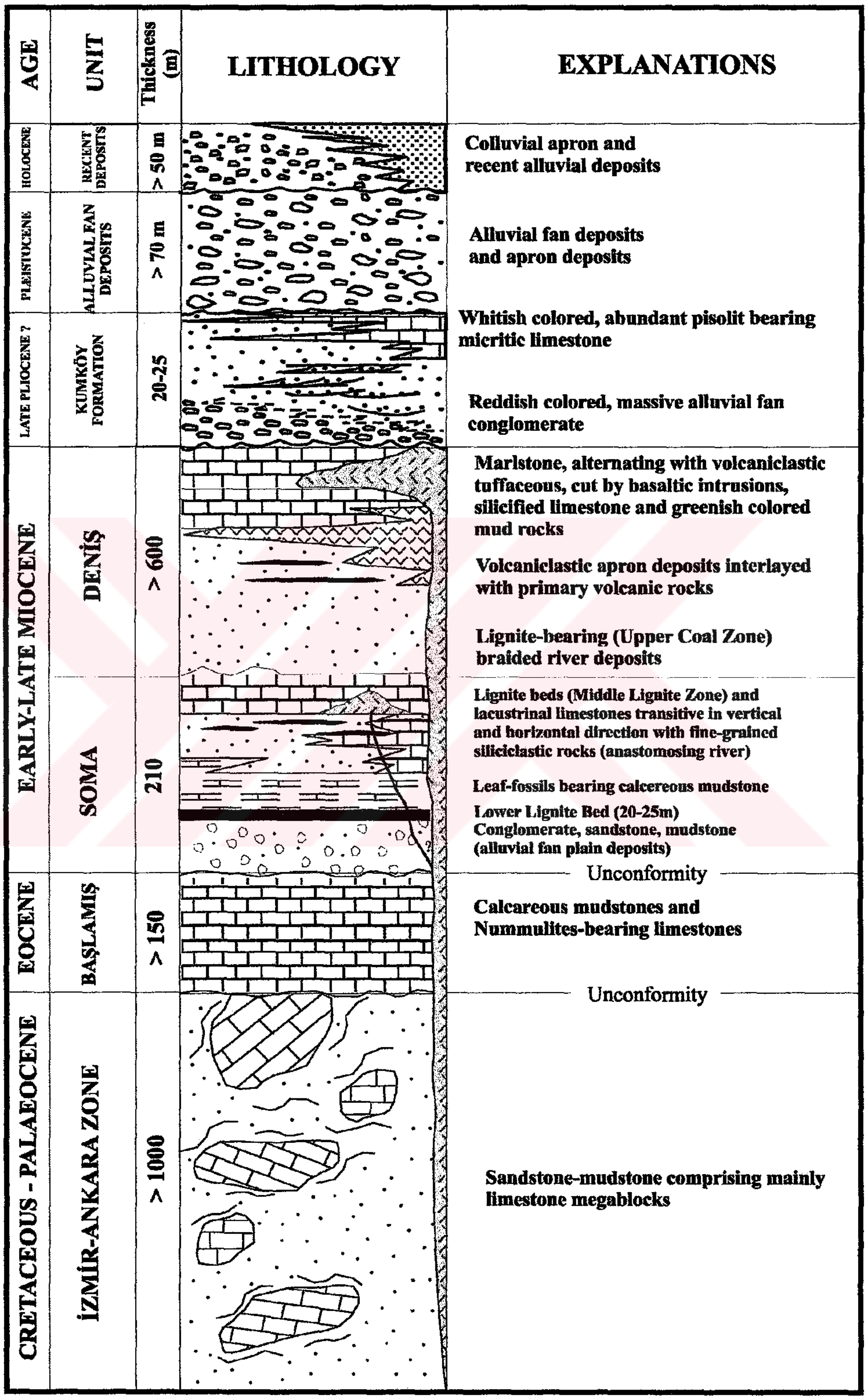


Figure 3.1 Generalized lithostratigraphic columnar section of the basement rocks in the study area (modified from İnci 1998a).

3.1.1.1.2 Carbonate Rocks

Huge Mesozoic limestone blocks are observed dominantly in the sandy flysch. The size of platform-type Mesozoic limestones changes from blocky to massive that reaches several kilometers in the flysch matrix. The most of these limestone blocks are Triassic in age. Some of them represent a sequence that interfered with unconformities from the Triassic to the Late Cretaceous (Okay and Siyako, 1991). Radiolarite and ultramafic rock blocks are rarely found in the flysch matrix of Şifa Dağı, the northern Soma.

The characteristics of these rocks are similar to the rocks in İzmir and surroundings. The Miocene coal-bearing sequence in the study area unconformably overlies the clastic and carbonate rocks of the İzmir-Ankara Zone.

3.1.1.2 Başlamış Formation

The sequence which is approximately 400 m thick and the Lower-Middle Eocene in age is firstly named as the Başlamış Formation by Akdeniz (1980). This sequence is underlain unconformably by ophiolitic rocks İzmir-Ankara Zone in the southeastern Akhisar and is overlain by clastic sedimentary rocks which are probably the Oligocene in age. Önoğlu & Göktaş (2000) described again the similar rock levels and gave the Middle Cuisian - Early Lutetian (Lower Eocene - Middle Eocene) in age.

Başlamış Formation cropped out in a narrow area in the east of the study area. It consists of calcareous mudstones and Nummulites-bearing limestones. These rock units represent the upper level of formation. The formation unconformably overlies the rocks of İzmir-Ankara Zone.

3.1.2 Miocene Basement Rocks

3.1.2.1 Soma Formation

Soma Formation rests unconformably on the clastic and carbonate rocks of İzmir-Ankara Zone. The formation is approximately 325 m in thick and is divided into three informal rock units (Nebert, 1978) (Fig. 3.1).

At the bottom, the Soma Formation is represented by conglomerates, sandstones, mudstones, limestones and the Lower Lignite seam (average 20 m) which was deposited in perennial lake-fan delta system (İnci, 2002). The approximate thickness of this facies assemblage is 50-80 m.

Massive and/or thick-bedded, abundant leaf-fossil bearing calcareous mudstones overlie the Lower Lignite seam. Calcareous limestones are transitive upward with fresh-water limestones and anastomosing river deposits which are transitive with these limestones and dominantly composed of greenish colored thin- grained sandstone-mudstones. The thickness of lignite beds changes from 0.5 to 2 m and form the Middle Lignite sequence. The environments which are represented by these facies units begin with thin sandy flood plain continue with coal-forming autochthon peat mires and end with small lacustrines/water heaps bearing anastomosing river system (İnci, 1998).

The NE-SW trending Soma Formation is observed along a zone that is approximately 3-4 km wide and 30 km long. The limestone levels of the formation overlaps on the rocks of İzmir-Ankara Zone. Strike-slip and dip-slip reverse faults and post/syn-sedimentary small-scale faultings are seldom observed in the Soma Formation.

3.1.2.2 Deniş Formation

Deniş Formation is composed of coarse-and fine-grained clastic rocks that were deposited in braided river system, the Upper Lignite zone, volcaniclastic apron deposits and shallow lake carbonate rocks from bottom to top (İnci, 1998b and 2002) (Fig. 3.1).

Braided river deposits are made of the alternation of greyish/reddish colored, cross-bedded channel conglomerates, greenish coarse to fine-grained planar, cross-bedded and parallel/cross laminated channel sandstones and flood plain/swamp mudstones and lignites. Volcaniclastic apron deposits consist of blocky volcaniclastic conglomerates (proximal and medial apron) which were deposited as interlaced with volcanic rocks and/or piroclastic volcanites in the northeast of the basin and volcaniclastic tuffaceous sanstones which are transitional in lateral and vertical direction in wide interval to the inner basin sedimentary rocks.

The sequence at the top is made of silisiclastic mud rocks, silicaeous limestones and calcareous mustones which deposited in shallow lacustrines and lake-margin carbonate plains. This carbonate sequence is transitional with tuffaceous sandstones. It is common in the surroundings of Soma. The total thickness of Deniş Formation is 600 m.

The flood plain sandstones of Deniş Formation overlie conformably the coal-bearing limestone beds which are the toppest rock unit of the Soma Formation. Red colored channel deposits of Deniş Formation were developed on the Mesozoic basement. Therefore, there is a depositional unconformity between these two units.

Post-depositional asymmetric folding and syn-sedimentary rock deformation in Deniş Formation are possible. Brecciation in beds, slip and slump structures are common in especially tuffaceous sandstones and carbonate rocks at the toppest level. Aaymmetric folds which were originated as structural deformations, were formed during the later period.

3.2 PLIO-QUATERNARY DEPOSITS

Miocene and Mesozoic rock units were deformed by the post-Miocene extensional tectonic regime and caused to the formations of the NE-trending Bakırçay (Bergama) graben and the WSW-trending Soma graben. The sediments and rock units that belong to the post-Miocene neotectonic period filled of these grabens.

3.2.1 Kumköy Formation

The total thickness of Kumköy Formation is between 200-250 m and it is overlain by the Quaternary deposits unconformably. Soma and Bakırçay grabens were filled by these deposits.

Kumköy Formation is generally represented by red-brown and greenish colored clastic rocks and whitisih colored carbonat rocks (Fig. 3.2). Typical sections of this unit are well observed in the outcrops at the west of Kumköy and along the Soma-Savaştepe highway (Fig. 3.3).

This unit rests unconformably on the Deniş Formation. The lower contact relationship of the unit with the older units is observed in Yağcılı village with in the Soma graben. The red colored channel facies conglomerates overlie the volcaniclastic apron deposits of the Deniş Formation by erosional contact.

The age of Kumköy Formation was accepted as the Pleistocene by Nebert (1978). Yeşilyurt and Taner (1999) gave the Late Pliocene (Romanian) age for this formation depending on the characteristic fauna of the formation (*Thedoxus fluviatilis, Pseudamnicola (A.) cf.kochi, Melanopsis (M.) alutensis, Melanopsis (M.) sandbergeri rumana, Melanopsis (L.) onusta, Melanopsis (C.) souberiani, Melanopsis (C.) cf.lanceolata, Melanopsis (C.) hybostoma amaradica, Melanoides (M.) curvicosta, Lymnaea (R.) cf.obtusissima, Gyraulus (G.) ignoratus*). The age of formation was also accepted as the Late Pliocene in this study.

Kumköy Formation was divided into five different facies and/or lithofacies in respect of grain size, sedimentary structure/fabric and composition features and named according to Miall (1978). These lithofacies were groupped as to their bedding features in the sequence, geometry and size. These facies associations are recpectively alluvial fan, river channel belt, proximal/distal flood plain and lacustrine.

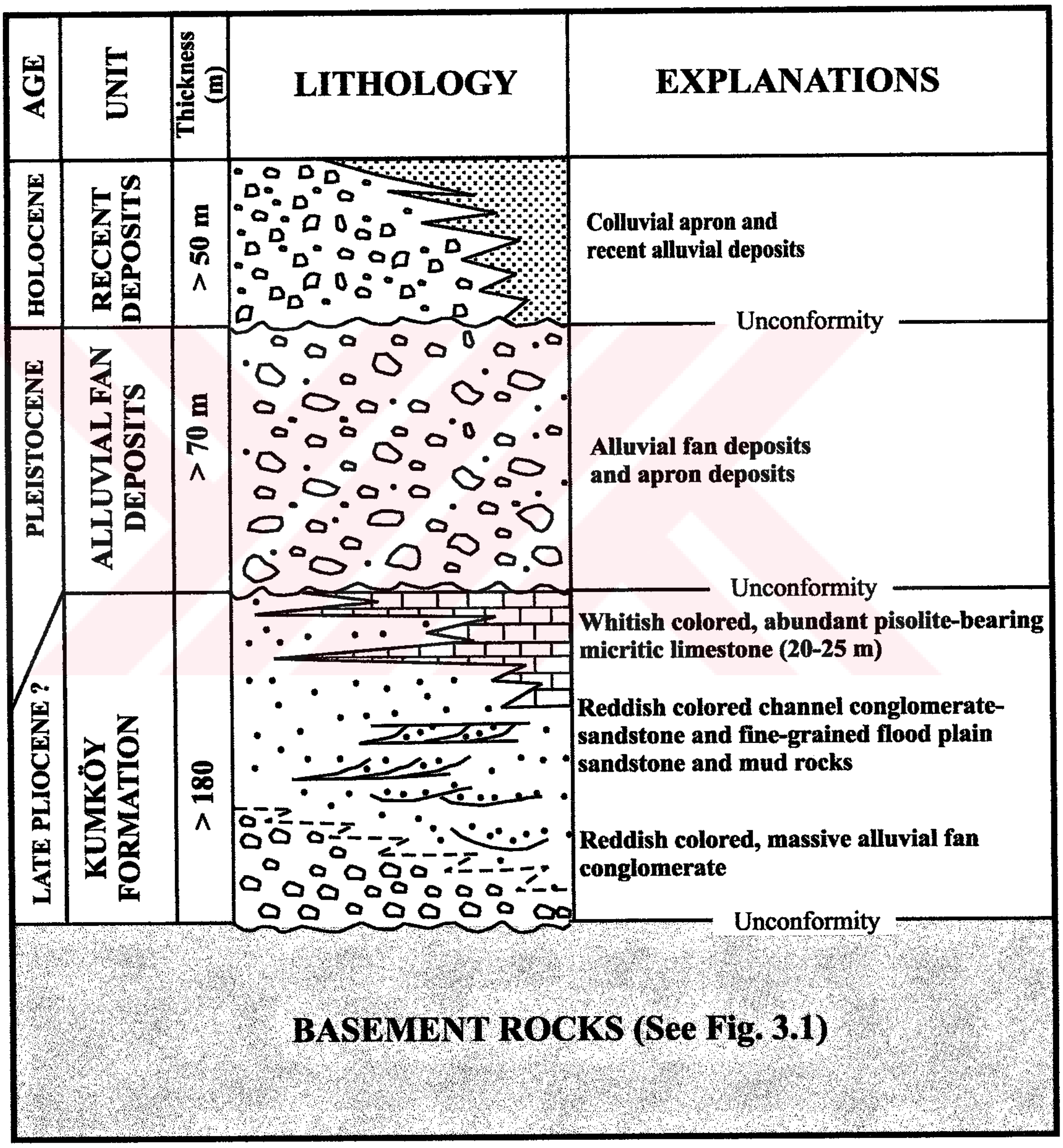


Figure 3.2 Generalized lithostratigraphic columnar section of the Plio-Quaternary deposits in the study area.

3.2.2 Alluvial Fan Deposits

Alluvial fan deposits is observed along the Soma and Kırkağaç grabens. These deposits are covered by recent colluvial deposits and represent fan morphology. It comprises gravels originated from older deposits (Fig. 3.4).

Figure 3.3 Greenish-colored clastics of Kumköy formation is observed in the west of Kumköy along the Soma-Savaştepe highway.

In the study area, there are a lot of large and small-scale alluvial fans represent these deposits in Soma. The most important one of these fans is firstly named as the Soma alluvial fan in this study.

Alluvial fan deposits are composed of matrix-supported conglomerates, planar cross-bedded conglomerates and pure sandstones. The gravel components of these deposits were originated from the basement rocks and the Plio-Quaternary deposits.

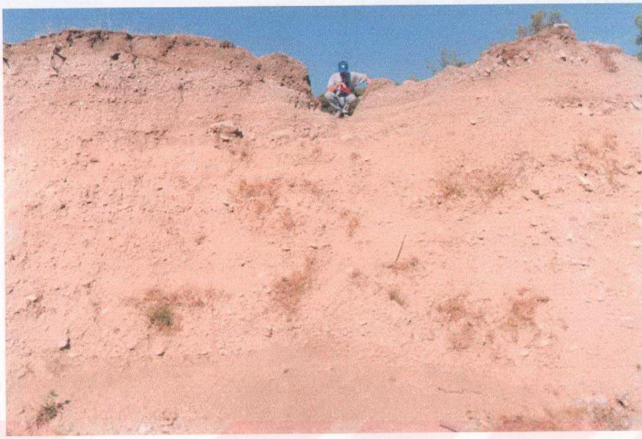


Figure 3.4 Representative alluvial fan outcrop observed at the Kırkağaç dump area.

3.2.3 Recent Deposits

The main river of the region is Bakırçay River in the Soma graben. Bakırçay River originates from the surface waters from the supply area in the north of Gelenbe and flows towards the south, and it is known there as Gelenbe River. It turns into the west in the north of İlyaslar village and it is known as Bakırçay River in the Kırkağaç graben. Bakırçay River passes through the Kırkağaç graben in E-W direction and flows approximately to the north in the east of Kırkağaç. The river runs in the Soma graben by change its direction to the west in Taşlıboğaz. Bakırçay River is fed by Yağcılı River flowing to the southwest and flows in the Bergama graben.

Bakırçay River and Yağcılı River are meandered flows. The width of the rivers is 50-250 m. Cross-bedded channel conglomerate and sandstones in the river channel are characteristic for meandered rivers (Fig. 3.5). Thin grained flood deposits, accumulated in the nearby places of river beds, forms the Recent Alluvial Deposits. Flood sediments form narrow flood plains in the Soma graben.

The thickness of Quaternary deposits that is controlled by an active fault in the Soma graben is variable according to DSİ borehole data. These deposits are composed of silty sand (12 m), pebble (2 m), silty sand (8 m), silty pebble (20 m) and clayey pebble (108 m) respectively as being observed in borehole number 119 (App. 4).

Borehole and field data show that the thickness of recent alluvial deposits varies from 50 m to 250 m.

Figure 3.5 Cross-bedded channel conglomerate and sandstones represent meandering river flow.

CHAPTER FOUR
SEDIMENTARY FACIES OF THE PLIO-QUATERNARY DEPOSITS

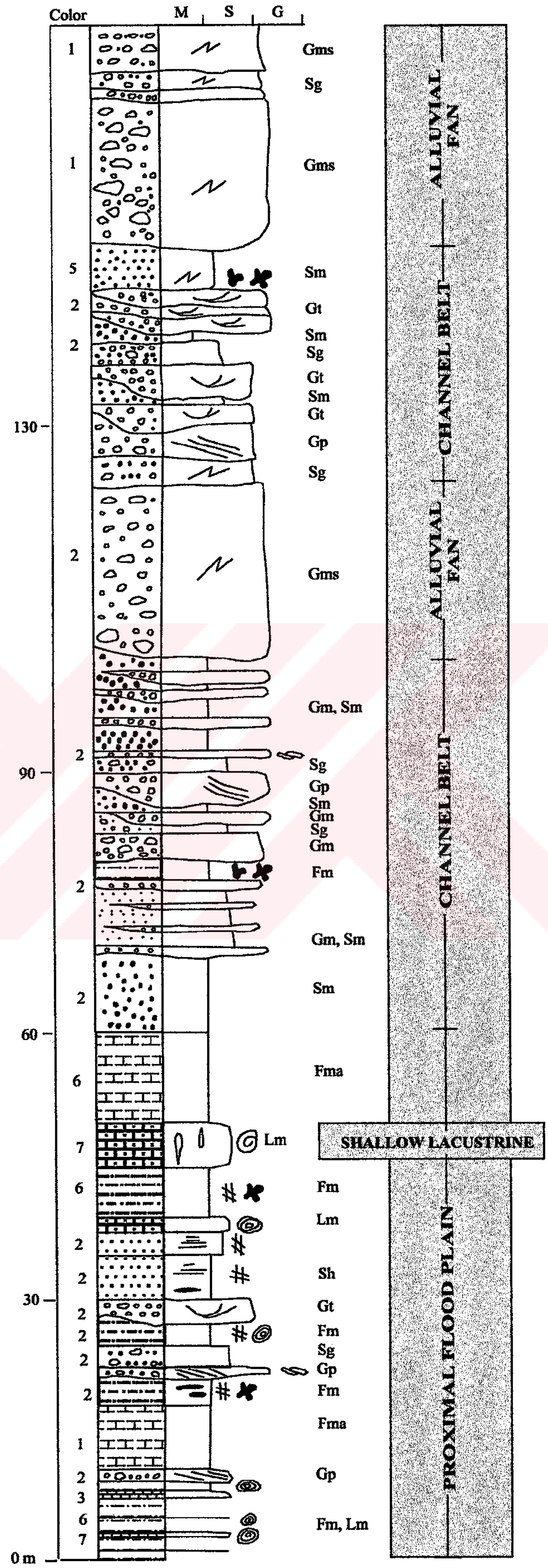
The sedimentary facies classification used in this study is based on types of individual beds, primary sedimentary structures and grain sizes. Detail descriptions of the sedimentary features and paleoenvironmental interpretations of the facies are given in Appendix 3 and Figure 4.14 shows the legend used in all drawings. The representative sedimentological details for each facies identified from the outcrops and the coal drill holes are shown in the related sections.

The facies description of Plio-Quaternary deposits in the study area was firstly made in this study.

4.1 Facies of the Kumköy Formation

Kumköy formation is divided into five major facies associations. They are named as "alluvial fan facies association", "river channel-belt facies association", "proximal flood-plain facies association", "distal flood-plain facies association" and "lacustrine facies association". Detailed facies characteristics were determined from the limited outcrops and measured sections (Figs. 4.1A, B, C and D).

A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2
Sg
90
Gp
Sm
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Sg
Gm
Fm
2
Gm, Sm
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Sm
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Fm
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Sh
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2
Fm
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1
2
Gp
3
6
Fm, Lm
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CHANNEL BELT
ALLUVIAL FAN
CHANNEL BELT
SHALLOW LACUSTRINE
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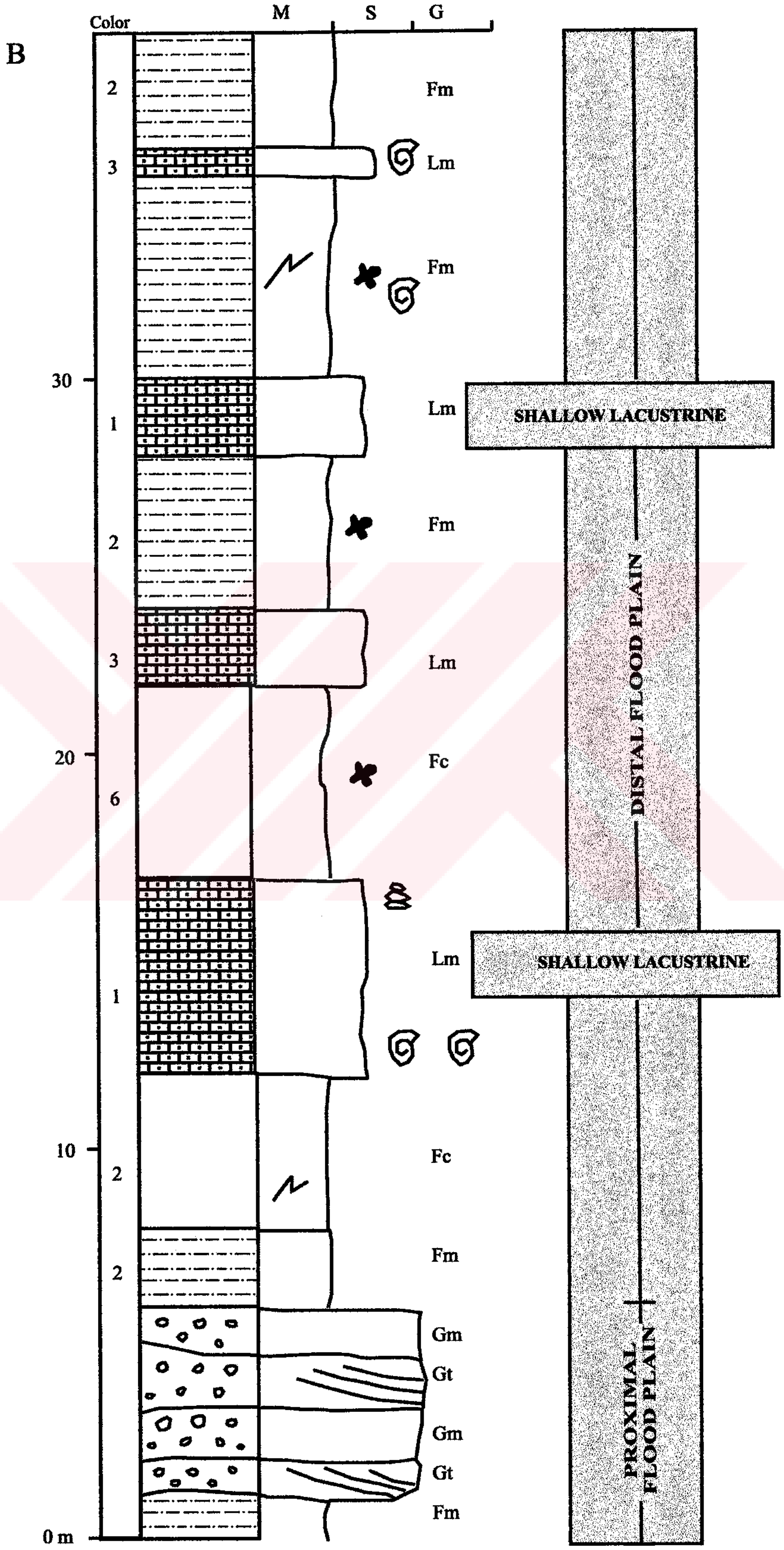
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Fc
Fm
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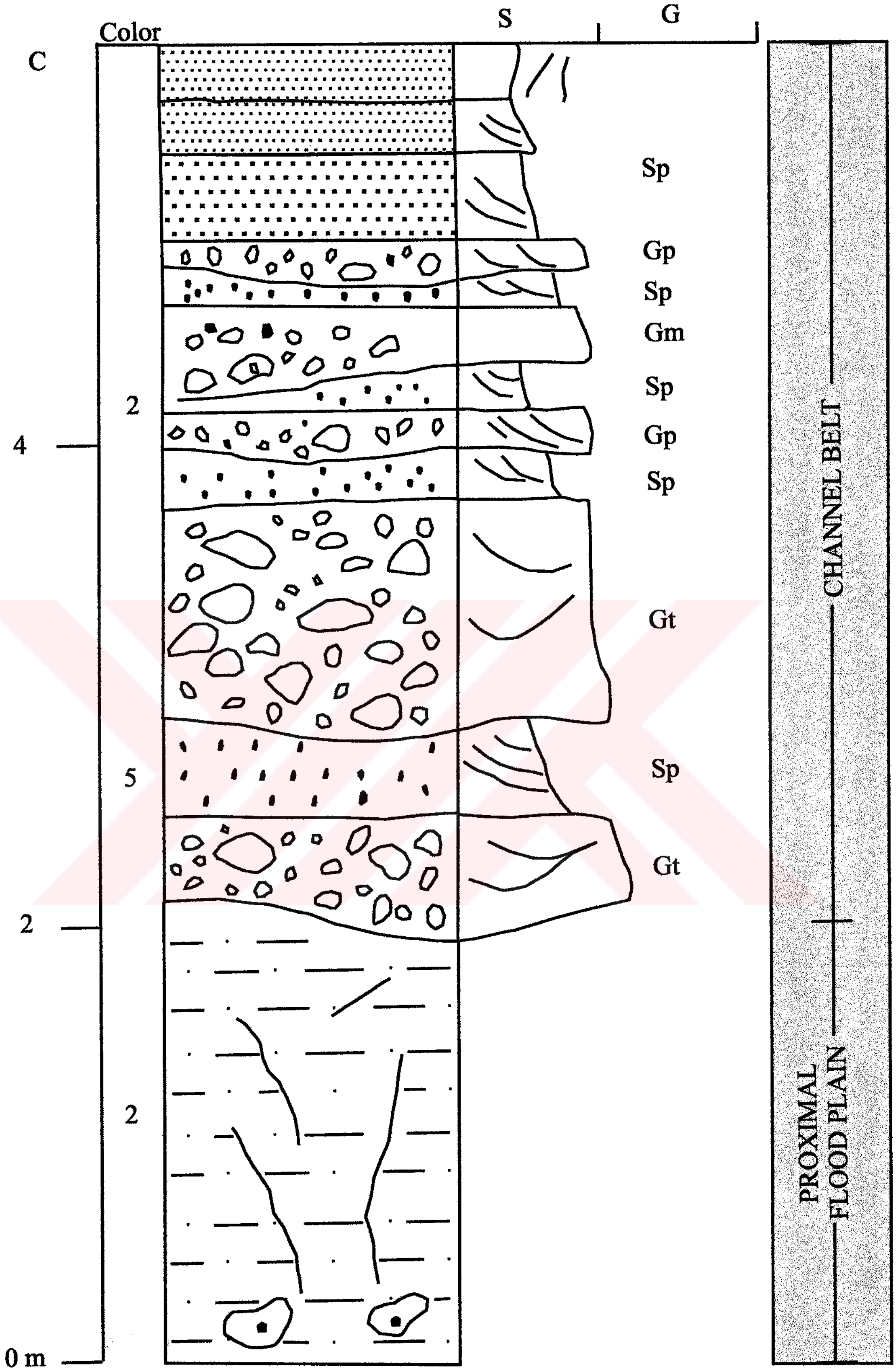
SHALLOW LACUSTRINE
DISTAL FLOOD PLAIN
SHALLOW LACUSTRINE
PROXIMAL FLOOD PLAIN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CHANNEL BELT
PROXIMAL FLOOD PLAIN

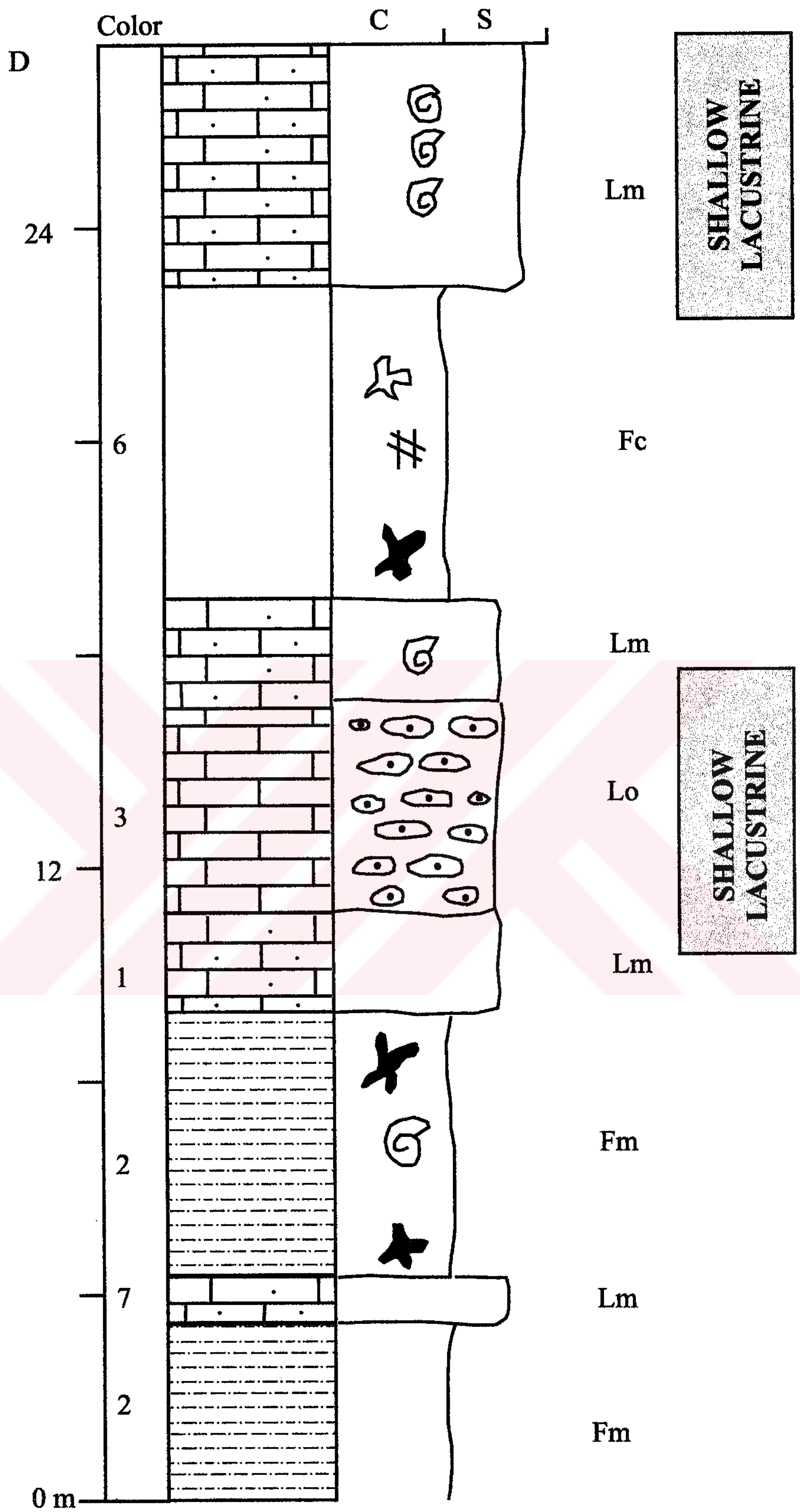


Figure 4.1 The measured sections and detailed facies characteristics of Kumköy Formation (A, B, C and D).

4.1.1 Alluvial Fan Facies Association

4.1.1.1 Description

This group is mainly made of matrix-supported conglomerates (Gms) and gravelly sandstones (Sg) (Fig. 4.1A).

Conglomerates are reddish colored, non stratified and thick bedded, low sorted and thin gravel-coarse sand matrix supported. The size of grains ranged between 1 and 20 cm and the average is 6 cm. Mainly gravel components are made of limestone and greenish sandtone which were originated from the İzmir-Ankara Zone and volcanic rocks and limestones. Some of gravels were eroded from the Miocene sequence lower down in the sequence. The measurable total thickness of this facies association in the Soma graben is approximately 20 m.

Reddish-brownish colored, thick bedded gravelly sandstone (Sg) facies forms the base of the graben and its thickness is approximately 15 m and less.

4.1.1.2 Interpretation

These deposits were accumulated by slow flowing sediment debris which were built up over inclined slopes. These kinds of sediment debris and mass flows are formed in alluvial fans which occur at front-slopes and fault-slopes (Nemec & Postma, 1993; Blikra and Nemec, 1998; Blair, 1999a, b). The sudden change of conglomerates to gravelly sandstones (Sg) in lateral/vertical direction may point out that the conglomerates were occasionally reworked by flood flows which mean excessive sediment loaded (Smith, 1986).

4.1.2 River Channel-Belt Facies Association

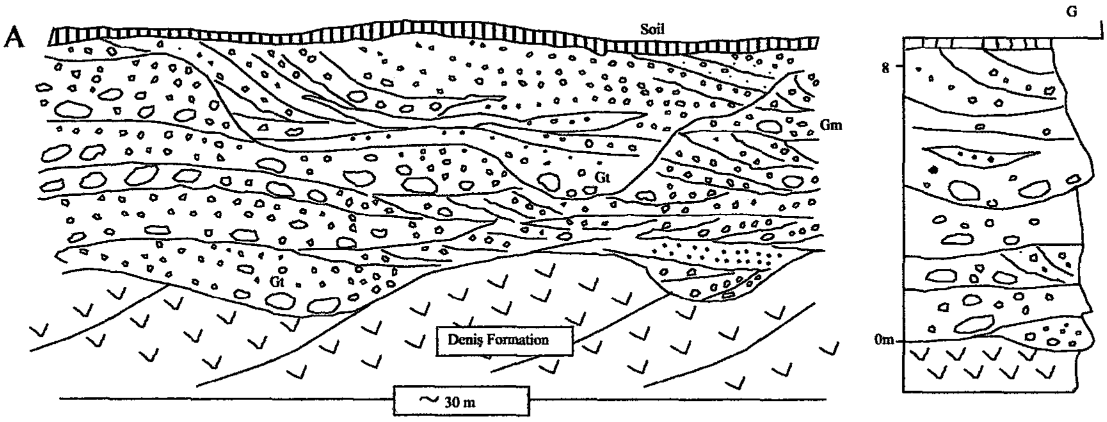
4.1.2.1 Description

This facies association is mainly represented by cross-bedded conglomerate and sandstone lithofacies.

Conglomerate lithofacies comprises trough, planar cross-bedded conglomerates (Gt and Gp) and coarse-grained flat-bedded imbricated conglomerates (Figs. 4.1 A, B and C). Flat-bedded conglomerates is 1-2 m in thickness, their base is flat and/or superficially eroded. All the conglomerate facies are grain supported, medium in gravel size and sorted medium-finely. Large-scale trough and planar cross-bedded conglomerate (Gt) facies are mostly wedge-shaped and their bases were eroded. The thicknesses of conglomerate facies change between 1 and 5 m.

Many erosional river channels which are represented by reddish colored conglomerate lithofacies of this facies association, were observed in a clay mine at 2 km southwest of the Yağcılı village (Fig. 4.2). The width of river channel is 30 m and its depth is approximately 10 m. Channel formation developed on thin-grained volcaniclastic apron deposits (tuffaceous sandstones) of Deniş Formation that changed into clay. Channel base is deeply eroded.

At the lowest part, conglomerates that were derived from the limestones of İzmir-Ankara Zone, were observed and their grain sizes are 28 cm and intermediatelly rounded. Average grain size is 3-5 cm. Channel interior is composed of dominantly trough cross-bedded conglomerates (Gt) and rarely flat-bedded thin-grained conglomerates (Gm). Thin sandstone lenses are possible in the channel. The unconformity relationship between the channel facies and the Miocene basement rocks is similarly observed along the Soma-Savaştepe highway outcrops. Massive conglomerate and sandstone facies (Gm, Sm) rest unconformably on the Miocene sequence with an erosional contact (Fig. 4.2).



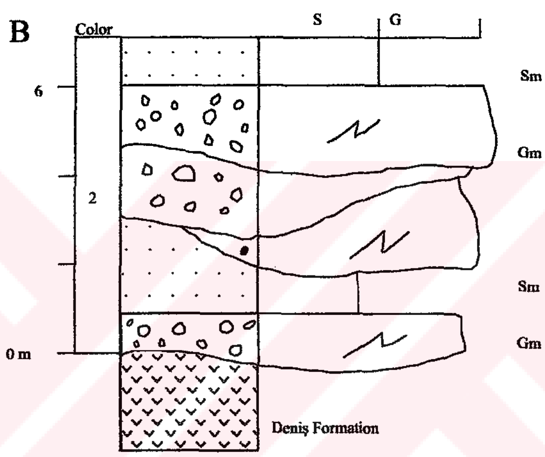


Figure 4.2 The facies characteristics of Kumköy formation in Yağcılı area and the contact relationship between Kumköy Formation (Late Pliocene ?) and Deniş Formation (Late Miocene).

Light reddish-brownish colored and flat bedded, coarse-thin grained sandstones (Sm) are generally accompanied by conglomerate facies. Sandstone lithofacies exhibit an erosional upper contact with conglomerates and comprise thin (0,5 - 1 m) channel-shaped conglomerate lenses (Figs. 4.1A and 4.2).

4.1.2.2 Interpretation

The conglomerates and sandstones in this facies were probably accumulated in braided river channels. Coarse grained flat bedded (Gm) conglomerates may be interpreted as longitudinal conglomerate bars of this braided channel. Cross-bedded conglomerates may be the main facies of channel fillings or transversal conglomerate bars. Massive and coarse-grained gravelly sandstone facies (Sm) accumulated in shallow channels along the sides of main channel after big floods (De Celles et al., 1991; Collinson, 1996).

4.1.3 Proximal Flood-plain Facies Association

4.1.3.1 Description

The dominant lithofacies of this association is flat bedded sandstones (Sh). Cross bedded conglomerates (Gt and Gp), thick bedded mudstones (Fm), claystones (Fc), calcereous mudstones (Fma), sandy limestones (Lm) form the secondary facies (Figs. 4.1A, B and C).

Red-light greenish colored, flat-bedded and laminated thin-grained sandstones (Sh) are low consolidated and comprise abundat carbonate nodules and mica. This facies is common in the south outside of the study area.

Cross-bedded channel conglomerates (Gt and Gp) are rarely observed and 0.5- 2 m in thickness. Mudstones, claystone and calcereous mudstones (Fm, Fc, Fma) are reddish and greenish colored and thick bedded. They are characteristic lattice shaped and lensoidal and include amorphous and elliptical (1 - 5 cm) pisolitic carbonat nodules. Reddish spotting is possible in greenish colored mudstones. Limestones (Lm) are whitish colored, thick-bedded and micritic. Scattered gastropod shells, pisoliticic nodules and dissolved voids that are perpendicular to bedding are common in limestones (Fig. 4.1D).

4.1.3.2 Interpretation

Sandstones (Sh) that are dominant lithofacies of this association with finer facies (Fm, Fc and Fma), which were mixed shallow river channels (Gt and Gp facies) were accumulated in proximal flood plain environment. Amorphous, lense and nodule shaped carbonate nodules which are observed in sandstone and mudstone facies and spotted green mudstones/claystones may be interpreted as flood plains where pedogenic conditions (underground water effected terrestrial conditions) are dominant in it (Kraus, 1997; Smith, 1990). Limestones (Lm) are accompanied with mudstone and claystone facies, small and shallow lacustrines and/or water holes which are near channel facies in flood plain. Dissolved voids, pisolitic and onkolitic carbonate nodules in limestones indicate that the environment was fed by carbonate-rich waters and occasionally dried and carbonatization in meteoric zone (Tandon & Narayan, 1981; Wright & Platt, 1995; Braithwaite, 1983; Armenteros & Daley, 1998; Tandon & Andrews, 2001). Small-scale cross-bedded mudstones in the facies may be interpreted as flood channel deposits of plain sediments caused by excavations of cross-flows.

4.1.4 Distal Flood-plain Facies Association

4.1.4.1 Description

This facies association is represented by mudstones and claystones without channel facies (Fig. 4.1B).

The most characteristic structures are light reddish-brownish color, thick bedding and amorph carbonate nodules. Mudstones consume abundat gastropod.

4.1.4.2 Interpretation

The alternation of mudstone and claystone represents the accumulation in the distal parts of flood plain. Thick bedding of the mudstones and claystones points out suspended load sedimentation from flood waters which were accreted in lower levels and distal parts. Calcereous nodules and mottling indicate drying of flood plain and probably early diagenetic calcerization in the environment. Early diagenetic calcerizations were widely recorded in this kind of river flood plains and the edge plains of shallow lacustrine (Smith, 1990; Armenteros & Daley, 1998; Tandon et al., 1998; Tandon and Andrews, 2001).

4.1.5 Lacustrine Carbonate Facies Association

4.1.5.1 Description

This facies association consists of sandy and pisolit-bearing limestones (Lm and Lo) (Fig. 4.1D). Sandy limestones are beige colored, thick-thin bedded, micritic textured and comprise abundant gastropod fossils. Pisolit-bearing micritic limestones are white colored, thick-thin bedded and include abondant dissolved voids. Both of limestone facies are transitive with flood plain deposits. Limestones are transgressive on the Miocene rock units. Pisolit grains are 2-22 cm in size, elliptical and sub-spherical shaped (Fig. 4.3). The pisolit grains generally comprise limestone core and whitish and brownish colored carbonate laminations which wrapped around this core. Small scale synsedimentary faultings are common in limestone beds.

4.1.5.2 Interpretation

Limestones deposited in small and shallow lacustrines that developed on the river flood plain. Pisolitic carbonate nodules and dissolved voids point out that lacustrine was dried and carbonates suffered diagenesis under the subarial conditions. The lateral and vertical stratigraphical relationship of limestones with flood plain deposits indicates that these lakes were developed depending on river floods. Pisolitic carbonate nodules (Fig. 4.4) may be formed in water heaps and shallow lacustrines which were fed by carbonate-rich spring waters (Peryt, 1983; Tandon & Narayan, 1981).

Figure 4.3 Pisolit grains are elliptical and sub-spherical shaped in lacustrine assocciation.

Figure 4.4 Pisolitic carbonate nodules occurred in Kumköy.

4.2 Facies of the Alluvial Fan Deposits

4.2.1 Soma Alluvial Fan

4.2.1.1 Description

The fan observed in the Soma district is named as the Soma alluvial fan. Although there is no palaeontologic age data, the Quaternary age may be suggested for this fan. Because the fan was covered by recent colluvial deposits, presents fan morphology and comprises gravels originated from previous units.

This fan which is in the Soma district, is developed adjacent to the margin faults of the Soma graben. The radial lenght of the fan is 1 km, the longitudinal lenght that is parallel to the active fault is approximately 2 km. The fan developed on the Miocene sequence. A section that is approximately 10 m in thickness belongs to the Soma alluvial fan (Fig. 4.3).

The fan facies are made of matrix-supported conglomerates (Gm), planar cross-bedded conglomerates (Gp) and pure sandstones (Sm) (Fig. 4.5). Gm facies is thick-bedded, sand matrix supported and there is no internal structure. Average gravel size is 5-6 cm, maximum size is 12 cm. Gravels are less rounded and generally consist of limestone that originated from the Mesozoic and Miocene units, marlstone and rarely sandstone. Rarely-observed planar cross-bedded conglomerates are grain supported and include sand matrix. Sandstones (Sm) are non-stratified, fine-coarse grained and include rare gravels.

4.2.1.2 Interpretation

The fan was dominantly formed by debris flows (Gm facies). Cross bedded conglomerate and gravelly sandstones indicate that the accumulation by reworking of diluted debris flows or occasionally formed floodings or the perennial rivers flowing on the fan. Debris flows, excessive sediment-loaded flood flow and sheetflood deposits are often observed facies in older and recent alluvial fans (Decelles et al., 1991; Nemec & Postma, 1993; Blair, 1999 b).

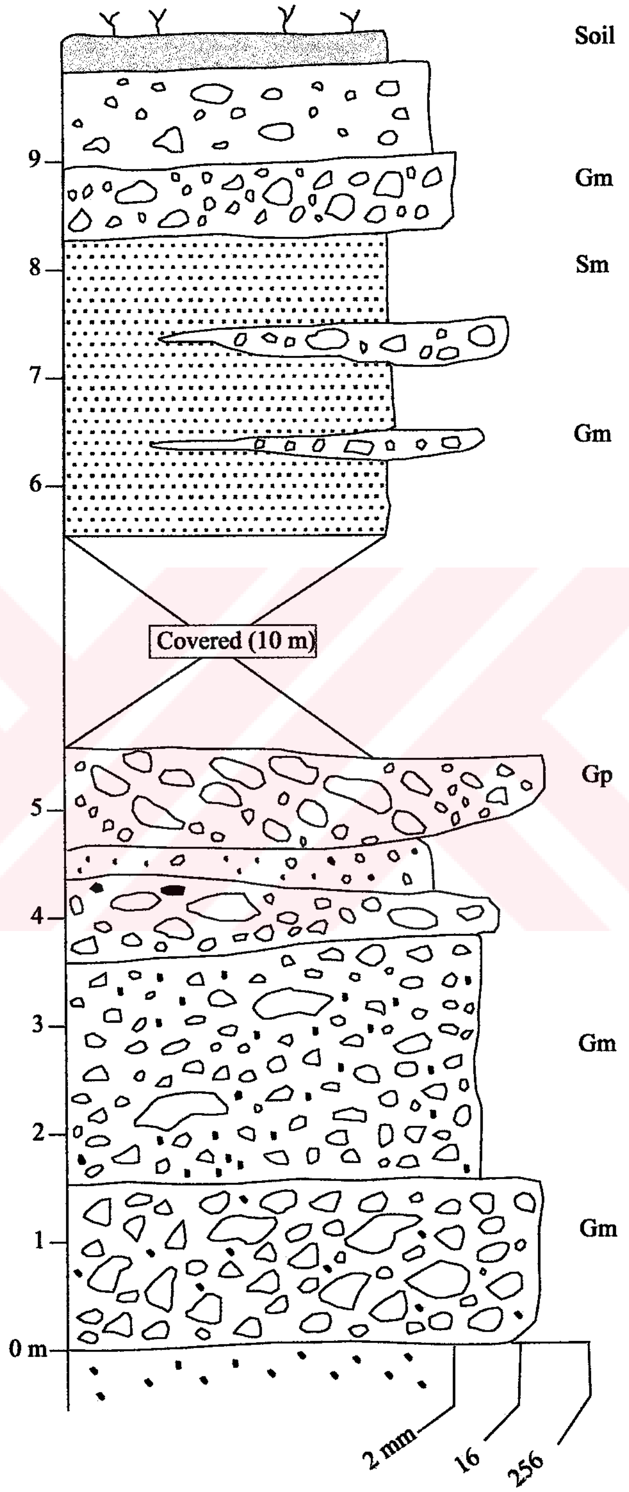


Figure 4.5 The facies characteristics of Soma alluvial fan.

4.3 Facies of the Recent Deposits

4.3.1 Colluvial Apron Deposits

Red-brown colored conglomerates are named as "Colluvial Apron Deposits". These deposits were formed by adjacent colluvial fans and were observed along the margin faults of the Soma graben. Colluvial and alluvial fans are different from each other due to their geological and morphological settlings, fan geometries, sediment concepts and sedimentation processes (for comparison look at Blikra & Nemec, 1988).

4.3.1.1 Karaman Colluvial Deposits

4.3.1.1.1 Description

The colluvial apron deposits that are adjacent to the Karaman fault are named as the Karaman colluvial deposits in this study (Fig. 4.6).

The lower part of Karaman sequence is represented by flat bedded conglomerate (Gms), the upper part is represented by blocky, soil matrix and slip surfaces-bearing conglomerates (Gmc) (Fig 4.7). The lower part dipped 15-20 degree towards to the fault (Fig. 4.8) .

4.3.1.1.2 Interpretation

Tectonic activity contributes to the different accumulation processes in colluvial facies formation. The changing from Gms facies to Gmc facies and slip surfaces-bearing conglomerates in Gmc in the Karaman sequence may point out small tectonic triggers. Small-scale faultings and the inclination of colluvial deposits to the fault scarpe show that the palaeoseismic triggers have important contributions in the formation of colluvial deposits.

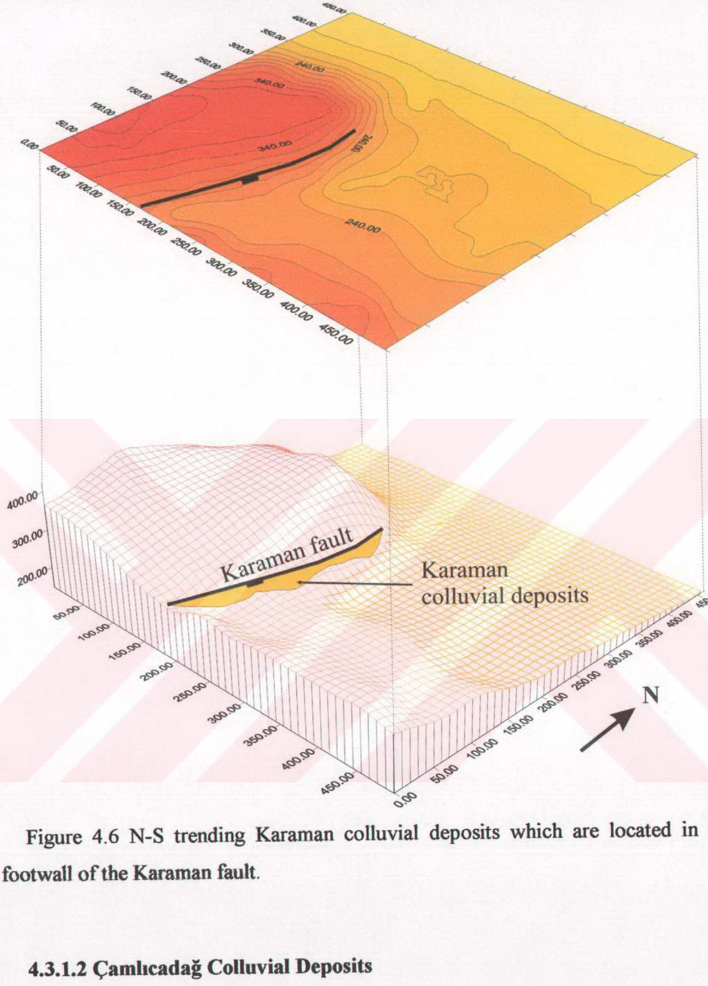


Figure 4.6 N-S trending Karaman colluvial deposits which are located in the footwall of the Karaman fault.

4.3.1.2 Çamlıcadağ Colluvial Deposits

4.3.1.2.1 Description

The deposits that are adjacent to the Çamlıcadağ fault in the Soma graben are characterictic and named as "Çamlıcadağ colluvial deposits" in this study (Fig. 4.9).

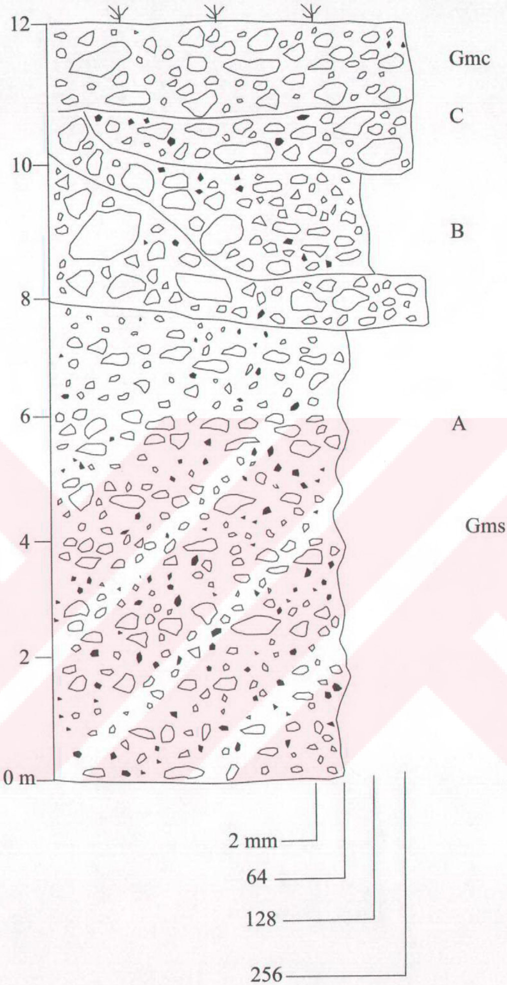


Figure 4.7 The facies characteristics and measured section of Karaman colluvial deposits which are located in the footwall of the Karaman fault.

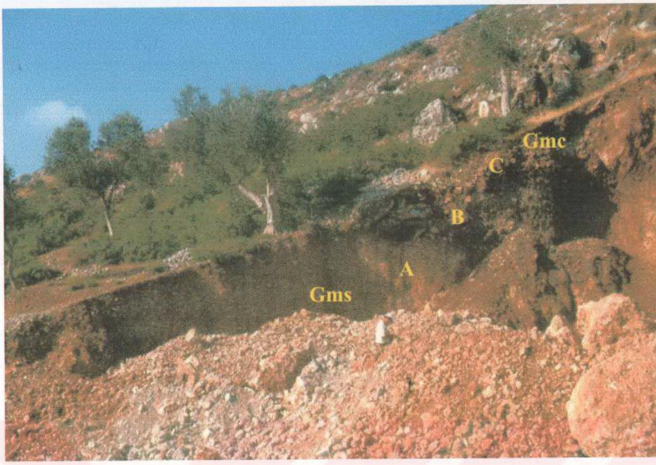


Figure 4.8 The facies characteristics of the Karaman colluvial deposits which are adjacent to the Karaman fault. A, B and C levels in the Karaman sequence were probably formed in the effect of three palaeoseismic activities, Gms (matrix supported conglomerate), Gmc (slip surfaces-bearing conglomerate).

It consists of alternation of yellowish and reddish colored, blocky and matrix supported conglomerates (Gm) (Fig. 4.10). The bed boundaries are generally indefinite and shallow eroded (Fig. 4.11). Small-scale (40-50 cm) sysnsedimentary faultings are observed in some beds.

4.3.1.2.2 Interpretation

The facies characteristics of Çamlıcadağ colluvial apron deposits indicate that the accumulation by debris flows. Debris flows is one of important processes of accumulation. Debris flows are gravity flows and were called in different names in geomorphology literature. Colluvial sedimentation is controlled by climate, slope steepness, the kind of source rock and tectonism (Blikra & Nemec, 1998). The slope stability of colluvial deposits accumulating fault scarps may be disorganised because of palaeoseismicity.

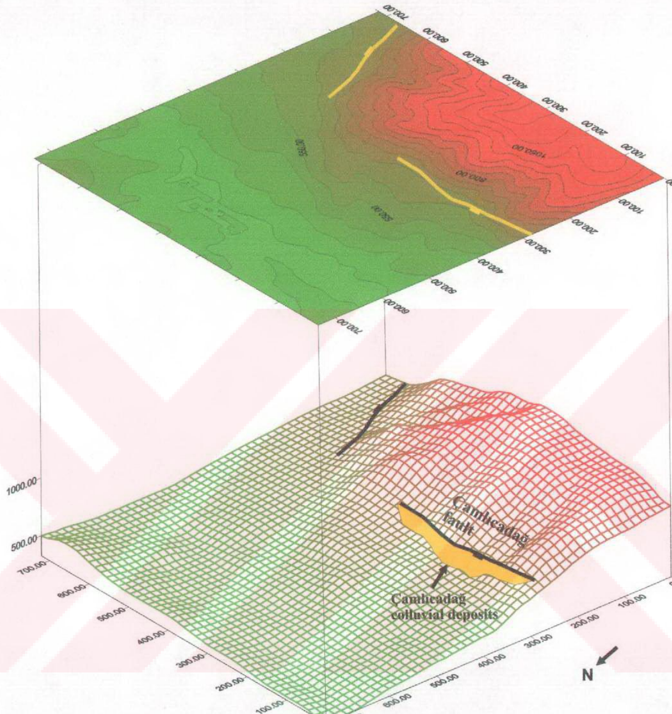


Figure 4.9 Çamlıcadağ colluvial deposits which are located in the footwall of the Çamlıcadağ fault.

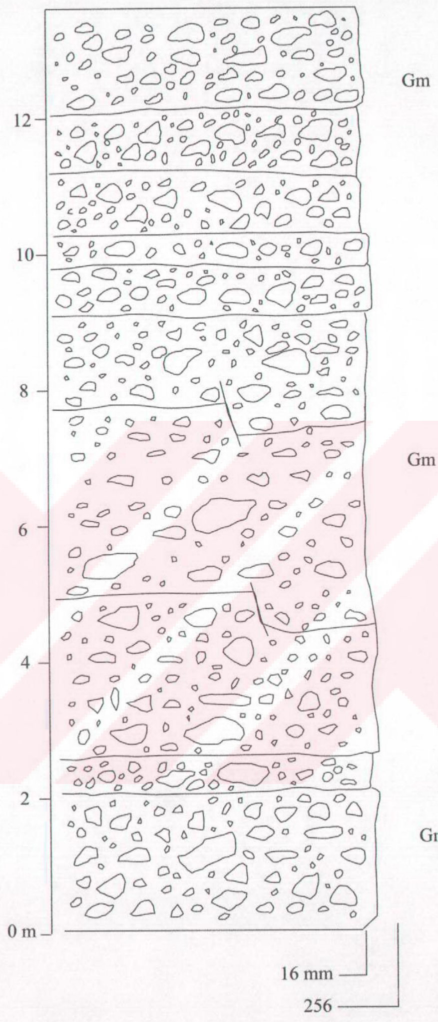


Figure 4.10 The facies characteristics and the measured section of the Çamlıcadağ colluvial deposits which are adjacent to the Çamlıcadağ fault.

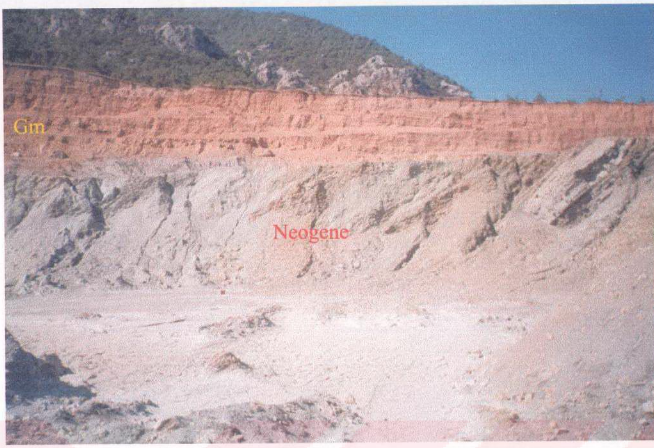


Figure 4.11 The facies characteristics of the Çamlıcadağ colluvial deposits which are located in the footwall of the Çamlıcadağ fault. The photo was taken from near of the Çamlıcadağ fault in the Soma coal mine.

4.3.2 Fluvial Deposits

The youngest deposits of Plio-Quaternary sequence are the fluvial deposits of the Bakırçay and Yağcılı rivers.

4.3.2.1 Bakırçay fluvial deposits

These deposits accumulated by the Bakırçay river and tributaries and the deposition still goes on active in present day. The fluvial deposits of Bakırçay is represented by clayey and silty sediments and covered by soils (Fig. 4.12).

Bakırçay fluvial deposits are low-consolidated and rest on the Plio-Quaternary deposits and basement roks. There are wide agriculture fields on these deposits.

Figure 4.12 Recent fluvial deposits are observed along the Bakırçay river channels.

4.3.2.2 Yağcılı fluvial deposits

Yağcılı fluvial deposits are composed of cross-bedded conglomerates, flat-bedded sandstones and siltstones in river channels. Deposition in the Yağcılı river still goes on. Some fluvial terraces are observed surround the Yağcılı river into the Sevişler Dam (Fig. 4.13).

These fluvial deposits rest on the Plio-Quaternary deposits and the basement roks. There are wide agriculture fields and settlement centres on these deposits.

Figure 4.13 The terraces of recent fluvial deposits are observed along the Yağcılı river channels.

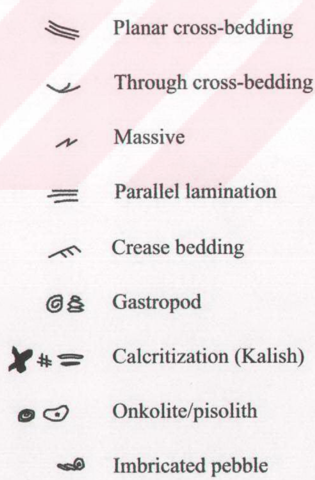


Figure 4. 14 The legend used in all drawings in Section Four.

CHAPTER FIVE

GRABEN FORMATION

5.1 Hacıyusuf fault zone

Approximately NE-trending faults that lie between Turgutalp in the northeast and near-east of Hamzahocalı in the southwest and controlling the southern margin of Soma graben are named as the Hacıyusuf fault zone (Fig. 5.12). Their intervals are close (0.5 - 1 km). They dip towards the north and the inner graben and, are approximately linear. Jurassic-Cretaceous Limestones, Early-Middle Miocene limestones and marlstones (Soma Formation) and Late Pliocene (?) terrestrial clastic sequence which forms the Kumköy Formation, have been cut by the Hacıyusuf fault zone. Because of vertical slip that along the faults, the southern margin of the Soma Graben changed into en-echelons structures. Similarly the folds that developed in Miocene rock units have been cut by the Hacıyusuf fault zone.

The sediments that accumulated on the fault-scarps and inclined towards the fault and back-tilting indicate that the faults forming Hacıyusuf fault zone are active seismically at least. As a matter of fact, epicenters of some small-scale earthquakes in this fault zone verified this result. Because of deficiency of well-preserved fault scarp, kinematic analysis of the faults that form the Hacıyusuf fault zone could not been made. But, morphotectonic structures indicate that this fault zone is made up from oblique-slip normal faults.

5.2 Soma graben

Western Anatolia is segmented into several horsts and grabens as a result of normal faulting related to intra-continental extensional tectonic regime (Koçyiğit, 1984; Westaway, 1990). Some of them are large-scale structures as the Bakırçay (Bergama), Küçük Menderes, Büyük Menderes and Gediz grabens and the others are relatively small-scale structures as the Soma and Kırkağaç grabens that reach approximately 15 km long (Koçyiğit et al., 1999).

In this study, the Soma graben is studied in detail. It is a subsidence area that 0.2-2.7 km wide, 16 km long, WSW-ESE trending and a little convex to the north (Fig. 5.12). It is separated from the Kırkağaç graben by the Taşlıboğaz horst in its eastern end, and the Bakırçay graben by the Boyalıktepe horst in its western end. But either the Soma graben or the Kırkağaç graben are indicated as an east part of Bakırçay (Bergama) graben by previous studies (Westaway, 1990; Yılmaz et al., 2000). Soma graben is an asymmetric graben in morphotectonics sense. For example; when the southern side of the graben is higher (~950 m) and steeply inclined, its northern side is relatively lower (~281 m) and less inclined. Soma graben deeply excavated the Taşlıboğaz and Boyalıktepe horsts and is drained by Bakırçay that gets connection with the grabens of Kırkağaç in the east and Bakırçay in the west. Soma graben is controlled by dense at interval and many normal faults en-echelons type and along the southern edge, even if a few number along the northern edge.

The faults that were effective in the formation of Soma graben and their kinematic analysis are clarified below.

5.2.1 Graben faults

The faults that are limited to the Soma graben and the horsts (Kösedağ horst, Kocatepe horst and Çamlıcadağ horst) in surrounding areas are composed of various dimensions (0, 2 - 21 km). The variety and directions of fault's strikes (WSW, WNW, N-S, NE and NW) resembles to the horst-graben system of western Turkey.

The most of these faults are active geologically and are the cause of multi-directional extension in the study area. The faults which form Soma graben and play a part in the formation of surrounding horsts have been mapped and named separately. The most important ones of these are the Soma, Eynez and Sarıkaya faults and, the Hacıyusuf, Dereköy and Çamlıcadağ fault zones.

5.2.2 Soma fault

It is one of the youngest faults limiting the Soma graben. Soma fault is 15 km long and trends approximately WSW-ENE between the Soma district in the east and the Küçük Avdan village in the west. Several present-day alluvial fans were developed on the north hanging wall of the fault and their proximal parts are adjacent to the fault. For this reason, the riverbed of Bakırçay between Soma and Küçük Avdan changed towards the north margin of the graben. The several fans could not been demonstrated on the geology map due to their small-scales.

Soma fault cuts and slips NE trending structures (Bakırçay graben and its margin faults). Similarly the Early Quaternary Soma alluvial fan that is approximately 1 km wide and 2 km long is cut by the Soma fault and is faced present-day graben fill on the hanging wall of the fault. However, this alluvial fan has got fault terrace characteristic on the south footwall of the fault because of uplift.

These observations indicate that the Soma fault is potentially active at least. But, the kinematics analyses of Soma fault could not been made due to its covered fault plane.

However, the morphotectonic structures (deformation style and the setting of fans, slipped and "S-shaped" rivers and the thickness of graben fill that reaches approximately 250 m) indicated that the Soma fault is oblique-slip normal fault that has a dextral strike-slip component.

5.2.3 Sarıkaya fault

Sarıkaya fault is 19 km long and the biggest structure which restricts the Kösedağ horst from the north. It lies from the Sarıkaya village in NNW to the south of Cumalı village in WSW. The Sarıkaya fault has a sub-linear trace and brought early-middle Miocene Soma Formation and Jurassic-Cretaceous limestones in the faulted contact. Colluvial sediments are deposited on the hanging wall of the fault and are dipped towards the fault plane. The upper surfaces of the blocks were restricted by the fault inclined to opposite of the fault dip. These morphotectonic structures show that the Sarıkaya fault is a normal fault. The most part of the fault scarp is covered by thick colluvial sediments. However, kinematic analyses were made by the measurements which were taken from locally outcropped fault scarps. These measurements show that Sarıkaya fault dipped with average 75^0 to the NNE and is an oblique-slip normal fault which has dextral strike-slip component.

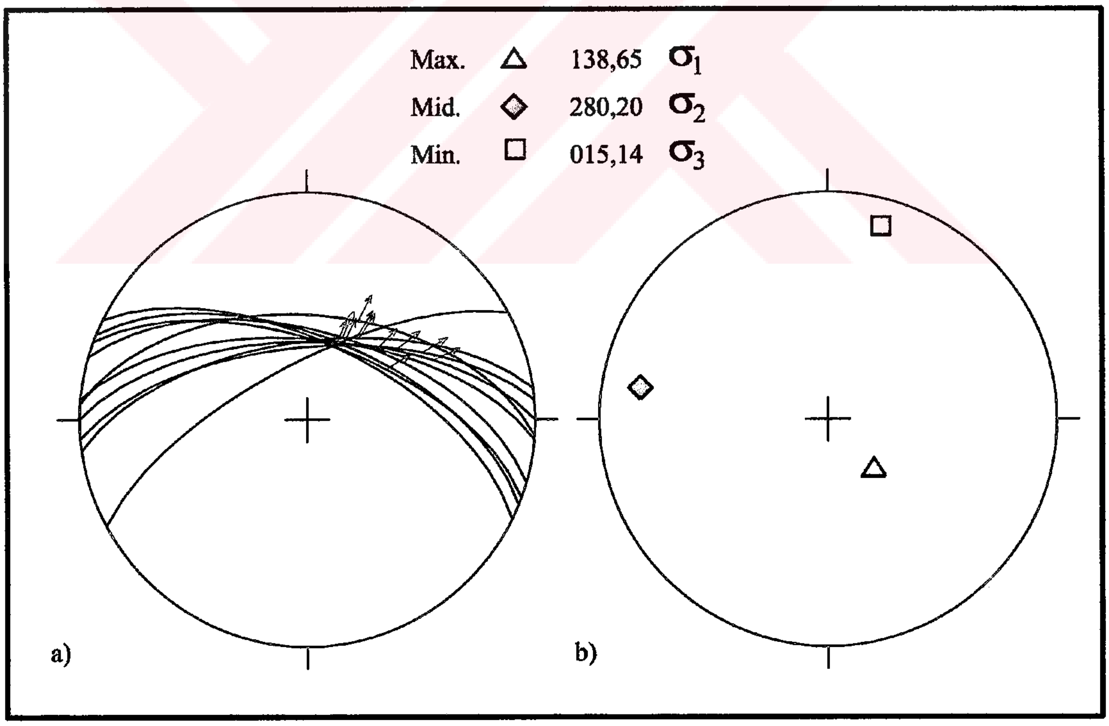


Figure 5.1 Schmidth lower hemisphere equal-area projections of fault slip data from Sarıkaya fault. **A)** Slip plane and stereographic projection of fault lines, **B)** The diagram that shows the situation of extension axes.

5.2.4 Other faults in the south margin of Soma graben

The faults which control the south edge of Soma graben were named one by one as explained above. Except for above mentioned the faults, there are several small-scale faults (0,5-6 km) especially in the near south of Soma district and a narrow area which is restricted by the Soma fault in the north and the Sarıkaya fault in the south (Fig. 3.6). These E-W, WNW, NW and NNE trending faults become intensity, dipped to the inner graben and are en-echelons-type normal faults. A part of them are developed completely in the early-middle Miocene Soma Formation (İnci, 1998), and some others developed in the Jurassic-Cretaceous limestones. Both of these units were locally brought to the faulted contact. Some of these faults present well-preserved fault scarp and slip lines. Kinematic analysis of the fault-scarp measurements from these outcrops show that this NNW trending fault is 0.5 km long with dextral strike-slip component and it is oblique-slip high angle reverse fault (Fig. 5.2). On the contrary, the kinematic analysis of the measurements from the fault-scarp on the station 1 show that the second fault is 4 km long with dextral strike-slip component, oblique-slip normal fault (Fig. 5.3). The extension direction of this second fault is also NNE (Fig. 5.3).

The WNW trending fault in the station 4 is approximately 3.5 km long. Recent Soma graben deposits and older units got together along this fault line. Kinematic analysis of the fault-scarp measurements from this station show that the fault, with dextral strike-slip component, is oblique-slip normal fault and it run before as reverse fault with high angle (Fig. 5.4).

Another fault is observed in the station 2. It is approximately 4 km long trending NNE. Kinematic analysis of the rare fault-scarp measurements were taken from this station shows that the fault, with dextral and sinistral lateral strike-slip component, is oblique-slip normal structure (Fig. 5.5).

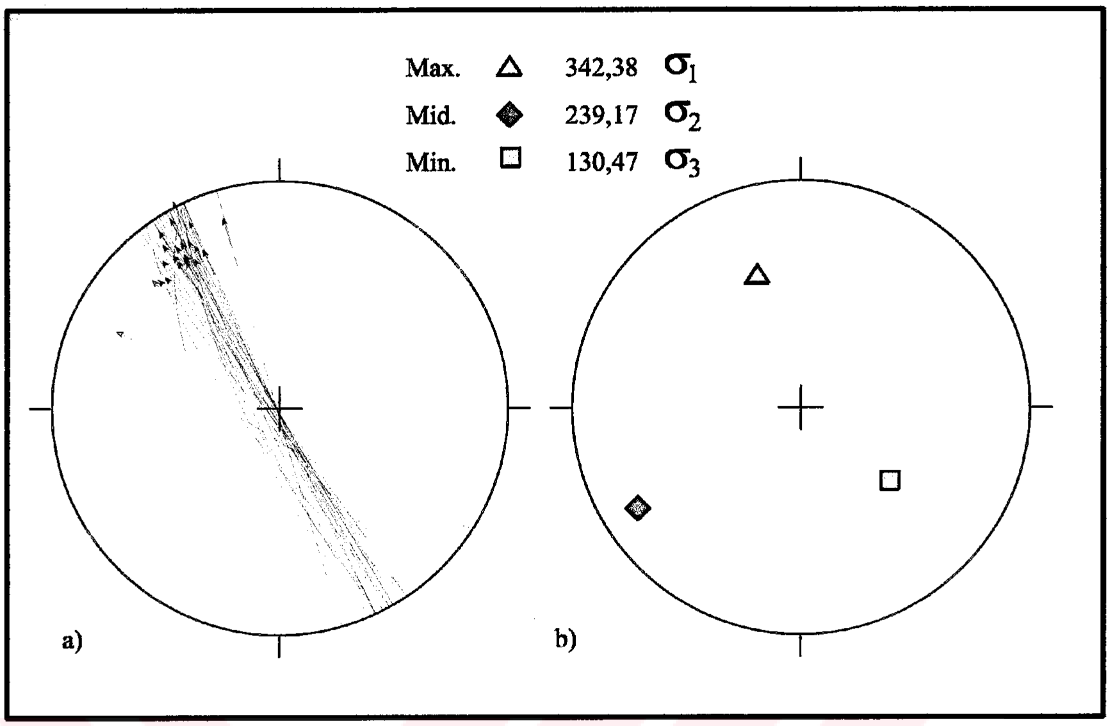


Figure 5.2 Schmidth lower hemisphere equal-area projections of fault slip data from station 3. **A)** Slip plane and stereographic projection of fault lines, **B)** The diagram that shows the situation of extension axes.

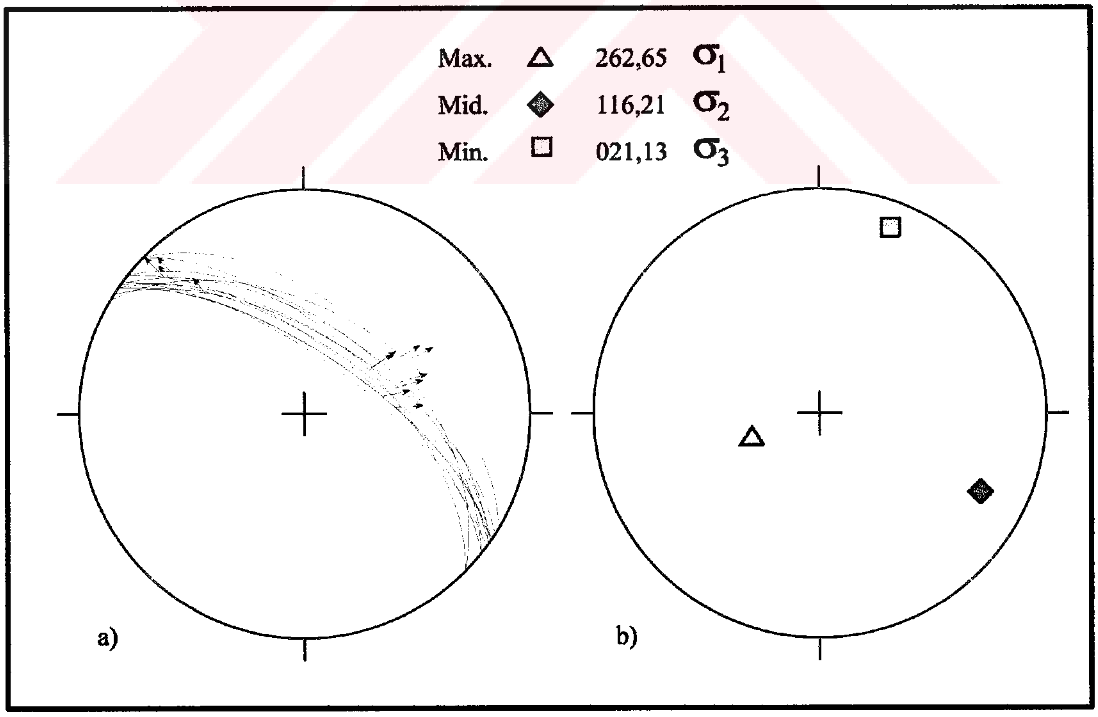


Figure 5.3 Schmidth lower hemisphere equal-area projections of fault slip data from station 1. **A)** Slip plane and stereographic projection of fault lines, **B)** The diagram that shows the situation of extension axes.

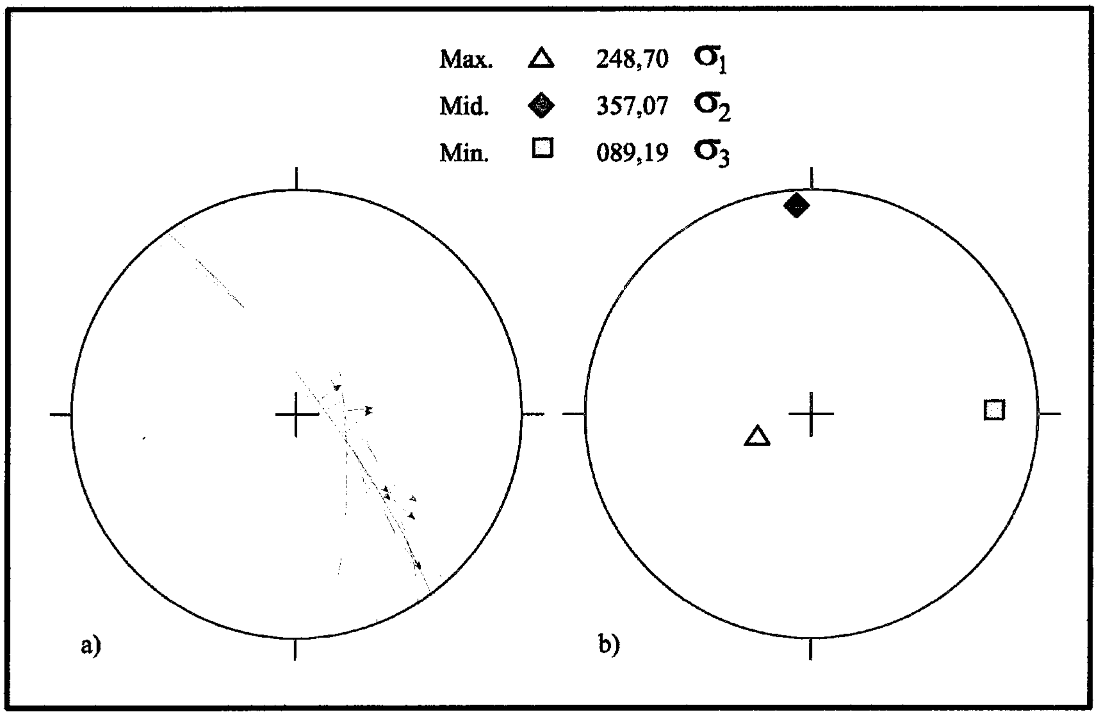


Figure 5.4 Schmidth lower hemisphere equal-area projections of fault slip data from station 4. **A)** Slip plane and stereographic projection of fault lines, **B)** The diagram that shows the situation of extension axes.

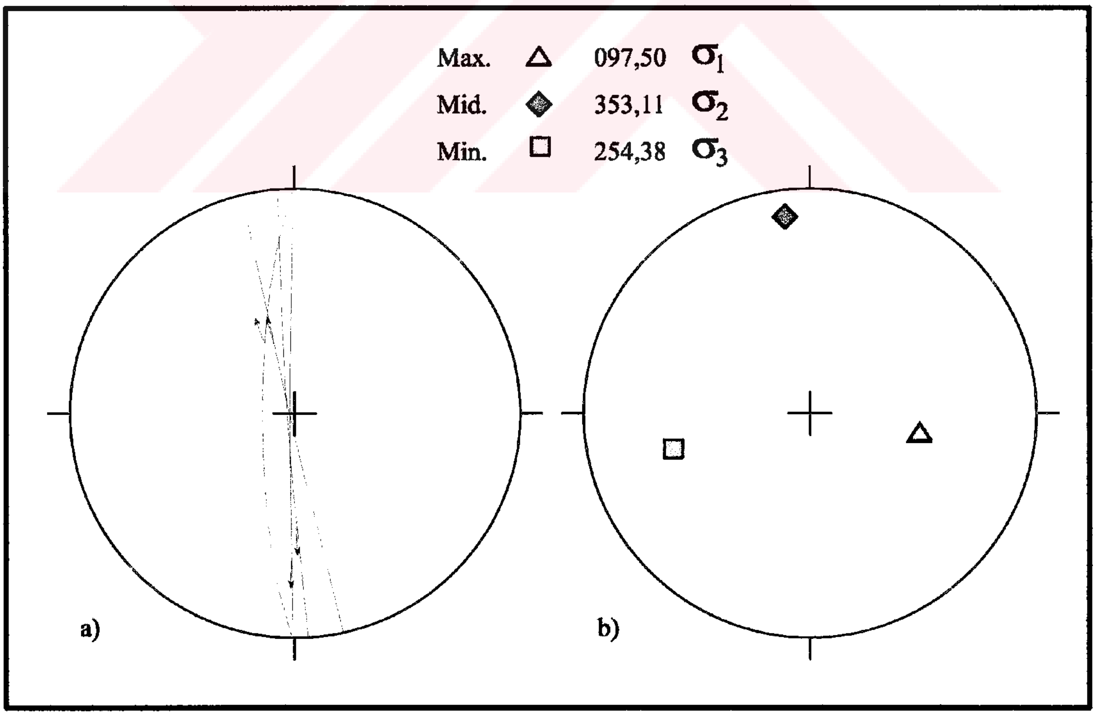


Figure 5.5 Schmidth lower hemisphere equal-area projections of fault slip data from station 2. **A)** Slip plane and stereographic projection of fault lines, **B)** The diagram that shows the situation of extension axes.

Another fault is observed in the station 2 (Fig 5.6). It is approximately 4 km long trending NNE. Kinematic analysis of the rare fault-scarp measurements were taken from this station shows that the fault, with dextral and sinistral strike-slip component, is oblique-slip normal structure (Fig. 5.5).

The fault-scarp which gives the most important and well-preserved kinematic data in the near south of Soma district is the Karaman fault. It is named as the Karaman fault because it is observed in Karaman quarter in western Soma. This structure is approximately 1.3 km long and a normal fault trending NNW and dips steeply to the east. The kinematic analysis of the linear and planar measurements taken from the fault scarp show that the Karaman fault with a small number dextral and sinistral strike-slip component is oblique-slip normal structure. The extension direction along this fault is 29 NNE. There are three subsequences upward-thinning in the sequence which accumulated on the hanging-wall of the fault. This observation is probable evidence indicating three activities in the Quaternary time.

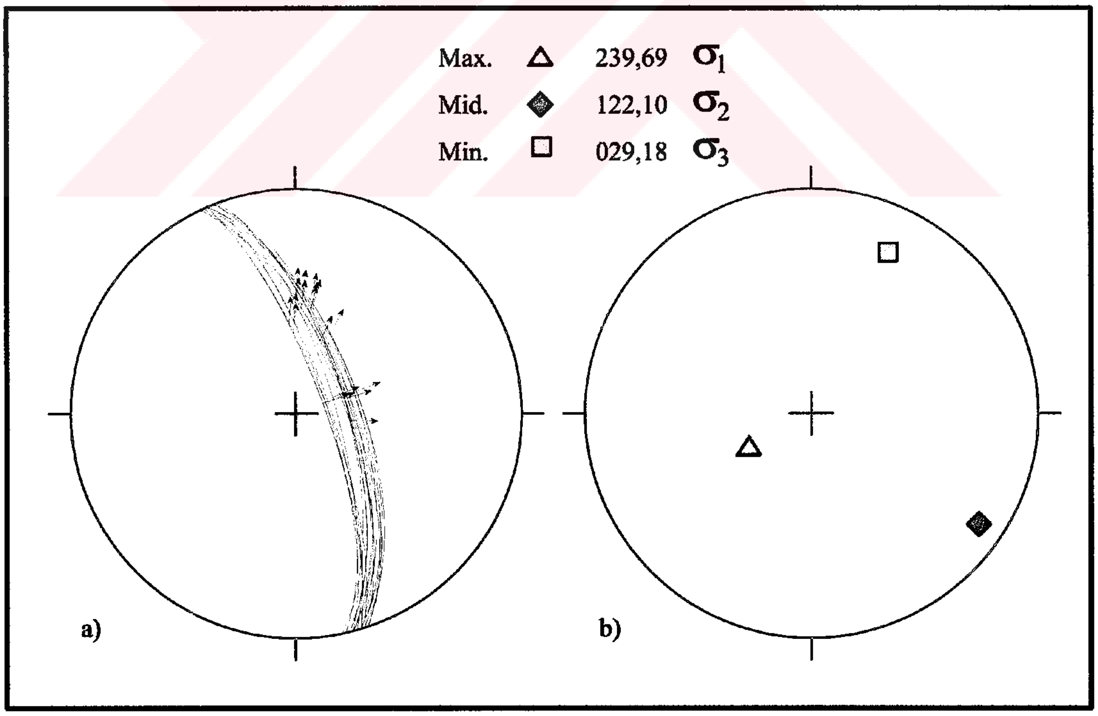


Figure 5.6 Schmidth lower hemisphere equal-area projections of the Karaman fault slip data from station 3. **A)** Slip plane and stereographic projection of fault lines, **B)** The diagram that shows the situation of extension axes.

5.3 Dereköy graben

E-W trending Dereköy graben is 2-11 km width and 13 km long (Fig. 5.12). The recent geometry and the young deposits of the graben were removed completely because of excavation of the Miocene coals in the graben. For this reason the determination of this geometry of graben and young deposits is too hard. Quaternary graben fillings were prevented from this processes in two places which the southern and northern edge of the graben on the hanging wall. Dereköy graben is surrounded by Kösedağ in the north, Kocatepe in the east and the Çamlıcadağ horst. Both of the horsts and the Dereköy graben are controlled by three different fault zones which inclined to the graben. These are named as the Dereköy fault zone, the Çiftlikköy fault zone and the Çamlıcadağ fault zone and their kinematic analysis were made. These structures are explained in shortly below.

5.3.1 Dereköy fault zone

The main structure controlling the northern slope of Dereköy graben and the southern slope of Kösedağ horst is named as "Dereköy fault zone". This structure is 1-4 km long, composed of a few E-W and NE trending fault segments. Quaternary graben filling is hanging on the fault in the north of Dereköy; the early-middle Miocene Soma Formation and the Jurassic-Cretaceous limestones were brought by the faulted contact in the other parts. The faults dipped steeply. Kinematic analysis of the measurements indicates that this fault zone is an oblique-slip normal fault which has dextral and sinistral strike-slip components (Fig. 5.7).

5.3.2 Çiftlikköy fault zone

Çiftlikköy fault zone restricts the eastern part of Dereköy graben and the western part of Kocatepe horst and its length changes from 1 to 13 km. It is composed of several linear-sub linear fault segments trending N-S and NNW, mostly inclined to the graben. This fault zone either cuts the early-middle Miocene Soma Formation and the Jurassic-Cretaceous limestones or brings these units that are two different facies and ages to the faulted contact. Faults form a morphotectonic structure which is en-echelon type towards the inner graben. Late Miocene (?) - Pliocene (İnci, 1998) olivine basalts represent the fissure eruptions and were developed adjacent to the fault.

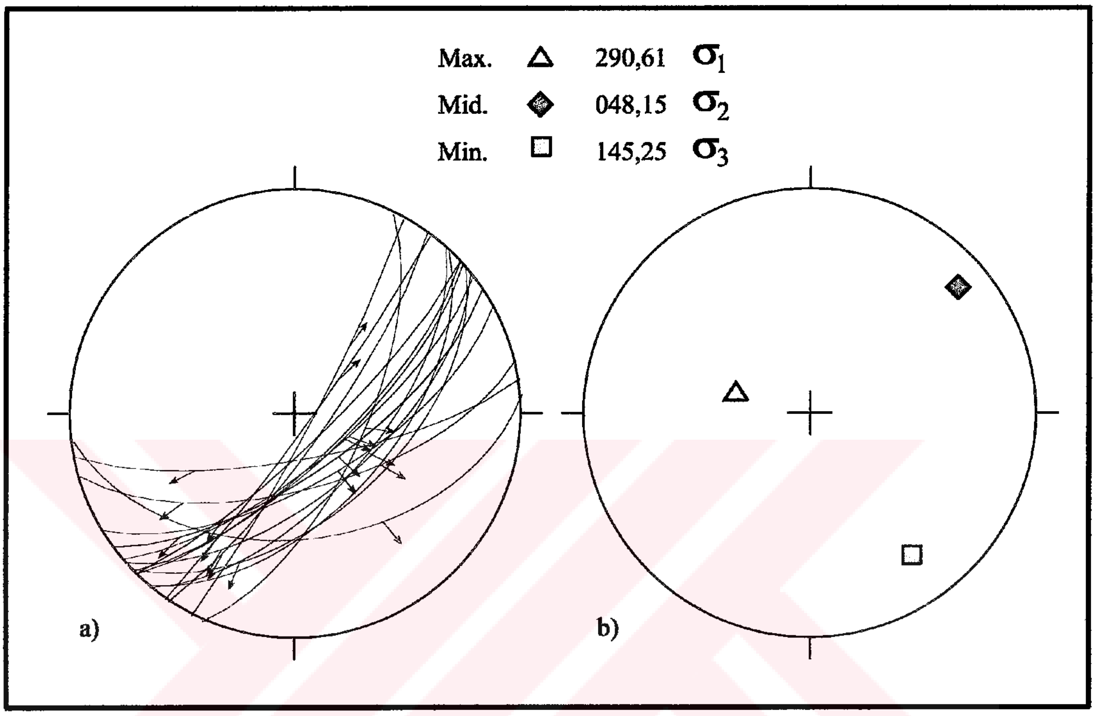


Figure 5.7 Schmidth lower hemisphere equal-area projections of the Dereköy fault zone slip data from station 6. **A)** Slip plane and stereographic projection of fault lines, **B)** The diagram that shows the situation of extension axes.

Çiftlikköy is on the main fault and there are several scarps steeply dipped to the west. Well-preserved surfaces are observed either on these scarps and or on the fault which cuts the Kocatepe horst. Kinematic analysis of these stations shows that the Çiftlikköy main fault and the other faults which lie obliquely. They are oblique-slip normal faults that have dextral and sinistral strike-slip components (Figs. 5.8).

5.3.3 Çamlıcadağ fault zone

This fault zone forms the border between Dereköy graben and Çamlıcadağ horst. It is composed of several fault segments trending N-S and E-W in linear and sub-linear and dense intervals. Çamlıcadağ fault zone forms fault slopes that are steeply-dipped into the graben and face to the north, the northeast and the west. The slope was covered by a colluvial sequence which is thick and dipped towards the fault. The colluvial sequence is 13 m thick and composed of alternating grain size with upward fining and coarsening. It also contains synsedimentary normal growth faults where their slips reach 40-50 cm (Karaman-Çamlıcadağ sections).

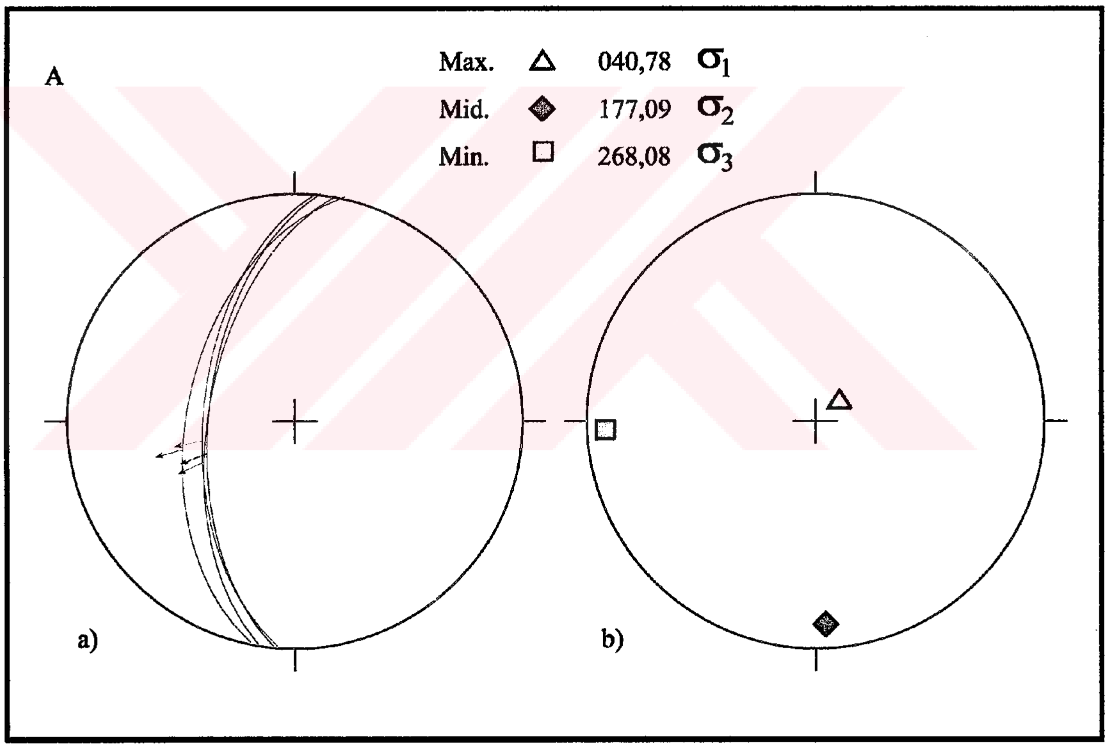


Figure 5.8 Schmidth lower hemisphere equal-area projections of station 7. **A)** Slip plane and stereographic projection of fault lines, **B)** The diagram that shows the situation of extension axes.

The fault scarp where the Miocene units and the Jurassic-Cretaceous limestones were came across along it and the coals in the early-middle Miocene Soma

Formation which is on the hanging wall of Çamlıcadağ fault zone, is exposed by mining excavation (Fig. 5.9).

The E-W ends of two en-echelon faults are dipped into the graben and the dense intervals (100 m) are outcropped along this slope. Kinematic analysis of these two faults shows that these faults are oblique-slip with lateral component normal faults (Fig. 5.10).

One of the faults form the Çamlıcadağ fault zone is the Eynez Fault. It shows linear trace and is observed near to the east of Eynez. The fault is 6 km long and NNW trending. Kinematic analysis of this fault shows that these faults are oblique-slip with dextral and sinistral component normal faults (Fig 5.11).

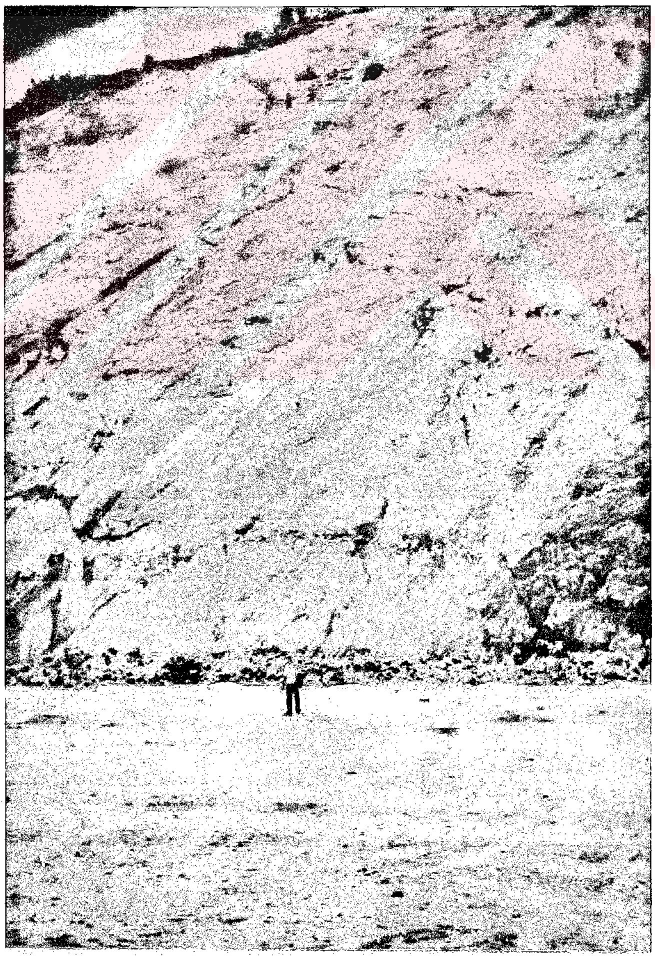


Figure 5.9 The general view of the fault scarp (stations 8 and 9) of the main fault of Çamlıcadağ fault zone looking from the north to the south.

Generally, the Quaternary sediments of Dereköy graben are removed by excavation and the recent geometry of the graben corrupted. For this reason, it is hard to say that the faults restrict the graben are whether active or not. But, the Quaternary colluvial sequences that are inclined to the fault in 10°-15° angles and are suspended in two places on the fault are acceptable as the data which represent the potential activities of these faults. However, the distribution of some small-scale earthquake epicenters shows that at least some of these faults are active.

5.4 Bakırçay (Bergama) graben

Bakırçay graben is a structure which has potential earthquake danger and it is located very near to Soma which is a large metropolitan centre. For this reason, Soma and the surrounding areas have been suffered damage from the middle or big earthquakes which were originated in these grabens in the historical periods (Ergin et.al, 1967; Soysal et al., 1981; Gençoğlu et al., 1990; Ambraseys & Jackson, 1998).

Bakırçay graben is a NE-trending active subsidence area which is 1-8 km wide and 75 km long (Fig. 5.12). Yılmaz et.al (2000) named the Bakırçay and Soma grabens as the Bergama graben and emphasized it is an E-W trending active subsidence area. However, this study shows that NE-trending Bakırçay and WSW-trending Soma grabens are not same grabens and they are separated from each other by the Boyalıktepe horst. The relationship between these two different grabens is well observed in the northwestern end of the study area.

The southwestern part of the graben is wider and is located outside of the study area. Kozak horst is in the north and the Yuntdağ horst is in the south of the graben. The drainage of this part is formed by the Bakırçay River. A part of the northeastern part of the graben is located inside of the study area and its drainage is formed by the Yağcılı River. Especially the Yağcılı River excavated deeply its bed and shows the seismic activity in this region. As a matter of fact, either the historical earthquakes (Ergin et.al, 1967; Ambraseys & Jackson, 1998) or increasing seismic activity in the northeastern margin (Savaştepe and surrounding) lately show that the faults that control the Bakırçay graben are active.

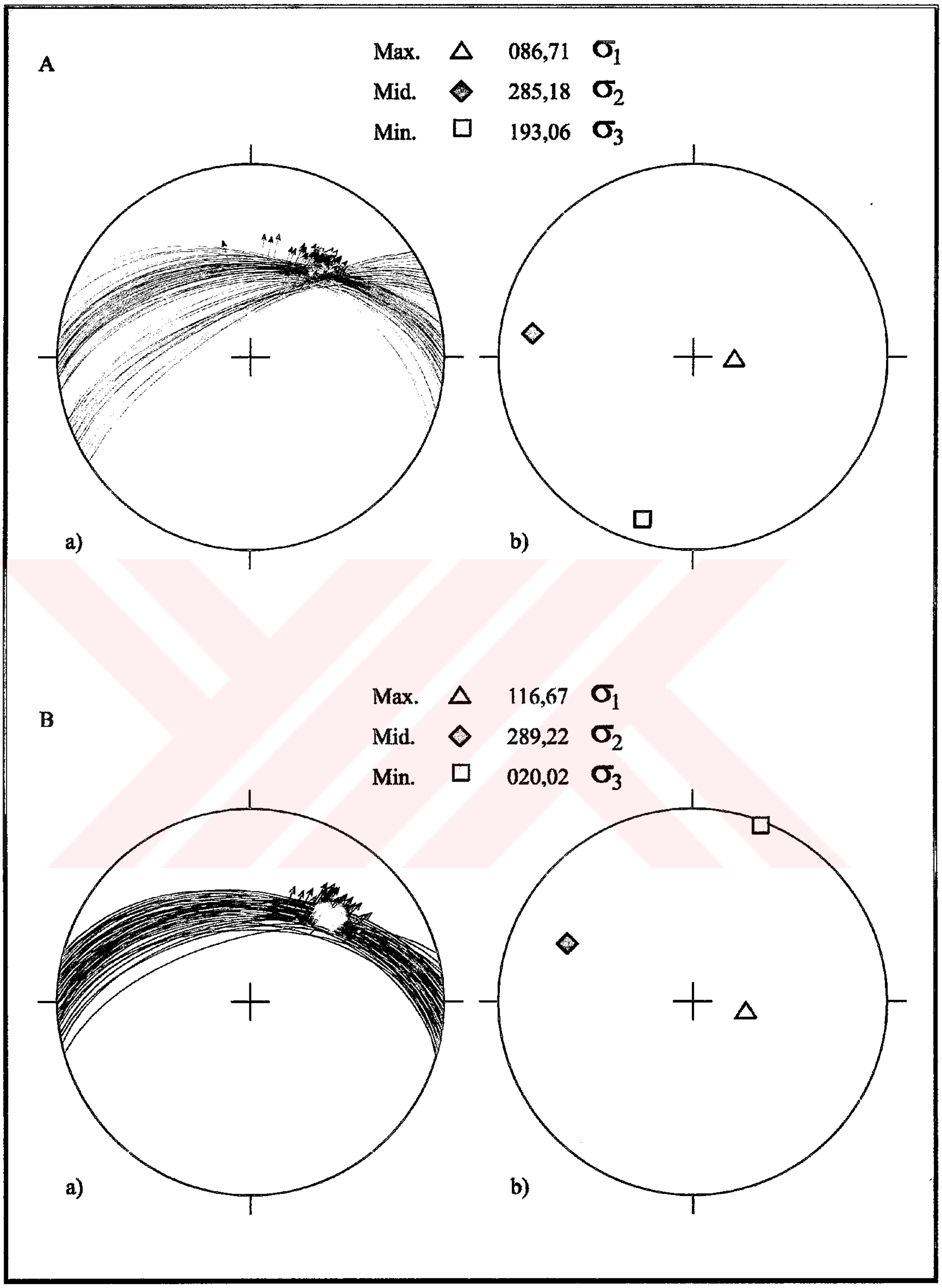


Figure 5.10 Schmidth lower hemisphere equal-area projections of stations 10 and 11. **A)** Slip plane and stereographic projection of fault lines, **B)** The diagram that shows the situation of extension axes.

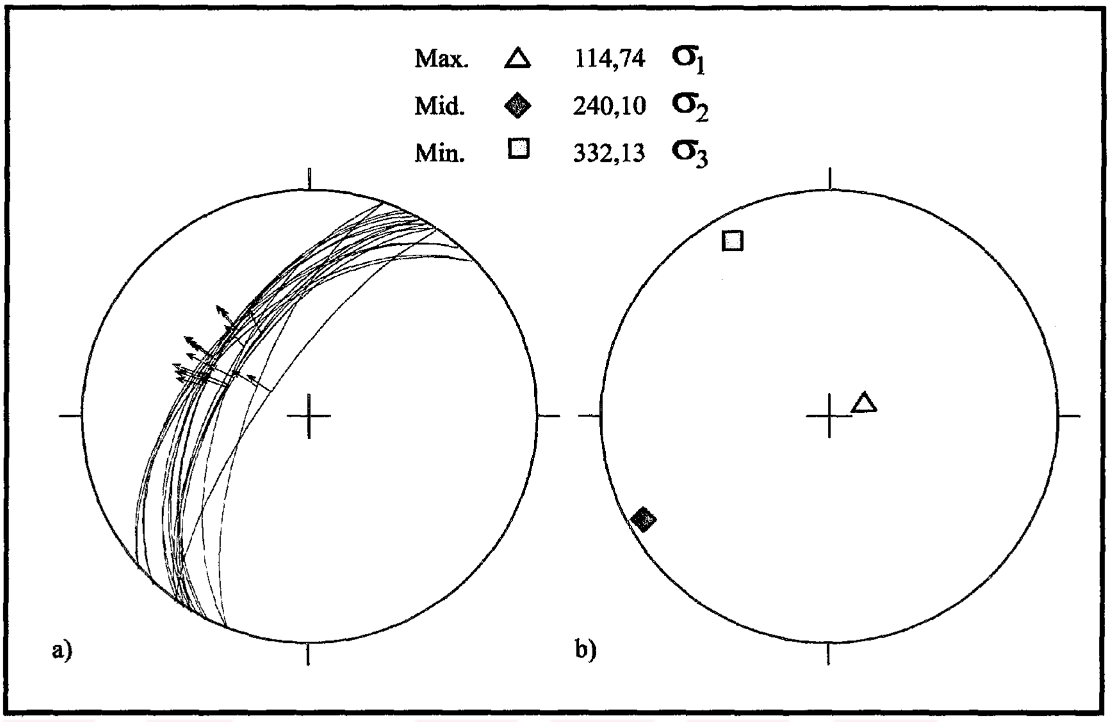


Figure 5.11 Schmidth lower hemisphere equal-area projections of the Eynez fault zone slip data from station 6. **A)** Slip plane and stereographic projection of fault lines, **B)** The diagram that shows the situation of extension axes.

5.5 The age and total vertical slip of the faults

The genetic relationship between the graben geometry and the field distribution of Miocene rock units (Soma and Deniş formations) with the Kumköy formation of late Pliocene (?) in age (Yeşilyurt & Taner, 1999) is not observed in the study area. These units were folded and were not only buried below the Quaternary-present graben fill but also outcropped on the horsts limiting the graben. Miocene and late Pliocene (?) rock units and the folds in the graben were cut and slipped by the faults. Fold axes are mostly NNE-trending. After the sedimentation, the Miocene and late Pliocene (?) units were deformed by a compressional period that was effective along about ESE-WNW strike. It means that the first extensional tectonic regime and the first graben formation which was started in the early Miocene were interrupted by a compressional period. This situation was also observed a lot of areas in southwest Turkey (Koçyiğit et al., 1999) earlier. But, since the age of Kumköy formation is not known exactly, the age of this compressional period is also accepted as the Pliocene for the present. The records of similar compressional regime (folds) were also observed and mapped in the Gediz graben by previous studies (Koçyiğit et al., 1999). For this reason, there are several possibilities about the ages of the faults in the study area:

1) These faults might be formed and activated as normal faults during the Miocene and their characteristics might be changed into high-angle reverse fault during the compression period; as a matter of fact the kinematic data observations indicate the reverse faulting strengthen this possibility,

2) The faults that were formed in the Miocene and were reactivated during the new extensional tectonic period which was dominant after the compression (folding) period in the Pliocene, have been continuing at the present day,

3) Oblique-slip normal faults were formed during the new tectonic period, or

4) The combination of 2 and 3 options may be possible. In other words, some of the faults in the study area are normal faults that are hereditary from the Miocene and these faults activated at the beginning of the new tectonic period (at least in the Quaternary for the Soma graben). The others are younger and were formed during the new tectonic period.

The clarity of these options depends on the determination of the age based on the Rodent fauna and magnetostratigraphy of Kumköy Formation because of the Kumköy Formation is the youngest unit which was deformed.

The faults controlling the southern margin of Soma graben present en-echelon geometry that face to the north and the faulting migrated from the south to the north. In other words, Soma fault controlling recent Soma graben is younger than the Sarıkaya fault controlling the old margin of the graben. The disconformity between the Miocene units and the Jura-Cretaceous limestones is slipped downward by en-echelon normal faults. Furthermore, the Soma fan-sequence, developed on the

Miocene units, cut by the Soma fault in the north. As a result, this sequence was raised on the footwall as terrace deposits and was slipped into the graben and deeper parts. The thickness of the graben filling was measured about 250 m in the drilling that was made by DSI in the Soma graben. Thus, the total vertical slip is about 575 m that was measured along the faults which control the Soma graben from the south according to both geological sections drilling data. This thickness means vertical deformation ratio of 0.36 mm/year.

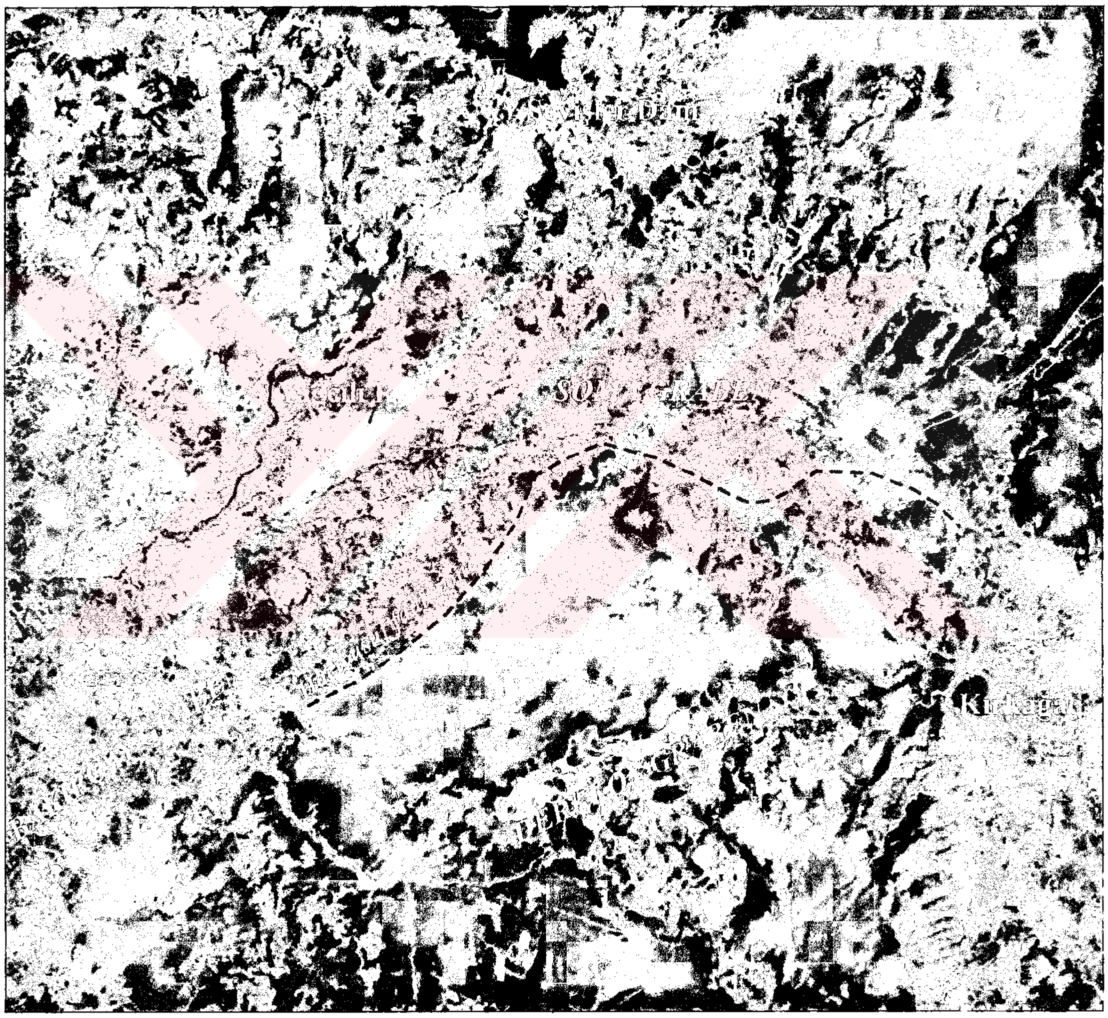


Figure 5.12 Satellite view of the study area representing major tectonic structures.

CHAPTER SIX

EARTHQUAKE POTENTIAL IN THE SOMA DISTRICT

6.1 Historical earthquakes

It has not been encountered to the historical earthquake records except for three historical earthquakes which caused serious damage in the living centers in the Soma graben and probably have epicenters in the northwestern edge of Bakırçay graben have been recorded (Soysal et al., 1981; Ambraseys & Jackson, 1998). These records are respectively the earthquakes of 253, 1296 and 1895. The epicenter coordinates of these earthquakes were given respectively as 39.10 N-27.15 E; 39.20 N-27.40E and 39.10 N-27.10 E and their magnitudes were recorded respectively as IX, VII and VIII. It has not been found any information about these earthquakes.

6.2 The earthquakes occurred within the last century (1900-2000)

There are a lot of (about 250) earthquake records of small or medium magnitudes (from M=3 to M=6.88) in the Soma graben and the surrounding areas during the last decade (the records of Kandilli Observatory and Earthquake Research Institute of Boğaziçi University) (App. 1). The distribution of epicenters of these earthquakes in different magnitudes is not linear and looks like groups and, intensified inside and surroundings of the graben. This distribution form is quite characteristic for the normal faulting, and the normal faults are developed in different strikes and are dipped into different directions (Fig. 6.1).

There is only one medium scale earthquake in the 20^{th}.century (18.11.1919) caused death and serious damage in the living centers of the Soma graben. But it was not well recorded because of insufficient conditions in its time. Short information about this earthquake will be given below.

6.2.1 Bergama earthquake (Ms=6.88) (18.11.1919)

This seismic event has been recorded as the Soma earthquake by Eyidoğan et.al (1991). The epicenter of this earthquake is the northwestern edge of Bakırçay graben according to the coordinates (39.20 N - 27.20 E; 39.11 N - 27.20 E; 39.35 N - 27.44 E) recorded by Ergin et al. (1967), Gençoğlu et al. (1990) and Ambraseys (2001). This epicenter is 30 km away from the Soma district center. In other words, this earthquake was originated from the fault which controls the southeastern edge of Bakırçay graben and dips into the northwest. It caused serious damage in the centers of population in the Soma graben and the northwestern edge of Bakırçay graben. A zone which lies 50 km long and includes Cumalı, Cenkyeri, Hamidiye and Beyce centers were affected from this earthquake. The earthquake caused the landslips in the Valley of Yağcılı River that located in the northwest of the study area and the deformations of railway nearby of Beyce. Furthermore, several houses, mosques and official buildings were collapsed during the earthquake according to records (Pınar & Lahn, 1952; Eyidoğan et al., 1991). Ambraseys (2001) reported the magnitude of Bergama earthquake of 1919 as 6.88.

Shortly, the geometrical relationship between the faults of graben edge and the epicenter distributions of the earthquakes (Apps. 2A, B, C and D) shows that the most of the faults controlled the edge of Soma graben are active and has the potential of earthquake formation.

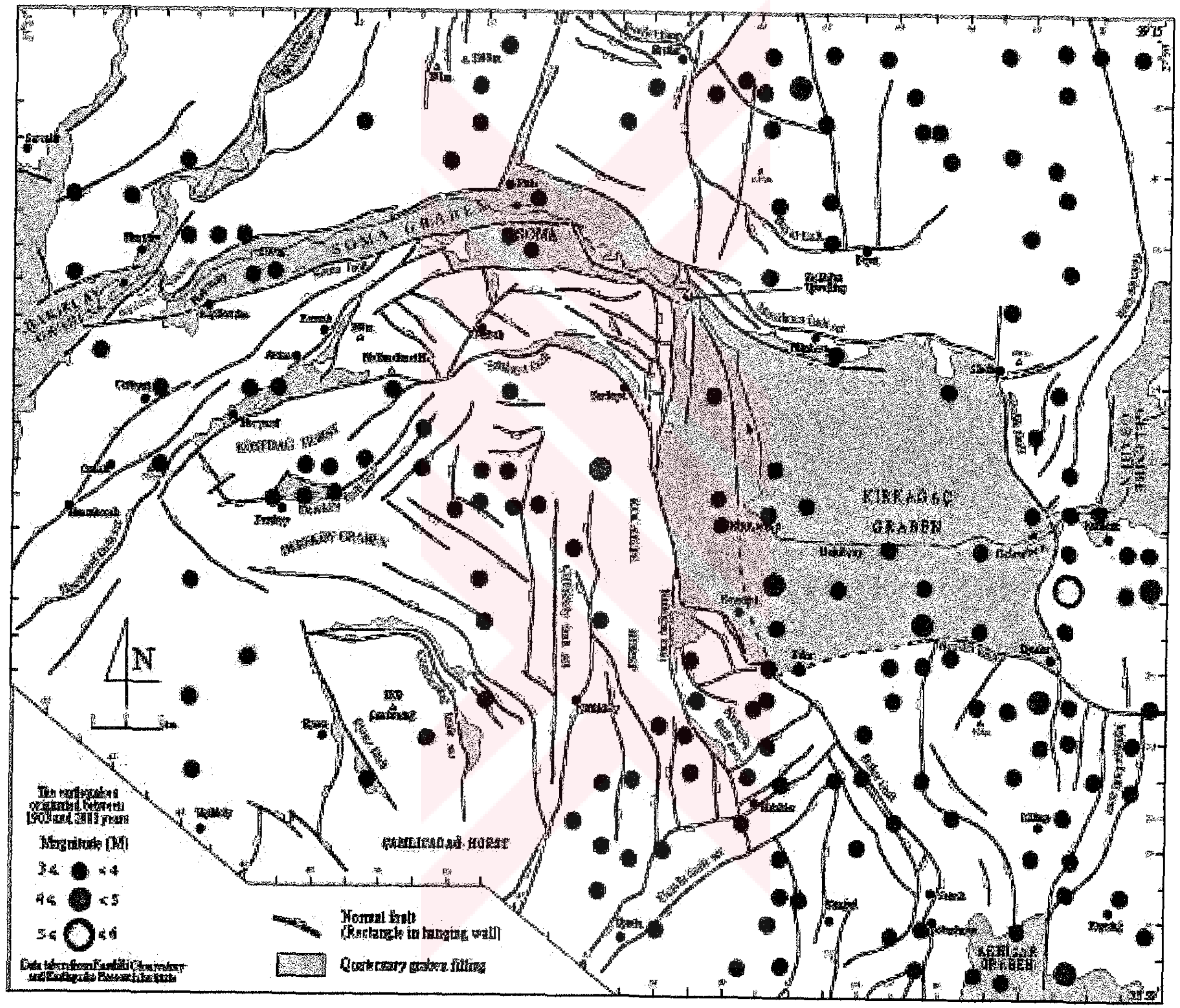


Figure 6.1 Seismotectonic map of Soma and Kırkağaç grabens and surroundings

CHAPTER SEVEN

CONCLUSIONS

Plio-Quaternary sequence in Soma district was firstly established in this study. The relationship between this sequence and the fault zone that restrict the grabens were researched and exposed the geometry of sequence.

The basement rocks in the study area are Mesozoic flysch-type siliciclastic and carbonate rocks of the İzmir-Ankara zone and lignite-bearing Miocene Soma and Deniş formations. The grabens of the study area developed on these basement.

The matrix in the flysch facies consists of mainly grayish-brown colored thin grained sandstone, less siliceous shale, mudstone and turbiditic conglomerates. The size of platform-type Mesozoic limestones changes from block to mass that reaches several kilometers in flysch matrix.

The Miocene coal-bearing sequence (Soma and Deniş Formations) in the study area overlies unconformably clastic and carbonate rocks of İzmir-Ankara Zone.

Soma Formation are represented by conglomerate, sandstone, mudstone, limestone and the Lower Lignite seam (average 20 m) which deposited in perennial lake-fan delta system (İnci, 2001). The formation is approximately 325 m in thickness.

Deniş Formation are composed of from bottom to top coarse and fine grained clastic rocks that deposited in braided river system, Upper Lignite zone, volcaniclastic apron deposits and shallow lacustrine rocks (İnci, 1998b and 2002).

Plio-Quaternary sequence rests unconformably on the basement rocks and it is divided into several facies that made of alluvial and colluvial deposits.

Kumköy Formation is generally represented by red-brown and greenish colored clastic rocks and whitisih colored carbonate rocks and rests unconformably on the Deniş Formation. The total thickness of Kumköy Formation is 200-250 m. Yeşilyurt and Taner (1999) gave the Late Pliocene (Romanian) age for this formation depending on characteristic fauna of the formation.

Alluvial fan deposits is observed along Soma graben. These deposits are covered by recent colluvial deposits and represent fan morphology. It comprises gravels originated from older deposits. The thickness is more than 70 m.

Fine grained flood deposits which accumulated in the nearby places of river beds forms recent alluvial deposits. The thickness of recent alluvial deposits changes from 50 m to 250 m.

The basement rocks in the study area were deformed and folded. Plio-Quternary sequence low-deformed. The age of the folds that indicate the compressional period is Pliocene.

The kinematic analyses show that the faults are oblique-slip normal faults and they have right and left-lateral strike-slip components.

The faults control the southern margin of the Soma graben are more dominant and active than the other faults relatively. For this reason the graben has been developing asymmetrical.

Several faults and fault zones were mapped in detail and named in this study.

The total vertical slip during Quaternary period (1,6 my) along the faults that control the southern margin of the Soma graben is 575 m. The vertical deformation rate is about 0,36 mm/year in the graben.

The total vertical slip and the size of the faults indicate that the region has middle scale earthquake risk and the repetition interval is wide.

Population increase, urbanization and industrialization in last decades make solid waste management related problems complex. Because of the Soma openpite coal mining area, the solid waste management system of study area has to challenge numerous multi-dimensional (soil, water and air) and multi-attribute problems.

CHAPTER EIGHT

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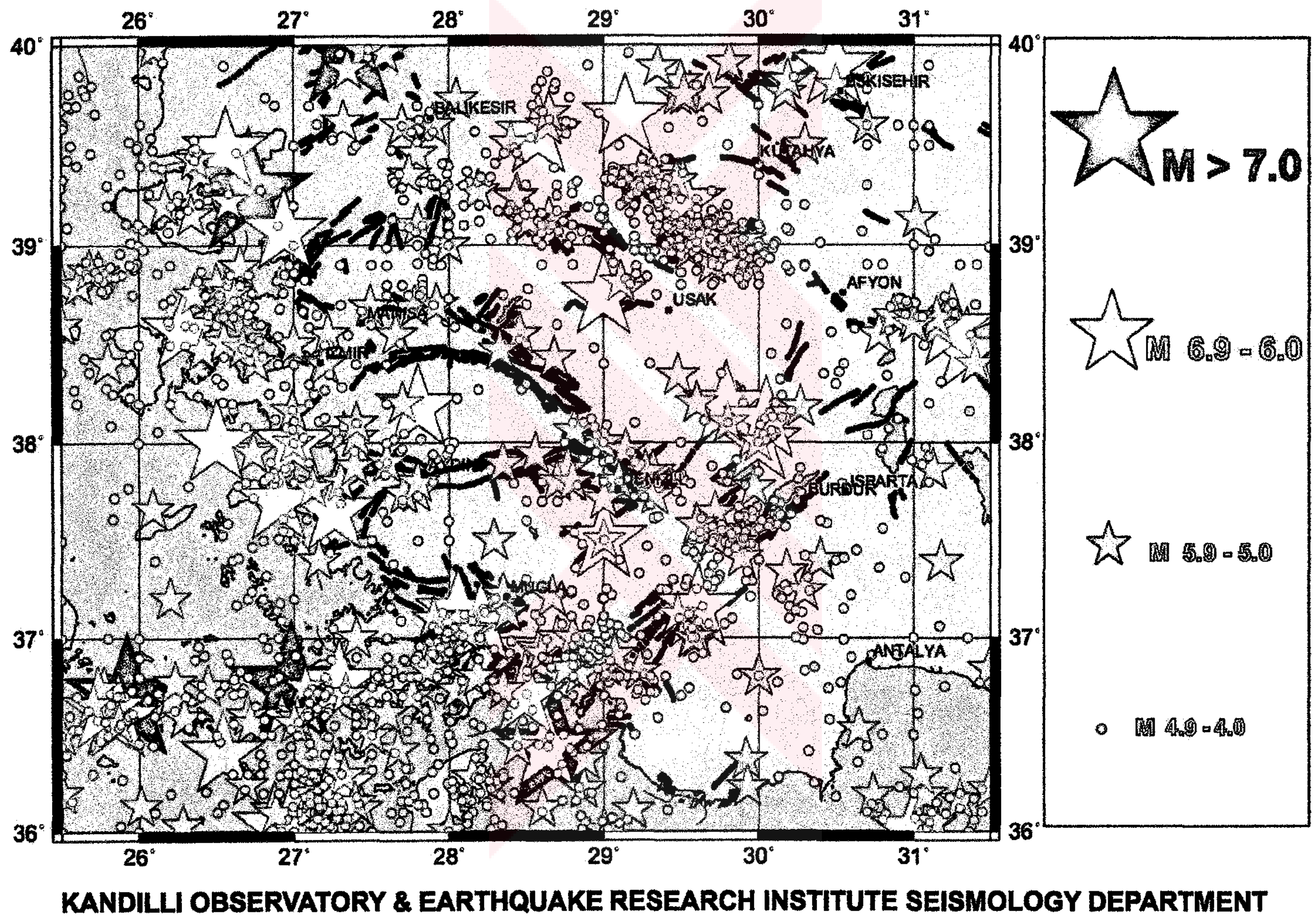
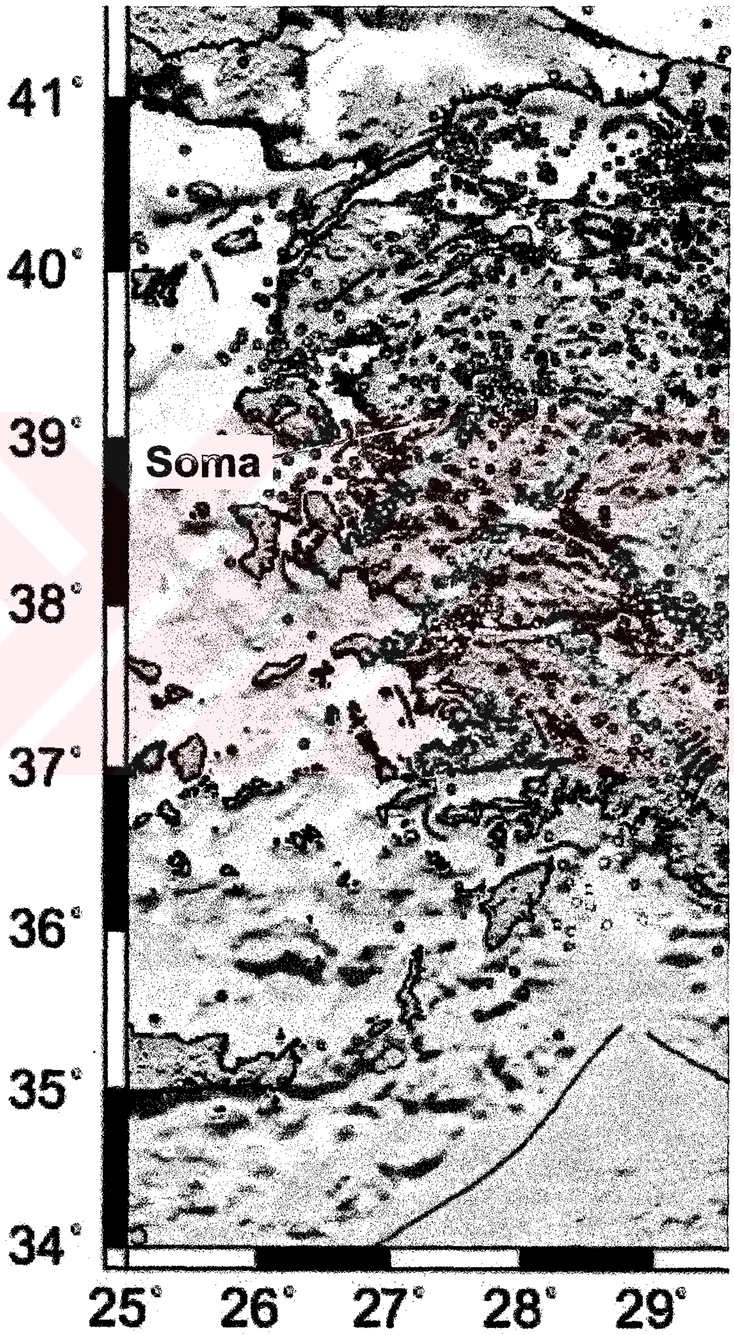
Appendix 1. Distribution map of the earthquakes (M>4.0) between the years 1900 and 2003 years according to the regions (WEB_1, 2003).



Appendix 2. Earthquakes within the last 4 years in the Aegean region (A, B, C and D)

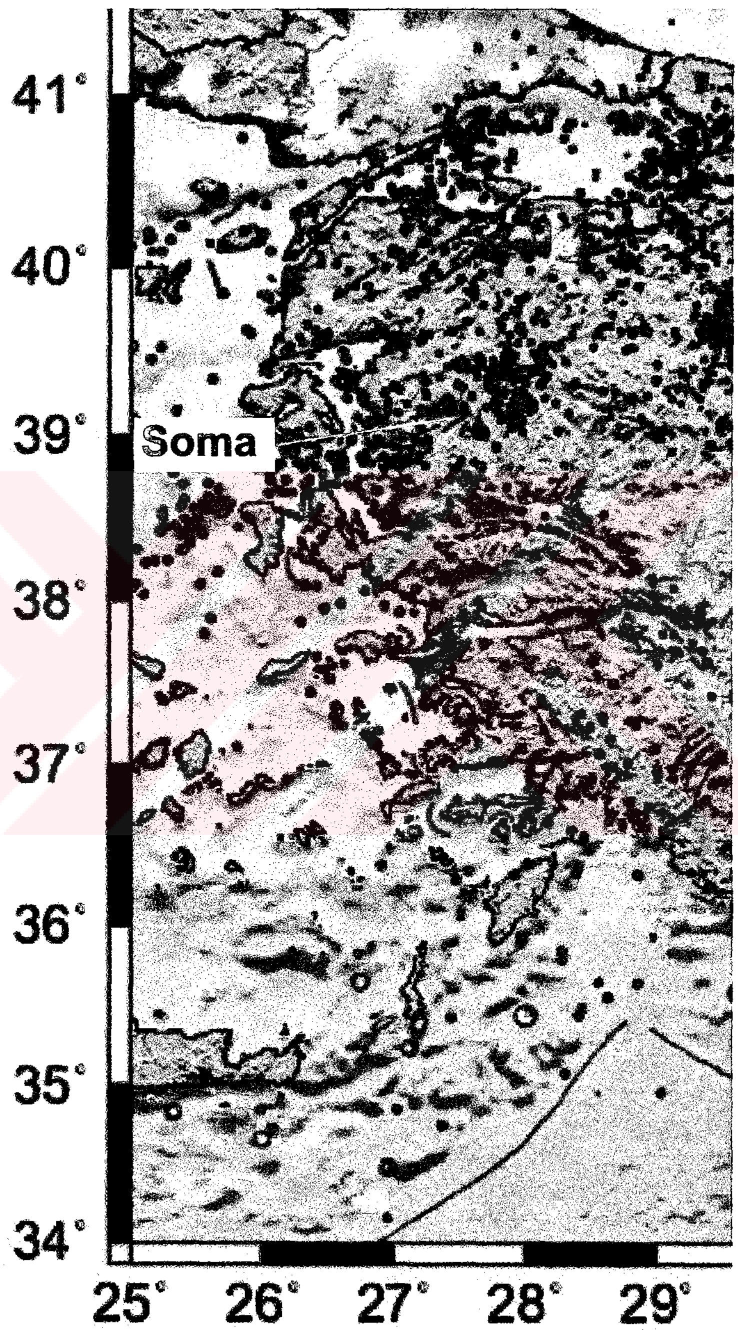
A

The earthquakes occured in 2000



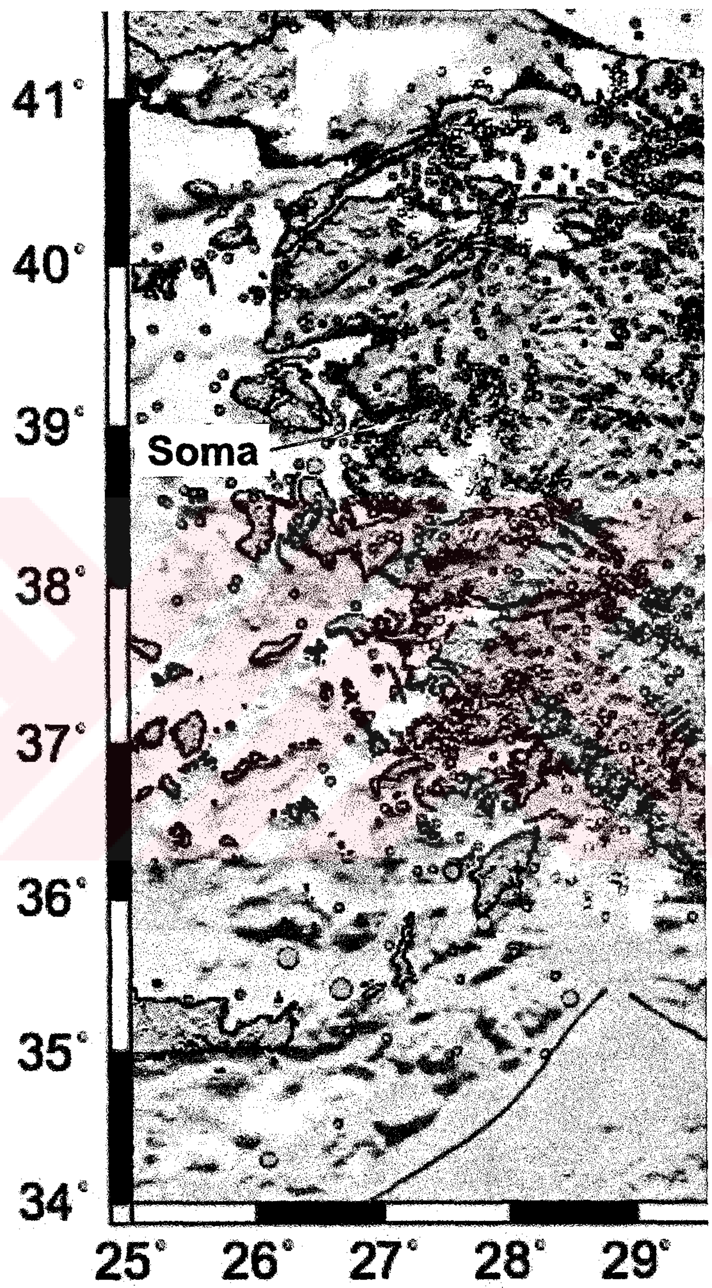
B

The earthquakes occured in 2001



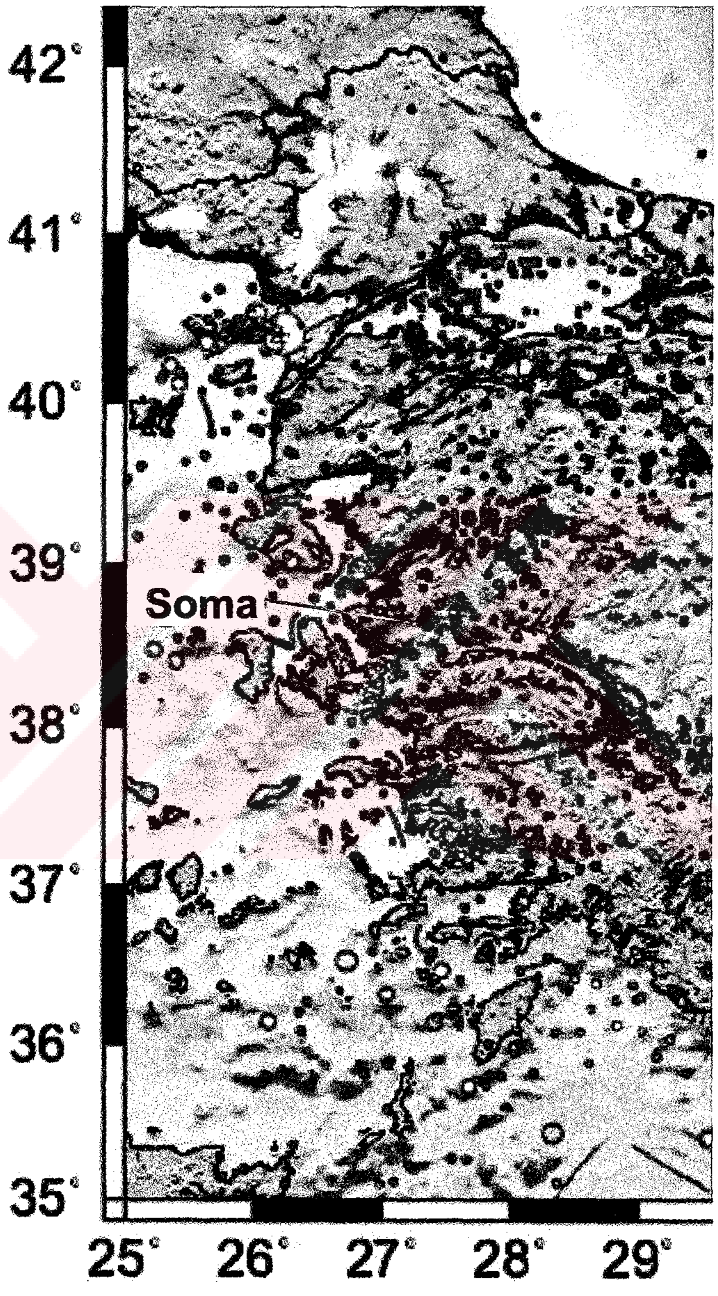
C

The earthquakes occured in 2002



D

The earthquakes occured in 2003



Appendix 3. Detail descriptions of the sedimentary features and paleoenvironmental interpretations of the facies.

Facies	Sedimentary features	Interpretation
Gms, matrix-supported conglomerate	Grain size 1-20 cm; non stratified and thick bedded	Slow flowing of sediment debris accumulated in inclined slopes
Sg, gravelly sandstone	Thick (< 15 m); reddish-brownish colored, thick bedded	Rreworking by flood flows which excessive sediment loaded
Gt, trough cross-bedded conglomerate	Thick (1-2 m); grain supported, middle-fine sorted, large scale	Channel fillings or transversal conglomerate bars.
Gp, planar cross-bedded conglomerate	Thick (1-5 m); middle gravel size, middle-fine sorted	Channel fillings or transversal conglomerate bars
Gm, massive and fine-grained conglomerate	Rarely flat-bedded fine-grained	Longitudinal conglomerate bars of braided channel
Sm, sandstone	Coarse-fine grained	Accumulation in shallow channels that near main channel after big floods
Fm, thick bedded mudstone	Reddish and greenish colored and thick bedded	Flood channel which flow by excavation flood-plain sediments
Fc, claystone	Grey colored; middle-thick bedded	Accumulation in proximal flood plain environment
Fma, calcereous mudstone	Light grey colored; carbonate - bearing	Flood plains where pedogenic conditions
Lm, sandy limestone	Whitish colored, thick-bedded and micritic	Small and shallow lacustrine and/or water heaps that near channel in flood plain
Sh, laminated fine-grained sandstone	Light greenish colored, flat-bedded; laminated; fine-grained	Mixing shallow river channels
Lo, pisolit-bearing limestone	Beige colored; thick-fine bedded; micritic textured; abundant gastropod fossils	Drying lacustrine and suffering diagenesis in subarial conditions
Gmc, slip surfaces bearing conglomerate	Blocky; soil matrix	Accumulation with small tectonic triggering