CHAPTER 5

Seismotectonics and Geology of Troia and Surrounding Areas, Northwest Anatolia

Y. Yılmaz

Kadir Has University, Cibali Merkez Kampüsü, Cibali, 34230-01 Cibali-Istanbul, Turkey

Abstract

The Troia area and the surroundings, in northwest Anatolia, are located between two most active fault zones. These zones have developed under the influence of the north Anatolian fault system coupled with the Aegean N-S extension.

These active fault systems have caused several severe earthquakes which damaged the Troia area.

The morphology and geology of the region have evolved under strong tectonic control. Major morphological features of the region such as the gulfs of Saroz and Edremit, the Çanakkale (Dardanelles) Strait and the Kazdağ high are young, post-early Pliocene entities. They formed when the transtensional tectonic regime in the Aegean began. One of the major products of this system are the listric normal faults. They caused back-tilting of the down-thrown blocks which, in turn, diverted the major drainage to the north. As a result, increasingly more clastic materials have been transported to the Troia area where a large alluvial plain has developed.

1 Introduction

This paper describes the tectonics and associated seismicity of the Troia area, which is situated in the northwestern tip of the Biga Peninsula (Fig. 1). These two subjects require treatment on a large scale, because they cannot be restricted to the size and limits of a small dwelling. Therefore, tectonics and associated seismicity of the region will be discussed, together with the Troia area within the limits of the available data.

Initially, tectonic forces that presently affect the region will be discussed. This will show how the region is deformed to, how these forces cause earthquakes, and then the geology of the region will be described in order to explain how the region has evolved through time.

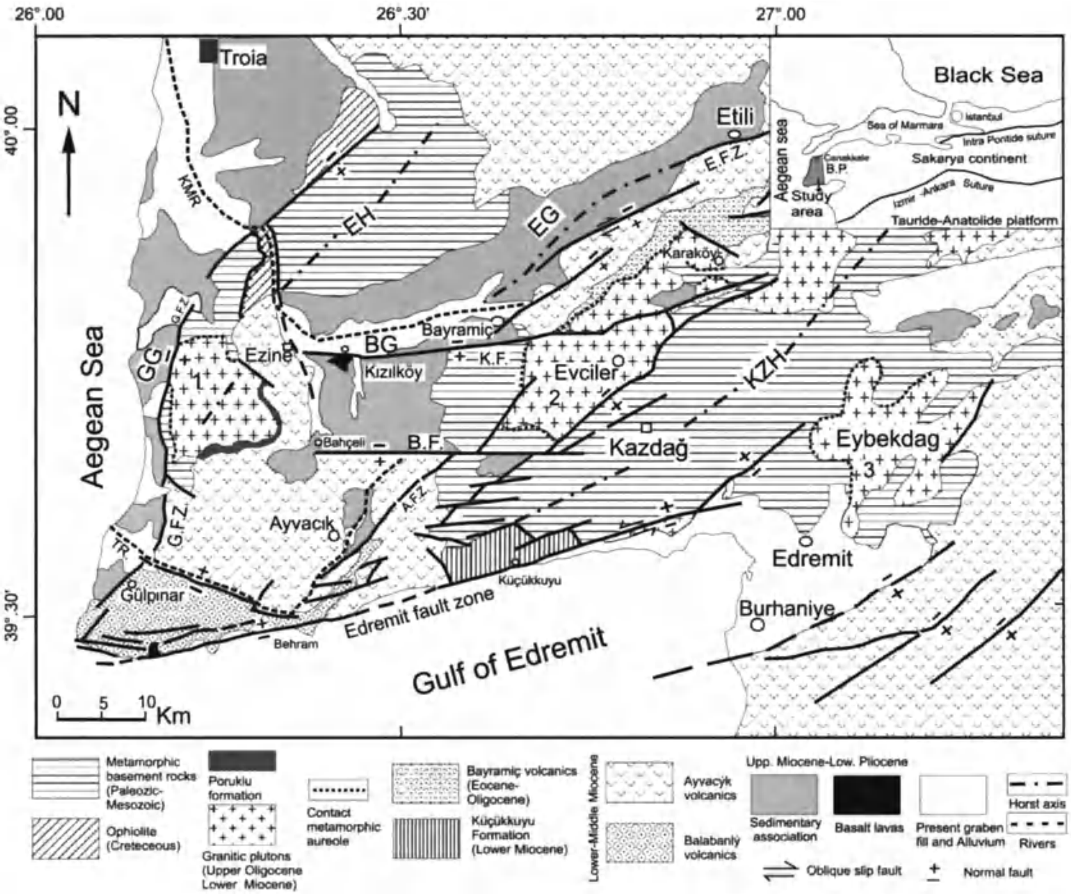

Fig. 1. Simplified geological map of the region to the north of the Gulf of Edremit. *GG* Gülpınar graben, *EH* Ezine horst, *EG* Etili graben, *KZH* Kazdağ horst, *BG* Bayramiç graben, *BF* Bahçeli fault, *KF* Kızılköy fault, *GFZ* Gülpınar fault zone, *AFZ* Ayvacık fault zone, *EFZ* Etili fault zone, *KMR* Karamenderes River, *TR* Tuzla River. *1* Kestanbol pluton, *2* Evciler pluton, *3* Eybek pluton, *BP* Biga Peninsula. The *inset* shows the study area within the context of the tectonic divisions of Turkey. (After Yılmaz & Karacık 2001)

2
Tectonics and Seismicity

The Aegean region represents one of the rapidly extending continental regions of the world (McKenzie and Yılmaz 1991 and the references therein). It extends in an approximate north–south direction. Major products of this continental extension are a number of grabens which run approximately E–W in the southern regions and ENE–WSW in the northern regions. The grabens are bordered by a set of either normal faults or oblique faults which have considerable strike-slip components. Around these structural depressions seismic activity is intense and has been recorded instrumentally (Fig. 2).

Determination of the time of initiation of the modern graben basins can be estimated from the present strain rate and the total amount of extension. Using a variety of techniques, the present rate of extension has been calculated to be of ca. 2.5–6 cm a^{-1} over a distance of ca. 800 km between Bulgaria and the Mediterranean (LePichon and Angellier 1979; Jackson and McKenzie 1988; Exström and England 1989; Main and Burton 1989; Sellers and Cross 1989; Westaway 1994). The β-factor of extension has been calculated from various sets of data, including: (1) topographic data, employing the Airy isostatic balance; (2) gravity data (Makris and Stobbe 1984; Meissner et al. 1987) and (3) seismic data (Makris and Stobbe 1984; Mindevalli and Mitchell 1989), obtained particularly from the wide grabens of western Anatolia (i.e., the Büyük Menderes and Gediz Grabens). This ranges from 1.2 to 1.6 in the land areas to 2 in the Aegean Sea. Using these data sets, the time period extrapolated for the amount of extension is less than 5 Ma.

Among the tectonic processes responsible for the Aegean extension, the major force is the westward extrusion of the Anatolian plate from the Karlıova area in eastern Anatolia, where the northward convergence between the Arabian plate and the East Anatolian accretionary prism (Şengör and Yılmaz 1981) has been continuing since their collision in the late Eocene (Yılmaz 1990; Fig. 3).

The westward escape of the Anatolian plate began to transfer the gravitational potential energy stored in the thickened East Anatolian crust, (38 to 50 km; M. Borazangi and N. Türkelli, pers. comm.) for approximately the last 3–4 Ma. The retreat of the Hellenic trench is viewed as another force being responsible for the Aegean extension, but this is secondary compared to the westward escape of Anatolia. According to Le Pichon (2000), the role of this secondary force in the Aegean extension is viewed as not more than one fifth of the total forces involved.

The present-day kinematics of the Anatolian-Aegean system are well constrained by GPS (Global Positioning System; Fig. 3) and SLR (Satellite

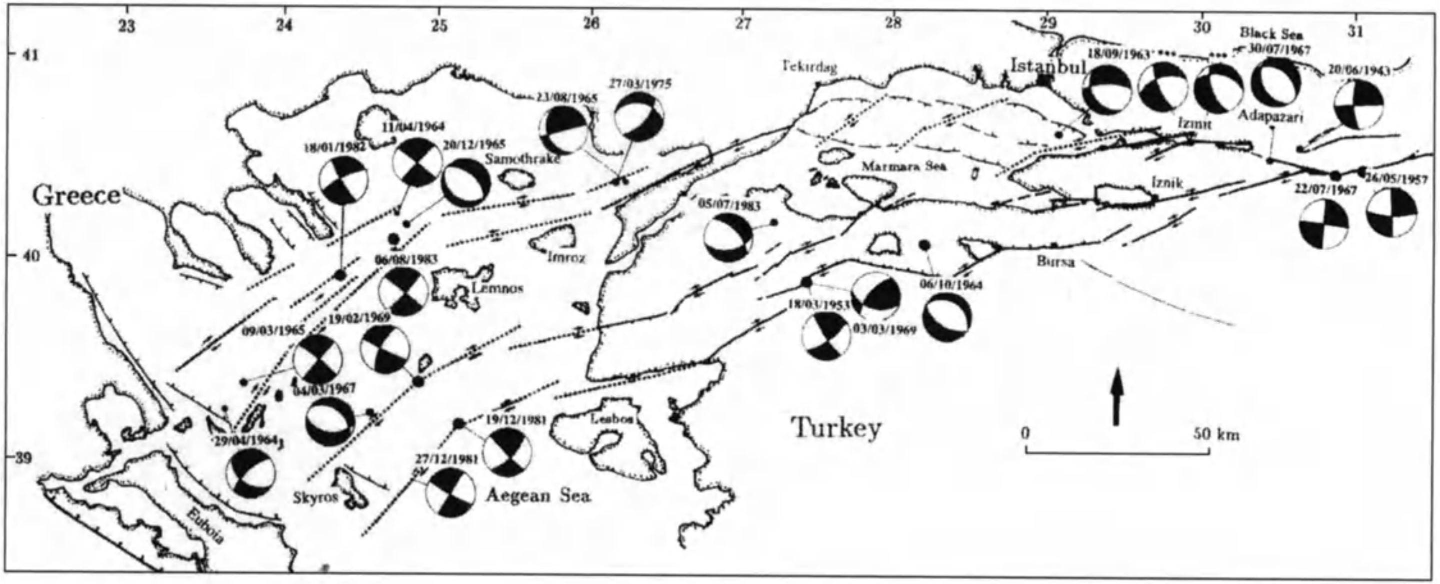

Fig. 2. Tectonic and seismicity map of the northern Anatolian-Aegean region, showing major fault zones and the fault plane solution of the big earthquakes. (After Barka 1992)

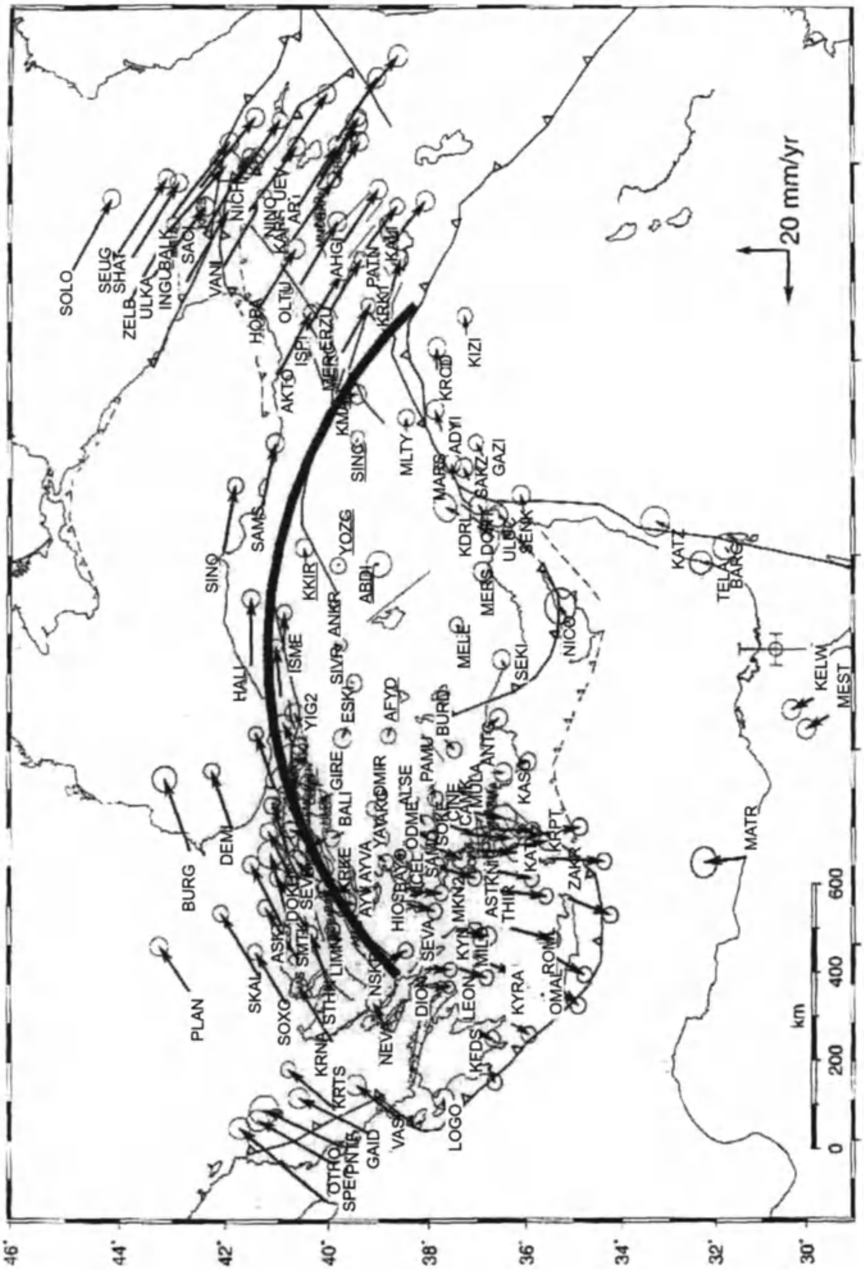

Fig. 3. The GPS vectors in the Anatolia and the Aegean region showing the present kinematics. (After McClusky et al. 2000)

Laser Ranging) measurements (Le Pichon et al. 1995; Reilinger et al. 1997) which indicate clearly that the Anatolian plate that is bounded by the north and east Anatolian fault zones is moving westward at a rate of about 20 mm/a. This motion makes a relatively sharp turn to SW around 30°N meridian. In western Turkey the motion has increased up to 40 mm/a due to the retreat of the Hellenic subduction.

The North Anatolian Fault (NAF) splays into two major branches before it enters into the Marmara region (Fig. 2) where it is buried under the waters of the Marmara Sea, and then appears again as a single trace in the Ganos-Saroz fault zone in the west. The southern branch is traced continuously to the eastern part of the Marmara Sea. From thereon, the fault splay is more complicated and does not extend as a single trace. Major strike-slip branches of the NAF are taken up by a zone of diffuse transtensional deformation. A number of subparallel, right-lateral strike-slip fault branches are formed in northwestern Anatolia. One of these fault branches trends toward the Edremit area (Fig. 2). Strike-slip motions, which prevail in the Marmara region according to field and seismic data (Barka 1992), are replaced by an oblique slip motion entering the Aegean Sea, where the Aegean extensional regime becomes dominant. Therefore, in this region, the oblique slip faults having major dip-slip motion coupled with strike-slip motion are common structural features (Taymaz et al. 1991). This region has strong background seismicity and major faults that have produced numerous earthquakes. Distribution of the earthquakes obtained from the historical data (Ergin et al. 1967) and from the United States Geological Survey (USGS) and National Earthquake Information Centre (NEIC) catalogues are displayed in Fig. 4 and tabulated in Table 1. The data, evaluated collectively, cover a 2000-year period and display clearly that the earthquakes are clustered along two tectonically most active zones. These are the Saroz bay and its western prolongation toward the North Aegean Trough in the north, and the western part of the Gulf of Edremit in the south (Fig. 2). Since geology and seismicity of these zones are detailed elsewhere (Taymaz et al. 1991; Yılmaz et al. 1999), they will not be repeated here again.

The conclusion of the seismological data may be summarized as follows. The city of Troia is situated within a tectonically active region, occurring between these two seismically most active fault zones of the region (Fig. 2). The city is surrounded by a number of active small faults; it is only about 50 km away from these two major fault systems. These major fault zones have produced many earthquakes greater than magnitude 6 in the past (Table 1). Periodicity of these big earthquakes may be estimated to be about 110 a. The earthquakes with a magnitude between 5 and 6 appear to have occurred in 25–30-year intervals. Any earthquake greater than magnitude

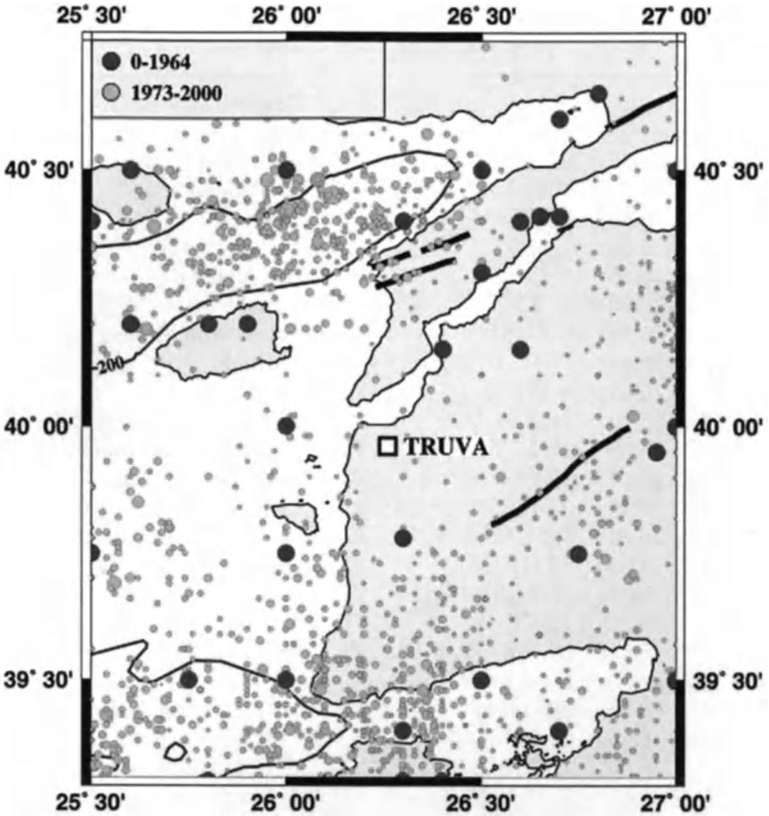

Fig. 4. Seismicity map of northwestern Anatolia and the surrounding regions (prepared by O. Tan and T. Taymaz). Data on the historical period are derived from Ergin et al. (1967), and for the instrumentally recorded earthquakes, from the Kandilli observatory (KOERI)

5 in and around these zones is assumed to have caused severe damage in the Troia area.

3 Morphology and Geology

Geology and morphology of the Biga Peninsula will be summarized from two regions, which are complimentary to one another, and both give a more complete history of the region. Firstly, the region north of the Gulf of Edremit will be described. In this region, the basement rocks and the early to middle Miocene units are exposed more extensively. Then the northern region surrounding the Çanakkale (Dardanelles) Strait will be presented.

Table 1. Major earthquakes recorded in the Troia and surrounding regions. (Data obtained from the catalogue prepared by Ergin et al. 1967)

No.	Lat.	Long.	Date	Io	Region
10	40.60	26.70	93	VI	Gelibolu peninsula
16	40.15	26.40	138	VI	Çanakkale
170	39.30	26.30	VIII-1384	VII	Lesbos
256	39.40	26.30	12-VI-1754	VI	Lesbos
264	40.15	26.40	2-XI-1762	VI	At Çanakkale
314	40.15	26.60	25-XI-1835	VI	Çanakkale
330	39.30	26.30	9-X-1845	VI	Lesbos and Manisa
334	40.41	26.65	19-IX-1846	VI	Gelibolu
336	40.41	26.65	4-VII-1847	VI	Gelibolu
364	40.20	25.80	21-VIII-1859	IX	Imroz
368	40.41	26.65	17/22-VIII-1860	VIII	Gelibolu, Chios and Edirne
381	40.30	26.50	10/14-VI-1864	VI	Gelibolu and Çanakkale
384	40.15	26.40	23-II-1865	VIII	Lesbos and Çanakkale Region
395	39.30	26.30	7-III-1867	VIII	Lesbos, Foca, Edremit and Ayvalik
396	40.41	26.65	20-III-1867	VI	Gelibolu
397	39.30	26.30	27/31-III-1867	VI	Edirne and Lesbos
398	39.30	26.30	22-VII-1867	VI	Lesbos
399	40.15	26.40	23-IV,17-V,30-VII, 5-VIII-1868	VI	Çanakkale
408	40.50	26.50	8-I-1870	VI	Vicinity of Saros Bay
419	40.41	26.65	11-X-1871	V	Gelibolu
425	40.30	26.50	13-XII-1872	VI	Gelibolu and Çanakkale
429	40.50	25.60	9-XI-1873	VII	Samotraki Island
439	40.15	26.40	III-1875	VII	Çanakkale
444	40.15	26.40	X-1875	VI	Çanakkale
453	40.15	26.40	25-X-1876	VI	Çanakkale
483	39.78	26.30	23-I-1884	VI	Ezine
511	39.30	26.30	III-1887	VI	Lesbos
529	39.30	26.30	13/15-VIII-1889	VI	Lesbos
530	39.30	26.30	13/25-X-1889	VII	Lesbos, Chios and Izmir
532	39.30	26.30	25-IV and 5-V-1890	VI	Lesbos
553	40.50	25.60	28-I-1893	VII	Samotraki Island
566	40.41	26.70	14-I-1895	V	Gelibolu and Edirne
652	40.15	26.40	IV-1910	V	Çanakkale
663	40.50	27.00	9-VIII-1912	X	Murefte, Sarkoy
675	39.30	26.40	1,17-V-1914	V	Lesbos
681	39.30	26.40	26-IV-1916	V	Lesbos
684	39.30	26.40	4-XII-1916	V	Lesbos Island
688	39.30	26.30	20-VIII-1917	VI	Lesbos
693	39.30	26.30	XI-1920	VI	Lesbos
729	40.65	26.80	3-V-1928	VII	Saroz Bay
761	39.50	26.00	12-VII-1931		
849	39.50	26.00	6-VII-1937	III[a]	Io: Thessaloniki

Table 1 (continued)

No.	Lat.	Long.	Date	Io	Region
887	39.95	26.95	1-I-1939	VI	Candarlı
1089	39.40	26.70	6-X-1944		Ayvalık
1090	39.40	26.70	6-X-1944	X	Edremit Bay and villages in
1091	39.40	26.70	7-X-1944		its vicinity
1135	40.20	25.60	12-IV-1947		Bayramiç
1136	40.20	25.60	12-IV-1947		
1277	39.30	25.80	8-VII-1950	VII[a]	Aegean Sea
1306	40.20	25.60	13-XII-1951	IV[a]	Aegean Sea Io: Lemnos
1309	40.20	25.60	3-II-1952	VI[a]	Aegean Sea Io: Samothrace
1379	39.50	27.00	9-VI-1953		West Turkey
1412	39.50	25.75	17-V-1954	V[a]	Aegean Sea. Felt at Dikili and Çanakkale. Io: Lesbos
1469	40.40	26.30	6-I-1956		Aegean Sea, east of Gallipolis Island. Io: Alexendropolis
1519	39.26	26.27	20-XI-1956	IV[a]	Aegean Sea Io: Lesbos
1596	40.00	27.00	11-X-1957		Northwestern Turkey
1616	39.75	25.50	24-I-1958	VI[a]	Aegean Sea
1735	40.00	26.00	22-IV-1959		Northern Aegean Sea
1848	40.50	26.00	9-III-1960		Northern Aegean Sea
1956	39.75	26.00	11-V-1961		Near the west coast of Turkey
1979	39.50	26.50	30-VII-1961	IV[a]	Aegean Sea Io: Lesbos
1980	40.00	27.00	1-VIII-1961		Northwest Turkey
1984	39.75	26.75	24-VIII-1961		Western Turkey
2011	40.20	25.90	28-XI-1961		Western Turkey
2054	40.40	25.50	29-IX-1962		Samotrake Island
2080	40.40	26.60	29-III-1963	VI	Turkey, Io: Lapseki and Ayvacık

[a] Earthquakes epicentered in the Aegean Sea.

In this latter area, late Neogene and younger rocks occur widely. In the southern areas the western Anatolian extensional regime is more prominent while in the north, the north Anatolian fault system plays a more dominating role.

In the development of the landscape and drainage system of the region, tectonic control is evident. Some major morphological features and distinct lineaments draw attention. Among those, the approximately ENE–WSW trending Saroz bay in the north and gulf of Edremit in the south are very prominent (Fig. 2). They are joined by an approximately north–south trending rather straight fault-bound Aegean shoreline (Fig. 1). The Çanakkale (Dardanelles) Strait, which is situated between the two major sea depressions, is a zigzagging shallow seaway bounded by linear and steep cliffs.

On the land there are also distinct morphological entities, such as the Kazdağ and Ezine highs intervened by the Bayramiç depression (Fig. 1). They correspond to horst and graben structures. Toward these the gulf of Edremit as the widest graben depression trends obliquely (Fig. 1). The linear coastlines are commonly fault-bounded.

The Edremit graben is one of the largest ENE–WSW trending grabens of western Anatolia (Fig. 1). It is about 80 km long and enlarges westward from about 5 km to more than 30 km. The graben is asymmetrical. The topography along the southern margin is subdued, forming many bays and inlets. The northern margin is bounded by a linear mountain front, which elevates to Kazdağ Mountain, over 1100 m. In the eastern part of the northern margin, there is a big, steep cliff along the coastline corresponding to a clear fault scarp (Fig. 5), which is commonly well exposed. Various drainage patterns on the down-slope side of the fault such as beheading, misaligned paired stream channels indicate important left lateral offset along the fault.

To the west of Küçükkuyu the topography along the western part of the northern margin of the Gulf of Edremit is more subdued. Big, steep cliffs are rare. The faults are oblique to the coastline, making narrow angles. At the intersection of these valleys with the coastline small alluvial fans have developed. A trellis drainage pattern with roughly parallel strike streams has been produced due mainly to multiple fault strands, shutter ridges and the associated back-tilting (Fig. 5). Rapid vertical movement along the faults are also evident in the central part, where elevated marine terraces and beaches occur, lying about 80–100 m above sea level between Küçükkuyu and Behram (Fig. 1). Paton (1992) identified lithophage borings about 2 km west of Behram, which were uplifted to the height of 8 m above the sea.

The topography on the different slopes of the Kazdağ; Mountain is distinctly asymmetrical. It is steep in the south, but relatively smooth along the northern slope, where there are E–W trending, north-dipping (>60°) normal faults (Figs. 1 and 5). On the steep southern slope fluvially eroded landscapes have not yet fully formed. Headward erosion along the stream valleys across both slopes of Kazdağ Mountain, particularly in the southern slope is in a very incipient stage. No major, deeply incised valleys have formed to drain the smoothly north-dipping plateau, which is over 350 m above the sea, into the gulf, because the major linear mountain front of the Kazdağ Mountain and the terraces at the top have been slightly back-tilted to the north (Fig. 5). Therefore, the Kazdağ Mountain forms a barrier in front of the southerly directed drainage preventing it from reaching the gulf in the shortest distance possible (Fig. 5). As a result, the drainage is diverted northward toward the Aegean Sea, and along this direction the main rivers, the Karamenderes and Tuzla Rivers follow courses more than 40 and 25 km, respectively, before reaching the sea (Fig. 5).

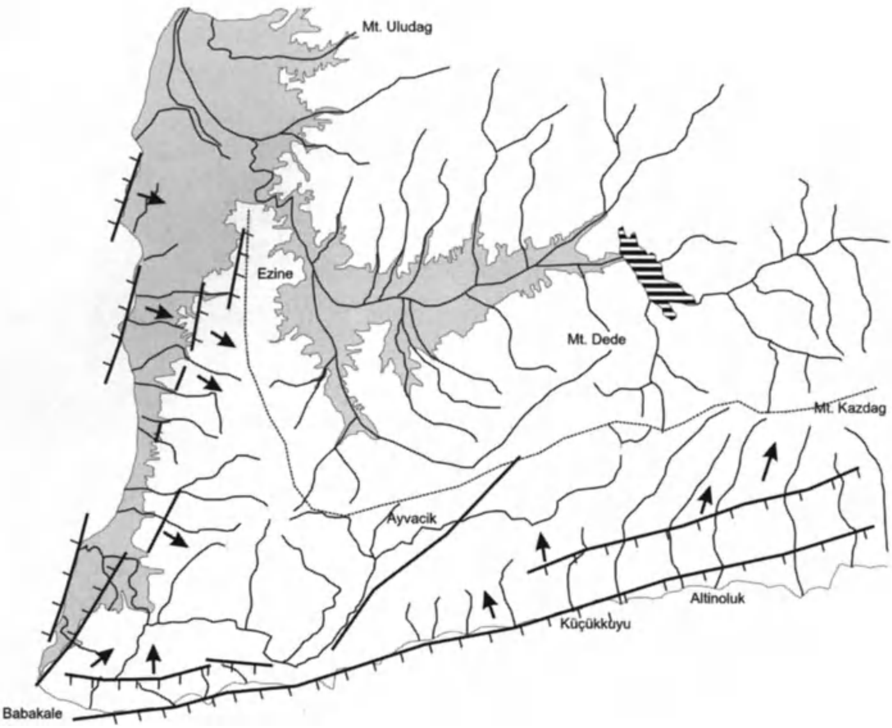

Fig. 5. Map showing drainage pattern and major fault zone in the western part of the Biga Peninsula. The *arrows* indicate the tilting direction of the fault blocks. The *hatched areas* indicate downthrown side of faults. The *dotted thin line* is the water divide

At the top of the Kazdağ Mountain remnants of a flattop plateau representing a severe phase of erosion are recognized (Erol 1992). On the northern slope, near the top, a cuesta is visible due to modest north tilting of this erosional surface. The remnants of this surface can also be recognized as small buttes at the top of the fault-bounded blocks in the northern part of the mountain range. Due to the back-tilting in the west and the south, the Menderes River makes a sharp turn as it is forced to flow northward and reaches the sea in the Troia region (Fig. 5). The present morphotectonics of the area is displayed in the simplified block diagram (Fig. 6). Continuous uplift of the Kazdağ with an approximately 2 mm/a concomitant erosion increasingly supply alluvial materials transported to the sea. This appears to be an important reason for the rapid growth of the alluvial plain which fills the Troia area, causing its progressive dissection from the sea.

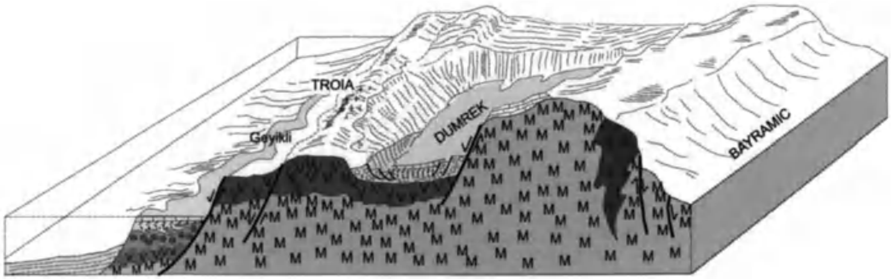

Fig. 6. Schematic block diagram showing major morphotectonic features of the Troia area and the surroundings

4
Stratigraphy

The stratigraphy of the region will be documented below from the horsts and grabens separately, because they have rather different successions.

4.1
The Ezine and Kazdağ Horsts

The two horsts share many similar geological features. The stratigraphic sequences in the horsts are displayed in Fig. 7. At the base of the sequence, metamorphic rocks of Paleozoic to Triassic ages are exposed (Bingöl et al. 1973; Okay et al. 1990; Öngen 1994; Genç and Yılmaz 1995; Yılmaz 1997; Karacık and Yılmaz 1998).

Plutonic rocks were emplaced into the metamorphic rocks during the late Oligocene–early Miocene period, i.e., the Karaköy-Evciler and Kestanbol plutons (Fig. 1). They are dated by the Rb/Sr method at 25 ± 0.2 Ma (Birkle and Satır 1995) and 28 ± 0.88 Ma (Fytikas et al. 1976), respectively. The plutons are elliptical with long axes lying in NNE–SSW directions as revealed by the map pattern of the contact metamorphic aureoles (Fig. 1). The plutons were emplaced using the faults and fractures trending NE or NNE, formed under an approximately ENE–WSW extension. There are close temporal and spatial associations of the plutonic and surrounding hypabyssal rocks, which in turn, are also intermingled with the surrounding volcanic rocks of Lower Miocene in age, the Ayvacık and Balabanlı volcanics (Fig. 1).

The lowermost rocks of the cover succession form a sedimentary sequence, the Küçükkuyu formation, represented by alternating shale, siltstone and sandstone. The shales dominate the sequence. This unit was ap-

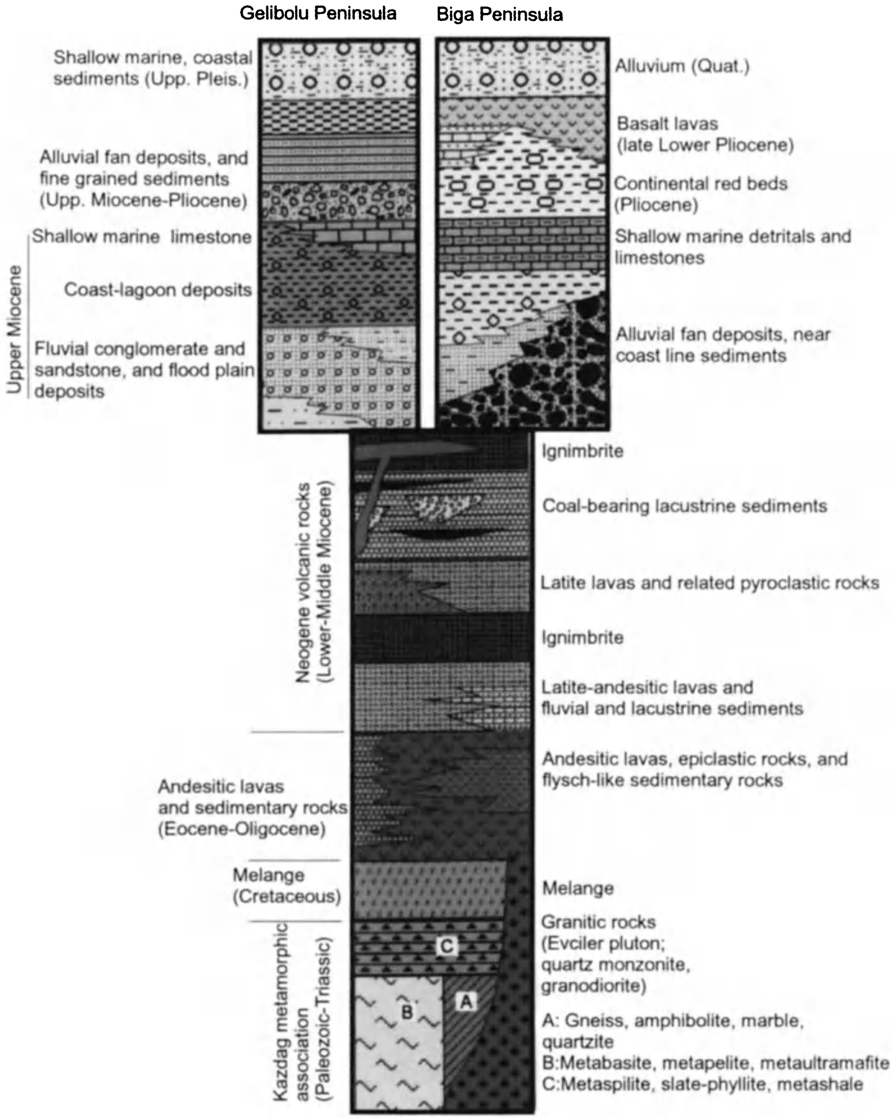

Fig. 7. Generalized stratigraphic sections for the Gelibolu and Biga peninsulas displaying the rock units around the Troia area

parently deposited in a low-energy lacustrine environment (Siyako et al. 1989). However, due to the flysch-like nature, it may be regarded as a unit deposited on a smoothly inclined slope (Fig. 8). According to the sporomorph association obtained from the shales, the Küçükkuyu formation is dated by İnci (1984) as the Lower Miocene. Above this, volcanic rocks, mostly pyroclastic beds, occur within the sequence. To the northwest of Kazdağ near the Kızılyar village the sequence begins with internally chaotic, red-colored coarse conglomerates. They were deposited in front of a NNW–SSE trending, closely (<1 km) spaced, en echelon oblique slip-fault zone, which had lateral slip and dip-slip components. The sediments are debris flow and lateral fan deposits, derived from the fault-elevated blocks. The conglomerate passes laterally and vertically into beige sandstones and gray shales, interfingered with the volcanic rocks.

The sequences in which the volcanic rocks dominate are known as the Ayvacık volcanics, which consist mainly of intermediate lavas and pyroclastic rocks. The petrological and field characteristics of these volcanic rocks are elaborated by Karacık and Yılmaz (1998) and Genç (1998). The lavas were formed close to the axis of the horsts. They are replaced gradually by lahars and pyroclastic flow deposits and pyroclastic fall deposits away from the axes of culminations (Fig. 8). The pyroclastic units were graded depending on their proximity to the volcanoes. This distribution pattern may be inferred to indicate that the NE trending volcanoes were developed above the plutons from the faults and cracks, formed in association with the granite emplacement. The pyroclastic and the epiclastic deposits are more voluminous in the southern areas (the Balabanlı volcanics) than in the northern areas (the Ayvacık volcanics). However, they interfinger on every scale.

The sediments intercalated with the Ayvacık volcanics are paleontologically dated, based on the Eskihisar sporomorph association as the late Burdigalian-early Serravallian in age (Ediger 1988; Benda and Meulenkamp 1979). This is in agreement with the K/Ar ages, obtained from the intermediate lavas, which range from 15.9 ± 0.4 to 21.5 Ma. (Borsi et al. 1972; Ercan et al. 1995). The Lower–Middle Miocene successions were deformed by folds and faults and later uplifted and eroded, prior to the deposition of the Upper Miocene units.

4.2 The Etili Graben

Deposition of the Upper Miocene rocks was restricted to the graben basins. They rest on top of the Küçükkuyu formation and/or the Ayvacık volcanics over a surface of unconformity. The Upper Miocene sediments are delimited commonly by NE–SW trending faults (Fig. 1).

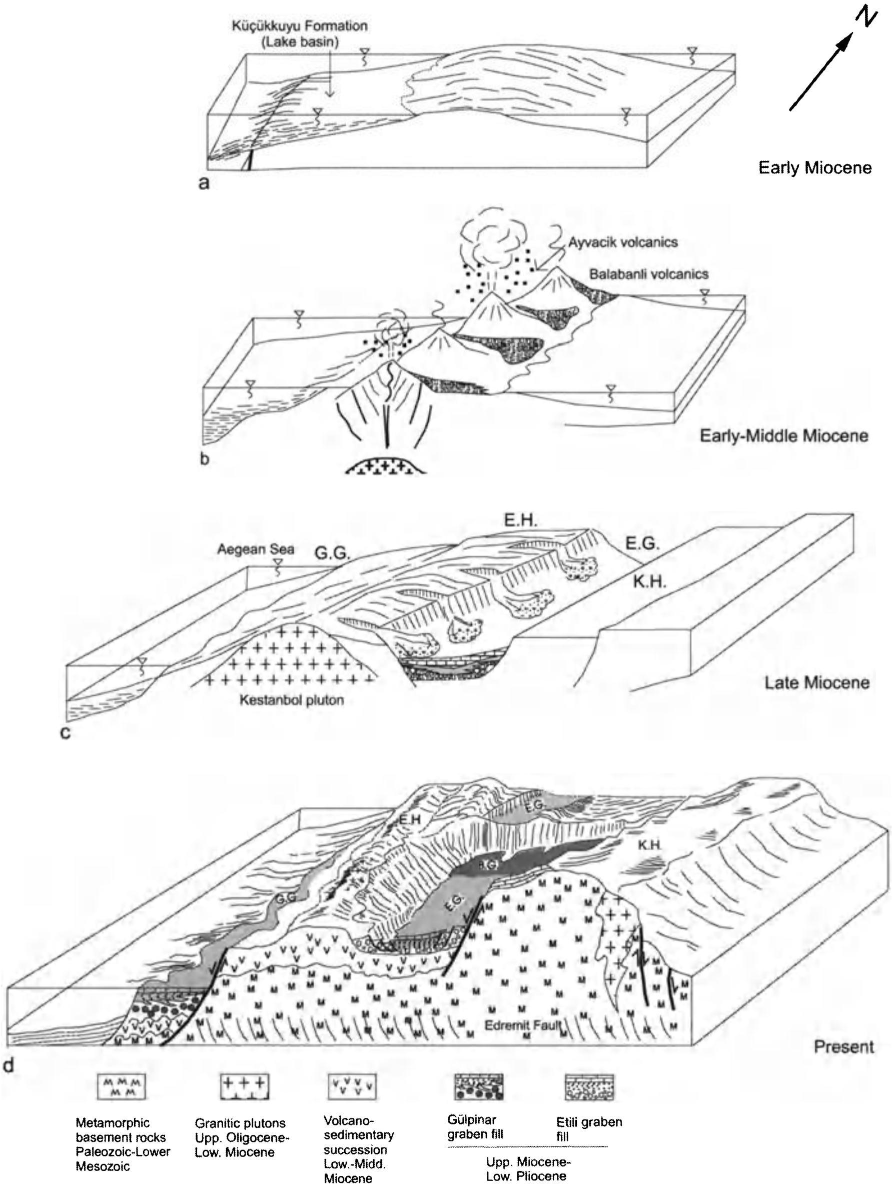

Fig. 8a–d. Schematic block diagrams showing consecutive stages of morphotectonic evolution of the western part of the Biga Peninsula from Early Miocene to the present. The Edremit fault represents the northern boundary of the Edremit graben. *GG* Gülpınar graben, *EH* Ezine horst, *EG* Etili graben, *BG* Bayramiç graben, *KH* Kazdağ horst

At the base of the sequence are thick, brown to red-colored, coarse conglomerates lying in front of the upthrown blocks. They are internally chaotic, and were formed as debris flow and fanglomerates. Away from the fault zone the conglomerates give way to fine-grained clastics, which in turn, are gradually replaced by white, medium to thickly bedded, clayey limestones having, in places, abundant fresh water gastropoda-rich fauna. Only a few scattered alkaline basalt lavas, dated at 9–3 Ma (Yılmaz 1997), are observed to be interbedded with the fine to coarse clastic rocks of the graben.

At higher levels in the sequence the lacustrine limestone overlap the upthrown blocks of the faults. The overlying succession may be traced southward toward the top of the Kazdağ Mountain. This suggests that during this period the Kazdağ Mountain was not yet elevated to the present position. The western boundary of the Etili graben is the Ezine horst. The Upper Miocene lacustrine succession is delimited by this elevation.

4.3
The Gülpınar Graben

This graben separated from the Ezine horst by the Gülpınar fault zone (Fig. 1), along which the Ezine high rises to over 300 m. The graben fill rests unconformably on the Ayvacık volcanics beginning with a 30–40 m thick conglomerate, followed by a sandstone-siltstone alternation (Fig. 7). They pass upwards into a 20–30 m thick, gently west-dipping, white limestone sequence. The western boundary of this unit is buried under the Aegean Sea. The succession at the base is represented by lacustrine facies sediments, which is replaced gradually by shallow marine units. Şamilgil (1966), Ozansoy (1973), Tekkaya (1973) and Kaya (1982) listed the following fauna from the limestones: *Pecten praebenedictus*, *Pecten pseudo-beudanti*, *Ostrea fibriata*, *Ostrea aff. edulis*, *Ostrea aff. Gryphoides*, which yield the Upper Miocene–Lower Pliocene age range. The facial and faunal characteristics reveal that the limestones represent a transitional environment of deposition, between marine and lake environment.

4.4
The Edremit, Bayramiç and Saroz Grabens

Three seismic sequences are clearly distinguished in the grabens. The lower and the middle units correspond to the Lower-Middle Miocene and the Upper Miocene-Lower Pliocene successions. Only the upper unit consisting generally of poorly consolidated clastics belongs to the present graben deposition. They are fan deposits and fluvial deposits, originating from the hills in the footwall. The age of the graben fill is not precisely dated. However, it may be estimated using the comparative stratigraphic data as the post Early Pliocene.

The small stream valleys across the northwestern slope of Kazdağ carry a huge amount of material into the Bayramiç graben. Large pebbles and boulders have accumulated along the southern edge of the graben as more than 50 m thick, unconsolidated or poorly consolidated conglomerates. Large clast size and poor sorting indicate proximity to the source revealing that a high rate of erosion from the Kazdağ high on either side of the horst has occurred only recently. The clasts are predominantly of metamorphic origin. Among the pebbles are also clasts of the Upper Miocene–Lower Pliocene limestones.

The geology and structural map of the region to the north of Troia is displayed in Fig. 9. On the map a fairly complicated fault pattern can be seen. Most of the faults have been formed after the Early Pliocene period as evidenced by the following data; the faults cut and postdate the Upper Miocene–Lower Pliocene limestones, cropping out at the plateau regions on both sides of the Çanakkale Strait. Two sets of oblique faults control the present zigzagging pattern of the Çanakkale Strait, causing abrupt changes in the trends of the strait. These faults are mostly transtensional in character, having strike-slip coupled commonly with dip-slip components. The straits were formed under these transtensional deformational forces. A number of normal-listric faults have been formed on both sides of the Çanakkale Strait, on the fault-elevated blocks which supply clastic materials on the downthrown blocks commonly as lateral fan deposits or debris flows.

The major fault sets are coeval, because they cut and offset one another and their development is compatible with a north–south extensional, east–west compressional deformation pattern. The consequent structural features have formed under an ongoing simple shear.

The rock sequence of this region is described in some detail by Önal (1986), Yazman (1996) and Yaltırak et al. (1998) and is summarized in Figs. 7 and 10.

As seen in Fig. 10, a gradual transition from a lake to a shallow sea occurred from the east to west through a lagoonal environment during the latest middle to late Miocene period. The sea gradually invaded the present coastal region during the late Miocene-early Pliocene period. The coastal environment is seen to have been established during Pleistocene-Holocene as evidenced by the presence of beach sands.

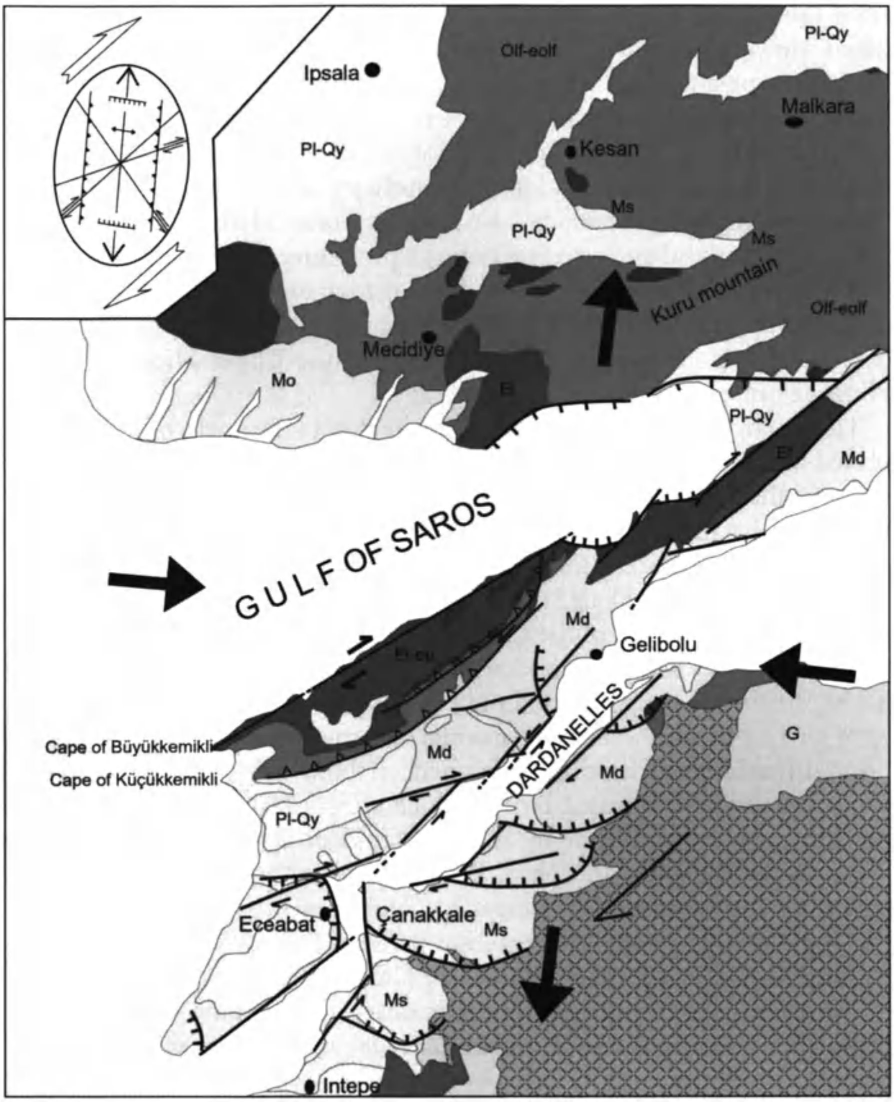

Fig. 9. Geology and structural map of the region around the Çanakkale strait. *Arrows* indicate compression and extension directions. The *inset* shows the deformation ellipsoid for a simple shear under which the region has deformed deformation

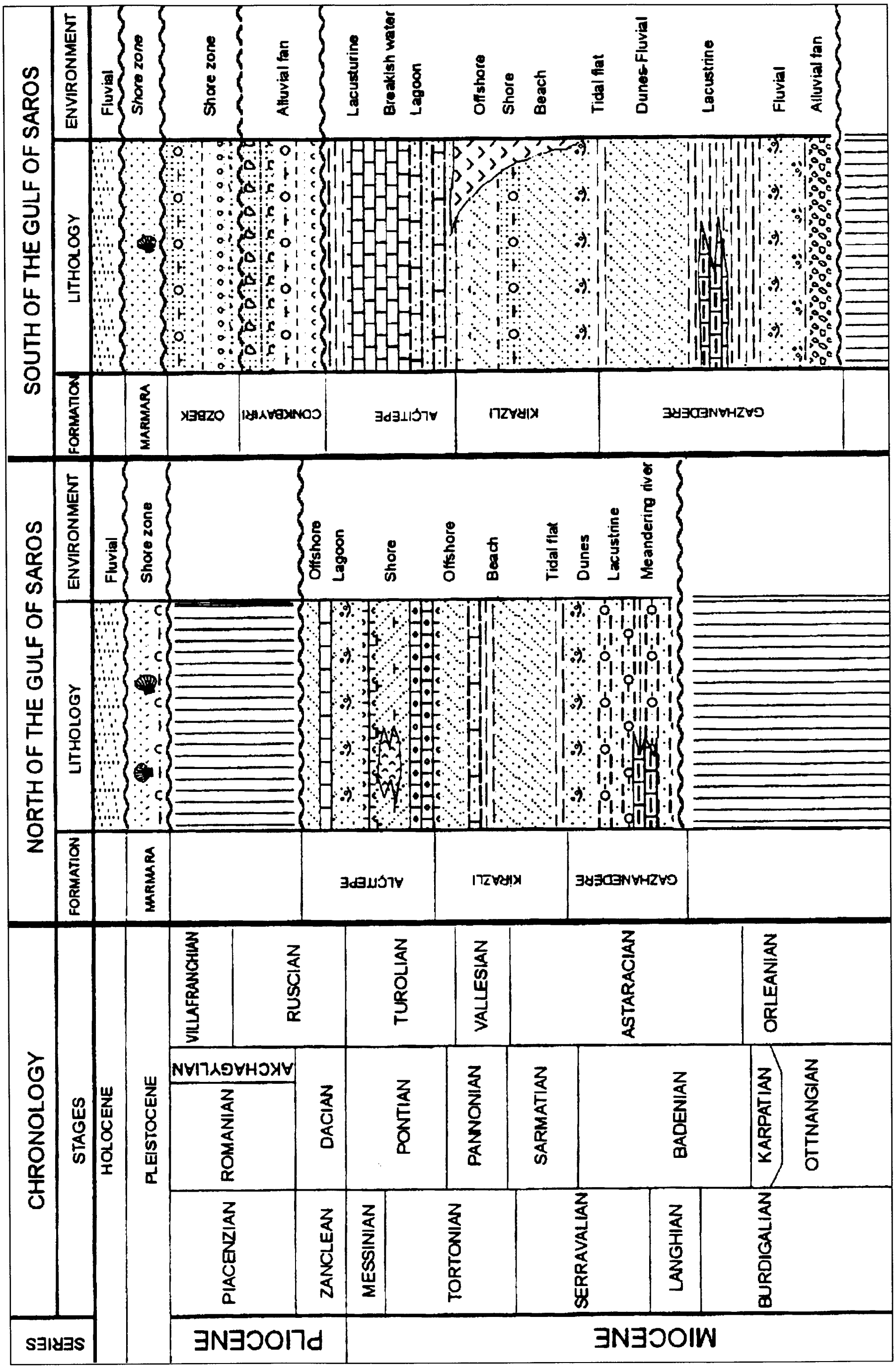

Fig. 10. Generalized stratigraphic sections for both sides of the gulf of Saroz. (After Yaltırak et al., 1998)

5
Discussion and Conclusions

When evaluated collectively, the rock sequences from the south to the north of the region studied, as illustrated in Figs. 7 and 10, suggest the following geological evolution (Fig. 8). During early Miocene, the western part of the Biga Peninsula was represented by a continental environment, covered by interconnecting lakes. Within the lake basins low energy lacustrine sediments, dominated by shales were deposited. A severe volcanic activity began during the early Miocene. The volcanoes were aligned along the north–northeast trending extensional faults. The volcanic alignment formed hill-like barriers and divided the lake basins. The pyroclastic rocks were transported away from the volcanoes and interbedded with the lake deposits. Widespread coal seams and beds of Neogene basins formed within these lakes.

The volcanic activity waned with the beginning of middle Miocene and the region was smoothened erosionally. This was followed by new tectonic activity. During this phase north–northeast trending major horsts, namely, the Kazdağ Mountains and the Ezine horst, began to elevate for the first time. Bounded by the transtensional oblique faults, the Etili graben and Gülpınar graben, intervened by the horsts, began to form as cross-grabens. Development of these basins are elaborated in Yılmaz et al. (2000) and Yılmaz and Karacık (2001).

These structural highs and lows were considerably obliterated after the early Pliocene time during a severe phase of denudation, and consequently a region-wide erosional surface was developed above all the units up to and including the Upper Miocene-Lower Pliocene lacustrine limestones. This erosional surface may be viewed as a peneplain, because a lateral transition from the continental deposits formed on the land toward the marine sediments within the present Aegean Sea, is generally gradational, which suggests a smooth topographical passage across the coastal zone.

The present elevation of the Kazdağ postdates this erosional phase. Remnants of the erosional surface are seen at the top of the Kazdağ Mountain, and the depositional equivalent of this uplifting is seen along the adjacent depressions as unconsolidated, poorly sorted coarse clastics accumulated rapidly above the Upper Miocene-Pliocene lake sediments (Yılmaz and Karacık 2001). The Kazdağ has been uplifted between the east–west-trending oblique fault system having major strike-slip motion coupled with considerable dip-slip component. These younger fault sets have formed under the influence of the North Anatolian Transform Fault zone, which is known to have dispersed within a large region in the Biga Peninsula (Yılmaz et al. 2000; Yılmaz and Karacık 2001; Güney et al. 2002).

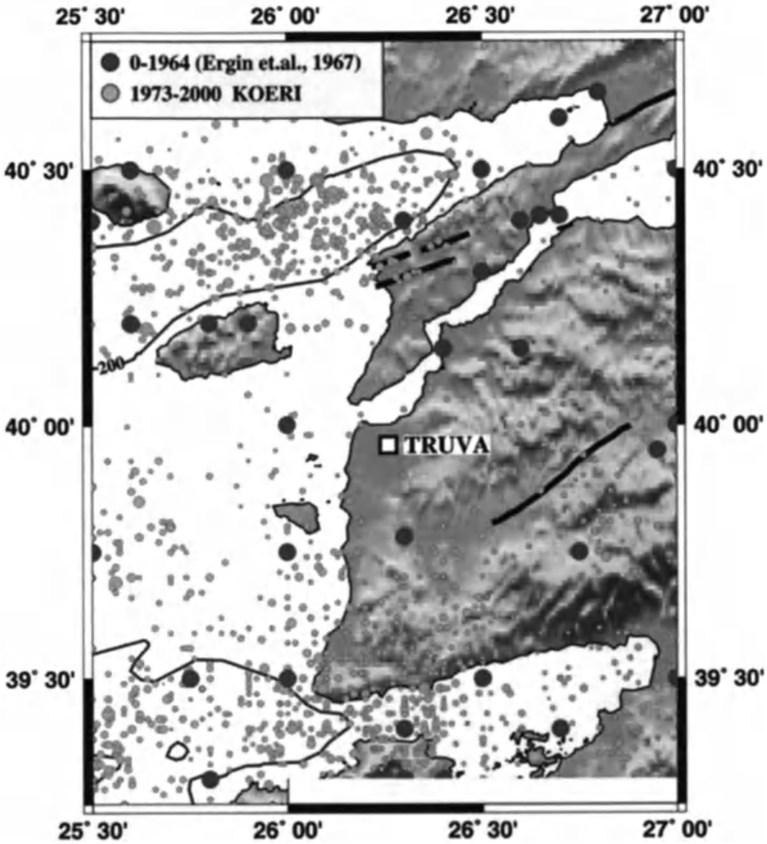

Fig. 11. Morphological map of the Troia area and surroundings

The north-northeast-trending Etili graben is also cut and bounded by a set of east-west-trending oblique faults which divert the trend of the basin to the east-west, and this newly developed asymmetrical basin formed at the western tip of the Etili graben is known as the Bayramiç graben.

The morphotectonic position of the Troia area, formed during the latest stage of the tectonic development of the region, is illustrated in Figs. 6 and 11.

The back-tilting due to the E-W and N-S striking faulting which controlled the drainage pattern, diverted the trends of the major rivers to the north and thus a large alluvial plain formed at the north of the Menderes river. The continuous uplift of the Kazdağ under the on-going transtensional regime supplies increasingly larger amount of materials into the alluvial plain.

Acknowledgements. I extend my sincere thanks to Prof. Dr. Tuncay Taymaz and Mr. Onur Tan for providing Figs. 4 and 11.