Turkish Journal of Earth Sciences (Turkish J. Earth Sci.), Vol. 18, 2009, pp. 209–224. *Copyright ©TÜBİTAK*
doi:10.3906/yer-0803-4 First published online 10 July 2008

The Relationship Between the Tectonic Setting of the Lake İznik Basin and the Middle Strand of the North Anatolian Fault

KURULTAY ÖZTÜRK[1], CENK YALTIRAK[2] & BEDRİ ALPAR[1]

[1] İstanbul University, Institute of Marine Sciences and Management, Müşkile Sokak, Vefa, TR–34116 İstanbul, Türkiye

[2] İstanbul Technical University, Faculty of Mines, Department of Geological Engineering, Maslak, TR–34469 İstanbul, Türkiye (E-mail: yaltirak@itu.edu.tr)

received 10 March 2008; revised typescript received 13 June 2008; accepted 24 June 2008

Abstract: The İznik Basin is an active depression created by a series of faults developed in relation to the Middle Strand of the North Anatolian Fault (NAFMS). The most important of these faults is the oblique Sölöz fault, which runs parallel to the NAFMS. It is interpreted as a releasing bend, and plays a crucial role in the evolution of the 75-m-deep ellipsoid-shaped depression in the southern part of the lake. The faults that limit the coastal alluvial plain on land, some of which developed during the early evolution of the NAFMS, are equally important in the development of the İznik Basin, and correspond to P-shear or secondary synthetic shear faults. These faults are cut by the main fault zone and are right-laterally displaced by approximately 7–8 km. Considering an annual slip rate of 2 mm on the fault, such a displacement is only possible in a time span of 3.5 to 4 million years. An earthquake periodicity of ~2000–2500 years is estimated on the basis of recent GPS data, and a limited number of historical earthquakes. Linear terraces observed on the northern and western parts of the Lake İznik, which have been affected by tectonic activity, show occasional rises of the lake level. The seismic data show that the lake level was approximately 40 m below its present level during the last glacial period.

Key Words: North Anatolian Fault, Lake İznik, tectonics, high-resolution seismic data, releasing bend

İznik Gölü ve Çevresinin Tektonik Yapısı ile Kuzey Anadolu Fayı Orta Kolu'nun İlişkisi

Özet: İznik Havzası, Kuzey Anadolu Fayı Orta Kolu (KAFOK) üzerinde yer alan aktif bir depresyondur. Bu depresyonun oluşumunda ana faktör KAFOK sağ-yanal bileşenli hareketine bağlı gelişen, farklı karakter ve doğrultulardaki fay takımlarıdır. Bu fayların içinde en önemlisi KAFOK ile paralel olan normal bileşenli oblik Sölöz fayıdır. İznik Gölü'nün güneyinde bulunan 75 metre derinliğindeki uzun oval biçimli çöküntünün oluşumunda gevşeyen büklüm fayı olarak rol oynamaktadır. İznik Havzası'nı sadece göl alanını kontrol eden faylar dışında kıyı alüvyonlarını sınırlayan kara fayları da etkin olarak kontrol etmektedir. Bu fayların bir kısmı KAF orta kolunun erken evresinde gelişmiştir. Bu faylar, P-makaslama veya ikincil sentetik makaslama faylarına karşılık gelirler ve KAF orta kolu tarafından biçilip, yaklaşık 7–8 km kadar sağ-yanal ötelenerek farklı bloklarda kalmışlardır. Bu ötelenme son 3.5–4 milyon yılda fay üzerinde 2 mm/yıl hız olduğu takdirde gerçekleşebilir. Çalışma havzasında sınırlı tarihsel deprem kayıtları ve güncel GPS verilerine göre 2 mm/yıl hıza sahip KAFOK'nun uzun dönemli deprem tekrarlanma aralığının yaklaşık 2000–2500 yıl olduğu anlaşılmaktadır. Havza çevresinde tektonik aktiviteden etkilenmiş teraslar göl seviyesinin zaman zaman yükseldiğini göstermektedir. Son buzul döneminde ise İznik Gölü'nün bugünkünden yaklaşık 40 metre aşağı düştüğü anlaşılmıştır.

Anahtar Sözcükler: Kuzey Anadolu Fayı, İznik Gölü, tektonik, yüksek ayrımlı sismik veriler, gevşeyen büklüm

Introduction

The study area is in the south-eastern part of the Marmara region (Figure 1). It is cut by many active faults forming some distinct tectonic features; such as Lake İznik, the largest (313 km^2, 12.2 billion m^3) fresh water lake, ~85 m above mean sea level, which occupies part of an E–W-trending depression and is 32 km long, 12 km wide and ~75 m deep.

Following the bifurcation of the North Anatolian Fault (NAF) master strand east of the Almacık block, the southern strand of the NAF zone follows the Mudurnu valley and further west bifurcates again around Pamukova village, 38 km east of Lake İznik (Şengör 1979; Barka & Kadinsky-Cade 1988; Koçyiğit 1988; Barka 1992; Bozkurt 2001; Yaltırak 2002). One of these faults extends westward from Pamukova into Lake İznik

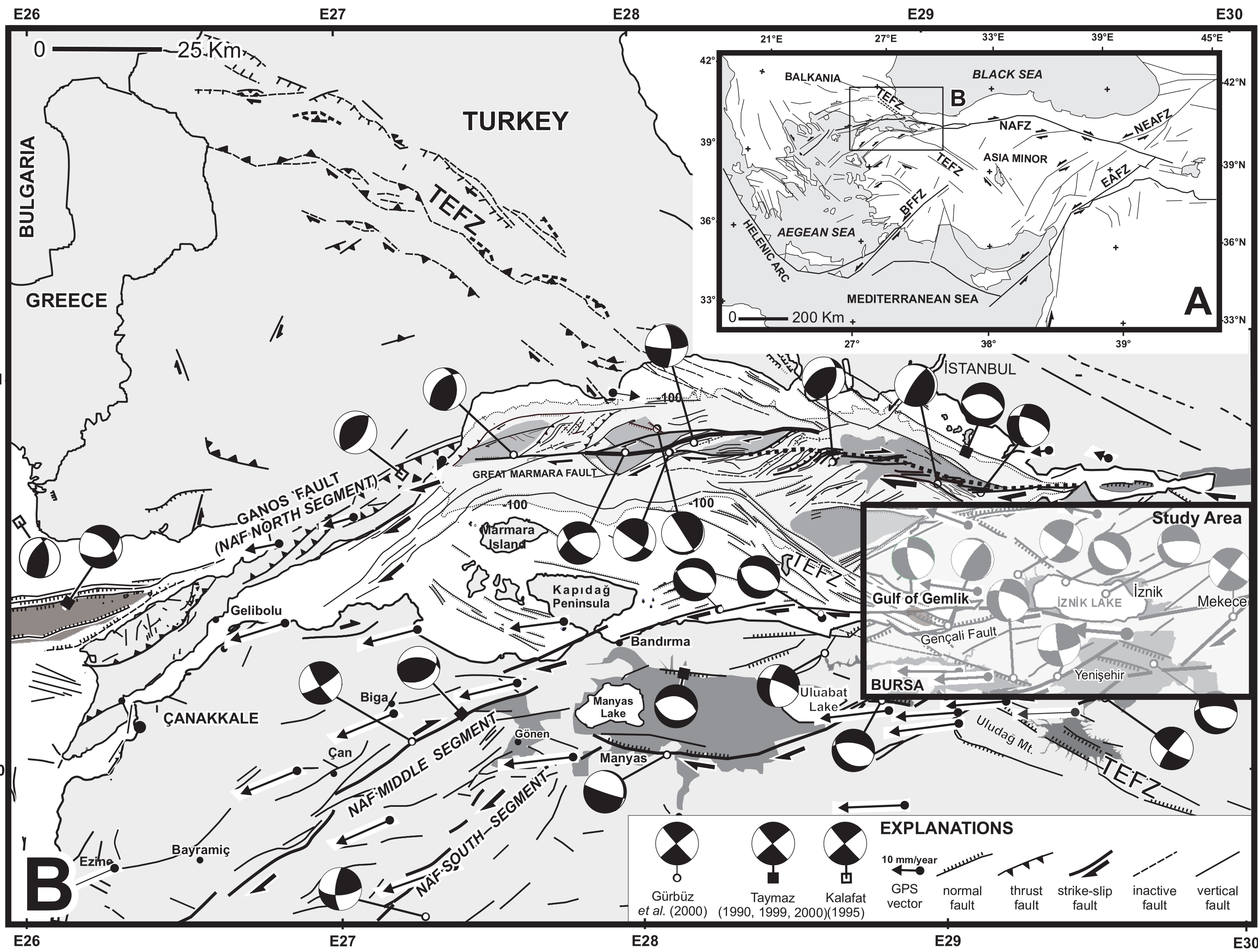

Figure 1. (A) Active faults of the Eastern Mediterranean region. TEFZ– Thrace Eskişehir Fault Zone, NAFZ– North Anatolian Fault Zone, BFFZ– Burdur Fethiye Fault Zone, EAFZ– East Anatolian Fault Zone, NEAFZ– North East Anatolian Fault Zone. (B) Regional tectonic map of the Marmara region and study area (Yaltırak 2002), Fault plane solutions are from Taymaz (1990, 1999, 2000); Kalafat (1995), and Gürbüz *et al.* (2000). GPS vectors are plotted with respect to a fixed station at İstanbul (from Straub *et al.* 1997).

(Koçyiğit 1988), while another fault extends from Mekece to the northern slopes of Uludağ Mountain along the Yenişehir plain (Barka & Kadinsky-Cade 1988; Yaltırak 2002) (Figure 1). Lake İznik is situated on the fault segments of the northern block of the North Anatolian Fault Middle Strand (NAFMS), which extend from Pamukova to the Gulf of Gemlik, along the southern coast of Lake İznik and through Gemlik town. Within this framework, the lake itself and almost all of its coastal plains are located on the NAFMS, which can be traced along a 97-km-long corridor from the town of Geyve to Gemlik. This region is made up of a series of structurally active basins, namely the Geyve-Pamukova Basin, Lake İznik and the Gulf of Gemlik (Bargu 1982; Koçyiğit, 1998; Barka & Kuşcu 1996). In this region, Tsukuda *et al.* (1988) defined two separate fault segments: the Geyve segment between the towns of Geyve and İznik, and the İznik segment (i.e., the Sölöz Fault). Both structures exhibit morphological features characteristic of strike-slip faults. Ikeda *et al.* (1989) interpreted the scarps of the Pleistocene-age terraces on the shores of Lake İznik as the footprints of the İznik-Mekece Fault, which was later defined as one of the main branches of the North Anatolian Fault (Ikeda *et al.* 1991). In their study on the evolution of Gulf of Gemlik, Yaltırak & Alpar (2002) pointed out that the NAFMS passes along the southern coast of Lake İznik, and bifurcates before entering the Gulf of Gemlik into a west-trending main branch which enters the Gulf of Gemlik and the southwest-trending dextral oblique Gençali Fault (Figure 1). On the basis of shallow sparker seismic data, it was concluded that the Thrace-Eskişehir Fault (TEF) in the Gulf of Gemlik has been intersected and shifted ~7–8 km by the NAFMS (Figure 1). Straub *et al.* (1997) calculated the relative slip rate along the NAFMS in the Gulf of Gemlik (i.e., between the southern block and the Armutlu Peninsula) as ~2–3 mm/year. This rate is rather slow when compared to that on the 19±2 mm/year slip rate of the northern strand of the North Anatolian Fault across the Sea of Marmara. Calculations based on GPS slip vectors, and the 7–8 km offset measured in the Gulf of Gemlik suggest that the tectonic activity of the NAFMS started ~3.7–2.6 Ma ago in the region (Yaltırak & Alpar 2002).

Because Lake İznik is situated on the active interface between the Eurasian Plate to the north and the Aegean-Anatolian microplate to the south, seismic exploration of the lake sediments should not only reveal recent depositional processes in the lake but also the dominant tectonic processes in the lake region. This study aimed to evaluate the general tectonic setting of the Lake İznik Basin by interpreting high resolution seismic profiles across the lake; and to understand the relation between the fault ruptures observed on land and the other structural elements we have traced in the lake.

Material and Method

A total of 30 km high resolution seismic sparker (1.25kJ) reflection profiles were collected in Lake İznik in 2005 (Figure 2). The data acquisition parameters were chosen depending on earlier field tests (Alpar *et al.* 2003). Shots were fired every two seconds (~4.1 m), and return echoes were recorded digitally for 250 ms (two-way-travel time, twt) with a surface-towed single-channel hydrophone streamer (11-element, 10 m-long). Such a recording configuration provided details of sedimentary deposits up to ~70–80 m below the lake bottom. Conventional data processing methods such as trim-statics, filtering and multiple suppression were used to achieve better definition of the seismic data.

Topography and Bathymetry

Lake İznik is bordered by the Samanlı and Katırlı mountains (Figure 3). The summits along the Samanlı ridge watershed are 890–982 m high, and in the east are much higher (810–1227 m) than the land to the north. The linear range of mountains in the south rises to similar heights (821–1293 m) above the eastern part of the lake, while to the west they range up to 893 and 926 m in height. The lowest elevations within the Lake İznik basin are 320 m north of Orhangazi, 410 m in the Mekece valley and only 95 m at the Karsak Pass. An interesting morphological feature of the study area is that whereas the highest elevations are in the west of the southern block of the NAFMS, they are towards the east end of the northern block (Figure 3).

The Karsak Pass is a deep valley cut by the Karsak River through which the fresh waters of Lake İznik drain into the Gulf of Gemlik. It resembles a sill developed on the pre-Neogene basement. Immediately west of the Karsak Pass, a small delta extends towards the town of Gemlik. The scarp of the mountains south of the Karsak

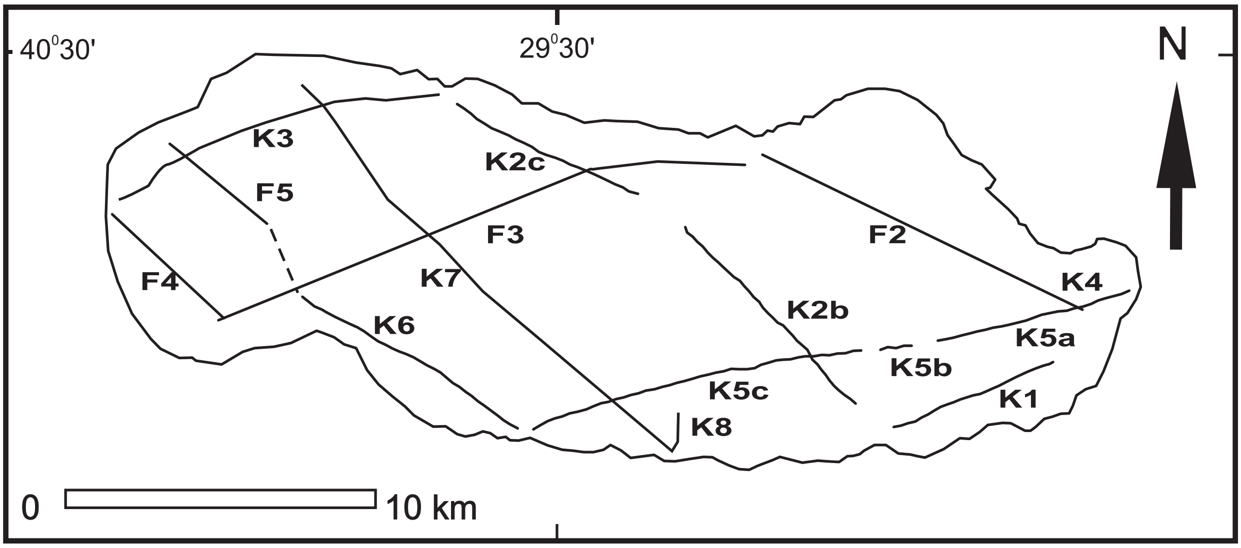

Figure 2. High-resolution sparker lines acquired in Lake İznik.

Pass is bounded by the NAFMS. At most places where the NAFMS cuts through some terraces can be seen but this morphology diminishes westward towards the Gemlik Plain. South of Samanlı Mountain, a coalescent alluvial fan system spreads towards the Orhangazi Plain, which is made up of river alluvium. The undisturbed surface of the plain indicates that the alluvial processes in the region continue. While reed covered marshes along the eastern coast of Lake İznik are at 85 m above present mean sea level, lake terraces observed in the western part of the plain at 105–110 m record previously higher water levels. Ardel (1953) suggested that the palaeo-İznik lake was largest during the last glacial period when its surface level was ~60 m higher than its present level.

The drainage area of the İznik Lake Basin is 1246 km^2, and fresh water input into the lake is limited. Stream profiles are steep. The most important rivers are Kocadere in Sölöz, Olukdere fed by a spring source called Nadir, Kurudere, Karadere and finally Kırandere which borders the city of İznik (Figure 3). While the coastal plain covers large areas in the east and west, it is very narrow along the southern coast except for the Sölöz and smaller deltas. The coastal plain surrounding the Kırandere to the east is relatively narrow and longer. The coastal plain along the northern shore is very narrow at Boyalıca, while the plains of the rivers Karadere and Kurudere are triangular (8 × 9 km). In the west Orhangazi town is located on a large L-shaped coastal plain, which is over 5 km wide in some places (Figure 3).

Lake İznik is divided into three sub-basins. In the west, a shallow, elliptical sub-basin (Western Flat: WF) (11 × 6 km) covers almost one third of the lake area (Figure 3). The shelves along the northern and western shores of the western sub-basin are smooth and ~2 km wide from shore down to 40 m water depth. This gradient is steeper along the northwest coast of the Sölöz delta, which is ~700 m wide from shore down to 40 m water depth (Figure 3). The deepest part of the western sub-basin or western flat has a circular shape with a radius of 2.5 km, and is relatively shallow (45 m). The eastern half of Lake İznik includes two sub-basins separated by an east–west-trending ridge (Figure 3). The southern sub-basin (Southern Trough: ST) is an elongate ellipse, 17.5 km long and 4.5 km wide, and forms the deepest parts of the lake, up to 75 m deep. The distance from the deepest places to the southern shores is very short, ~1 km (Figure 3). The northern slope of this sub-basin is wider; it is ~2.4 km wide, from 45 m water depth down to the greatest depth. Finally, the northern sub-basin (Northern Trough: NT) is 7 km long, 1.8 km wide and elongate east-northeast – west-southwest. The width of its northern and eastern slopes varies between 2 and 7 km (Figure 3).

Geologic Setting of the Study Area

The Basement

The geology of the region surrounding Lake İznik includes Late Palaeozoic, Mesozoic and Palaeogene successions,

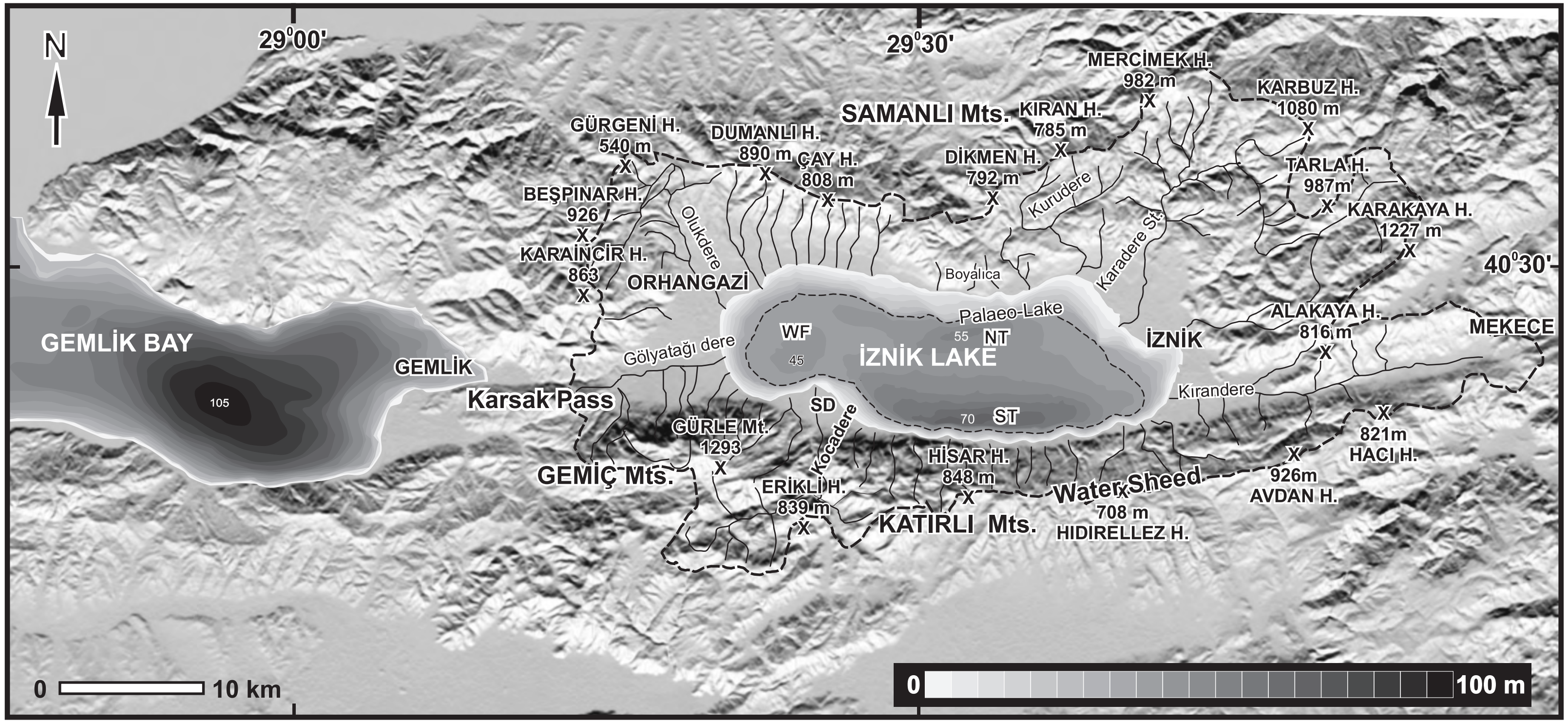

Figure 3. Shaded relief and bathymetry map of the İznik region and surroundings WF– Western Flat, NT– Northern Trough, ST– Southern Trough, SD– Sölöz Delta (İznik bathymetry modified from Ikeda *et al.* 1991; Budakoğlu 1999; Gemlik bathymetry from Yaltırak & Alpar 2002).

forming the pre-Miocene basement. The Miocene sequence unconformably overlies the basement rocks and is covered by Pliocene–Quaternary units (Figure 4). The metamorphic rocks of the basement have undergone multiple deformations. The Karakaya units (Şengör & Yılmaz 1981) and the Sakarya Zone units (Göncüoğlu *et al.* 1992; Genç 1993; Genç & Yılmaz 1995) were metamorphosed following closure of the Karakaya Basin in the Late Triassic and the Intra-Pontid Ocean in the Late Cretaceous, respectively. The metamorphic basement around Lake İznik is represented by greenschist facies Triassic meta-pelites, metabasites, metatuffites, calc-schists, slate/phyllites and marble. The Jurassic recrystallized limestone series unconformably overlies Triassic metamorphic rocks west of the lake (Göncüoğlu *et al.* 1992; Genç 1993; Genç & Yılmaz 1995). Permian marbles occur in the NW and W parts of the lake while Permo–Triassic schists, phyllites and meta-pelites cover relatively larger areas in the NE (Göncüoğlu *et al.* 1992). To the south, Permo–Triassic volcaniclastics, the Jurassic–Cretaceous limestone series and Upper Cretaceous detrital and carbonate rocks were all deformed, but not metamorphosed (Genç & Yılmaz 1995). The Palaeogene basement units were made up of Eocene volcanics, turbidites as sandstone and shale intercalations, and Oligocene deltaic sandstones (Genç *et al.* 1986; Bargu & Sakınç 1990; Ece 1990).

Mio–Pliocene Units

Late Miocene units can be observed in the cliffs along the main road north of Orhangazi village (Figure 4). In this locality yellowish-grey sands intercalated with gravels and grey clays were deposited in a fault-controlled basin. This unit corresponds to the Kılınç Member of the Yalova Formation. It is ~200 m thick and best observed in the north–south-trending valleys east of the town of Yalova (Alpar & Yaltırak 2002). Fresh water ostracods, such as *Condona compressa*, observed on the Armutlu Peninsula and *Pseudocattilus psedudocattilus* s*inzov* observed around Orhangazi, collectively imply that a brackish lake existed in the region. Bivalve assemblages suggest that this unit is Late Miocene–Early Pliocene in age [Sarmatian (Akartuna 1968) or Pontian (Emre *et al.* 1998)].

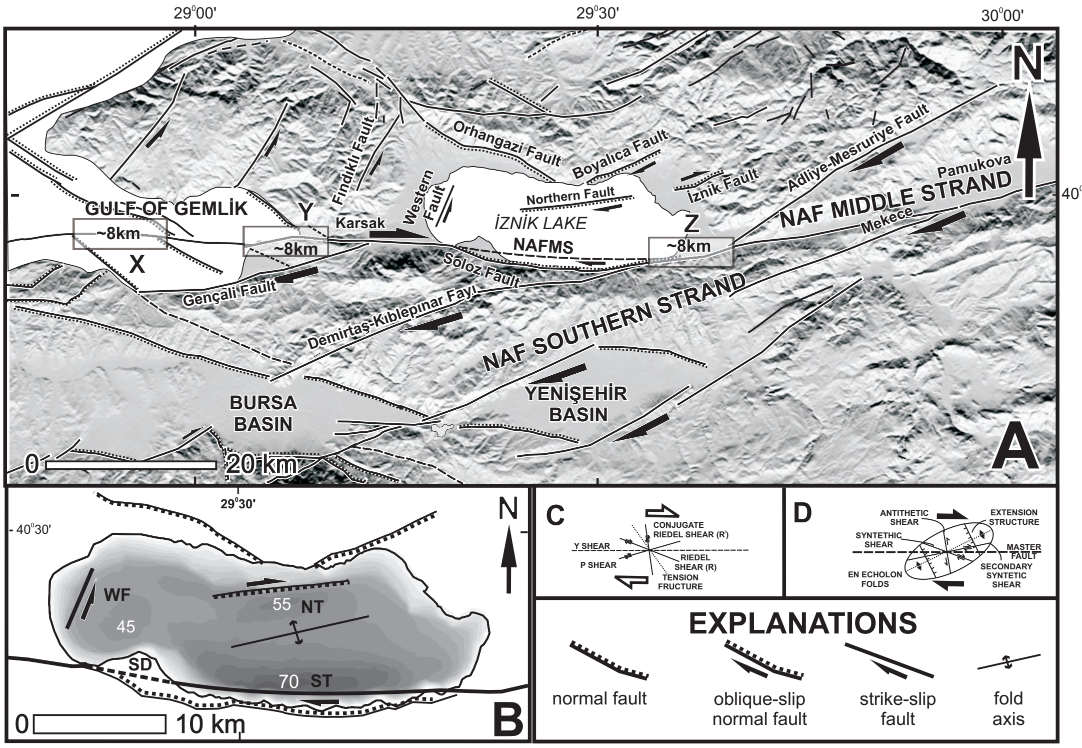

Figure 4. Geological map of the İznik Basin and surroundings. Reproduced from the field observations by Genç *et al.* (1986), Imbach (1992), Yaltırak & Alpar (2002), Alpar & Yaltırak (2002). Gf– Gemiç Alluvial Fan, Of– Orhangazi Alluvial Fan.

Pliocene–Quaternary Units

Thick sandy and gravelly sequences and conglomerate lenses unconformably overlie Late Miocene–Early Pliocene units in the Armutlu Peninsula (Eisenlohr 1995), particularly cropping out around the villages of Esenköy, Termal, and Orhangazi, and on the hillsides south of Yalakdere (Figure 4; Alpar & Yaltırak 2002). The Pliocene–Quaternary units consist of sand and gravel layers with laterally variable thicknesses. They record braided river and alluvial fan deposition around the basin margins. Pliocene–Quaternary deposits around Lake İznik include alluvial plains, fans, marsh areas, lake terraces and beach facies, especially in the eastern and western sectors (Figure 4). The Orhangazi and Gemiç alluvial fans cover the largest areas in the west. The Gemiç fan consists of alluvial material derived from Gemiç Mountain in the southwest, intercalated with thick, mixed flood plain sediments (Figures 3 & 4). The Sölöz delta is more like a hill in the south. The Kıran and Karadere fans in the east consist of siliciclastic material with different particle sizes coming from older units outcropping in the region.

A beach facies comprising coarse-grained sand and gravel is distributed along the western shores of Lake İznik, with marshes situated between the backshore and lacustrine terraces. These lacustrine terraces were considered to be old coastal deposits of the lake by Chaput (1936), while they have been interpreted as the coast of the palaeo-lake which reached its maximum extent during the Pleistocene (Tanoğlu & Erinç 1956).

The most impressive sedimentary sequences in the lake sediments are the submerged deltas of the Karadere River. These deltaic units represent a palaeo-shoreline when the lake level was 35 to 40 m below its present level (Figure 5: Section F3 and K7). In the eastern half of the lake, the sedimentary sequences thicken southward. A local thickening was also observed in the northern trough. Thinner sedimentary deposits forming the east-northeast-trending central ridge gradually thicken towards the northern and southern depressions, which suggest syn-depositional folding. The faults north and south of the central ridge played an active role in its folding. In contrast, the sedimentary layers in the western sub-basin show parallel to sub-parallel stratification, locally affected by the Sölöz delta. Reflection profiles on seismic data show that the observed sedimentary deposits are thicker than 200 ms (twt) implying that the Pliocene–Quaternary deposits are at least 150 m thick in the lake.

Lower sedimentation rates occur in the northern areas and on a ridge in the lake centre (Ülgen *et al.* 2007). On the basis of a dating of core recovered from the sedimentary ridge in the lake centre, the topmost 33 cm represents the last 100 years. The sedimentation rate in the southern deep sub-basin is higher, and has been strongly influenced by distinct changes in siliciclastic input and authigenic carbonate production (aragonite) during the last 5 ka (Franz *et al.* 2007).

Structural Elements

Lake İznik and its basin lie in a fault-controlled depression: the most important bounding fault is the NAFMS, passing along the southern shore of the lake. The NAFMS and other secondary faults in the study area reveal a right-lateral transtensional structural pattern (Figure 6a).

Two distinct faults north of the Lake İznik Basin trend NW–SE and WSW–ENE, respectively. The Orhangazi fault in the west trends NW–SE, and separates the basement and Pliocene–Quaternary fans (Figure 4). It is a normal fault with >200 m of dip-slip. It exhibits a characteristic topographic lineation (Figure 6a). The fault scarps can be seen along the eastern side of the Yalova-Orhangazi highway. The Boyalıca Fault is also a normal fault with a small right-lateral component of movement (Figure 6a).

The Sölöz Fault runs almost parallel to the NAFMS. It has been thought that the NAFMS cuts through the southern part of the Lake İznik on land (Barka 1992). The main fault extending from Mekece into the lake is located in a narrow area between the coastal alluvial plain and the basement rocks. The north-dipping fault scarps can be seen on the coastal topography south of Lake (Barka 1992). *En-échelon* segments of this fault form the arcuate high topography of the southern margin, which extends ~24 km in a N85ºE direction (Figure 6a, b). In front of this fault, the southern trough forms the deepest part of Lake İznik in a narrow elliptical basin extending westward as far as the eastern edge of the Sölöz Delta. The west-trending fault scarp in the east changes its orientation to northwest behind the Sölöz Delta region where the fault forms a releasing bend with changed orientation for ~10 km (Figure 6a, b). Its orientation reverts to west where the Sölöz Delta abuts basement rocks. The Sölöz Fault, extending along the southern shore of the lake, is dominantly a north-dipping normal

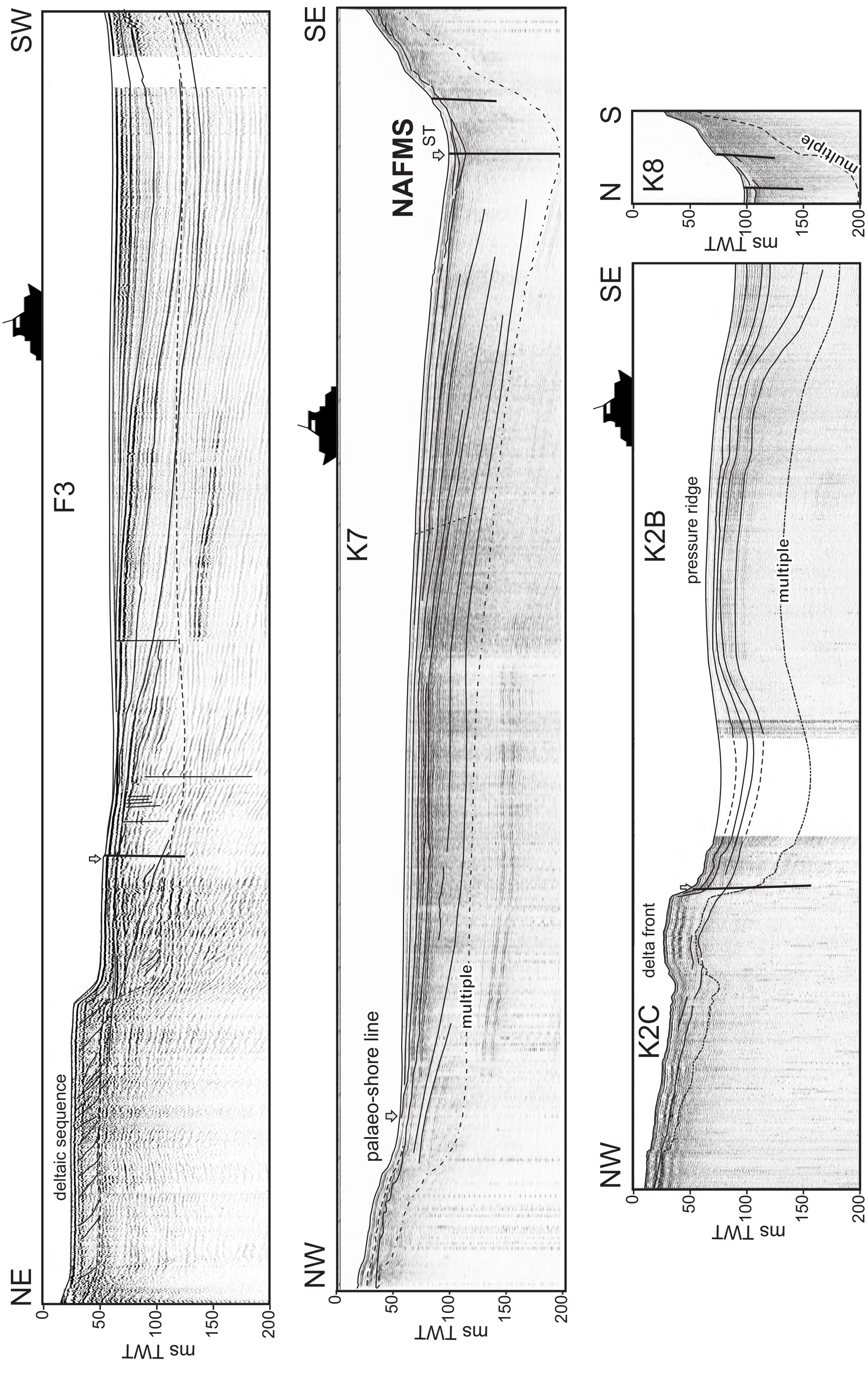

Figure 5. Interpreted line drawings of seismic stratigraphic units and structural elements on the high resolution reflection sections in Lake İznik. See Figure 2 for location. Line F2 is taken from earlier test studies (Alpar *et al.* 2003).

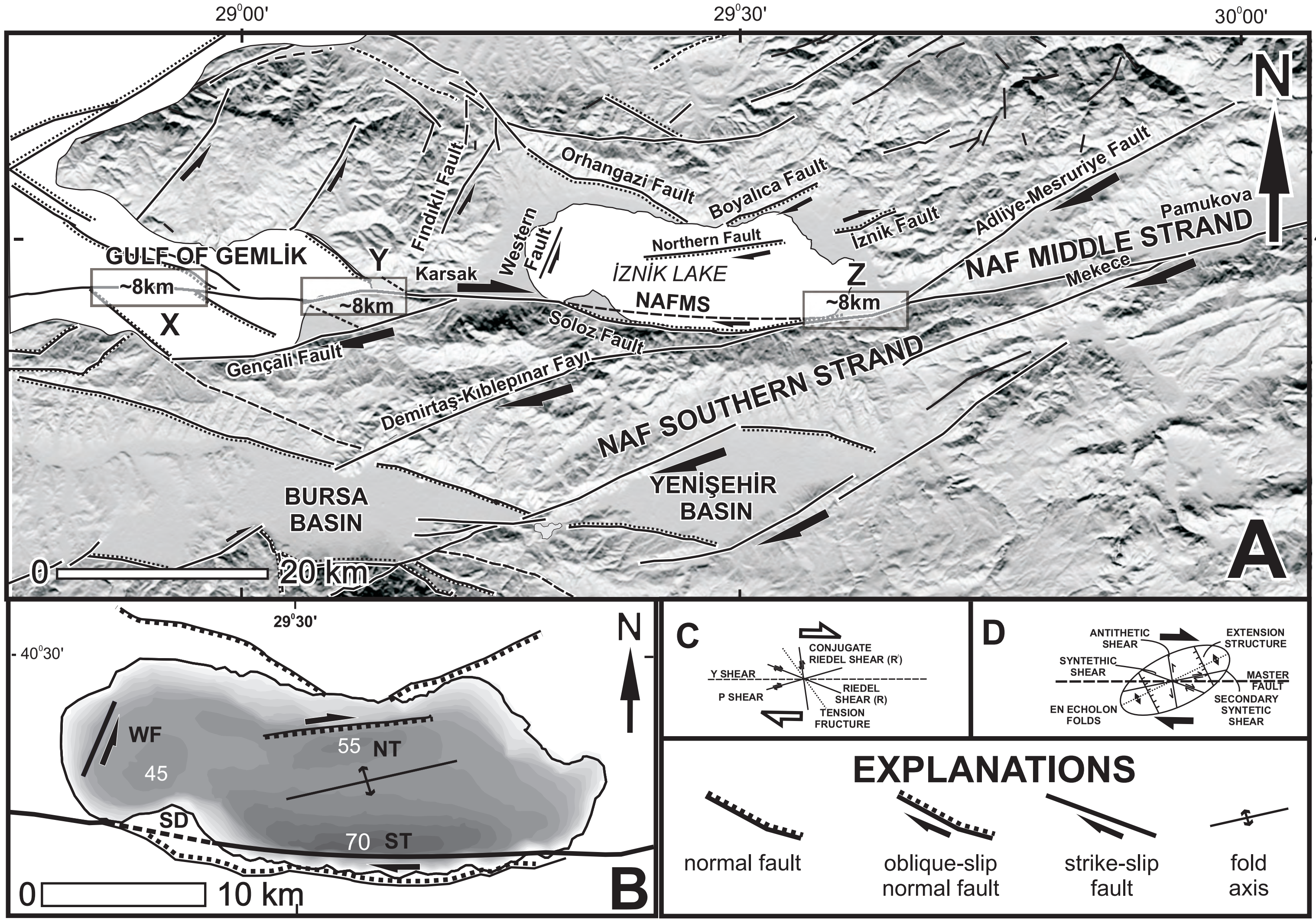

Figure 6. (A) Shaded relief tectonic map of the İznik Basin and surroundings, X, Y, Z shows displacement of the NAFMS. (B) The main structural elements of Lake İznik superimposed on the bathymetric map with 5 m contour interval. (C) Riedel shear model modified from Tchalenko (1970); Tchalenko & Ambraseys (1970) and Bartlett *et al.* (1981). The Riedel orientations are in harmony with the trends of the faults given in this paper and also obtained from the fault plane solutions (see Figure 7). (D) Strain ellipse for overall deformation from Wilcox *et al.* (1973).

fault, but it also displays minor right-lateral slip, which can be observed in the valleys and in some places between the fan deltas filling the valleys and extending into the lake in the south. In this structural framework, the Sölöz Fault played an active role as a releasing bend in the early development of the basin.

In the western part of Lake İznik, the western Fault extends SSW–NNE, almost parallel to the Fındıklı Fault (N5E) west of Orhangazi and similar faults on the Armutlu Peninsula (Figure 6a, b). These faults correspond to left-lateral conjugate Riedel shear or antithetic shear faults, which are rotated due to a dextral shear mechanism (Figure 6c, d).

The major axis of the southern trough in Lake İznik is located ~2 km away from the aligned segments of the normal faults observed on land (Figure 6b). Within the bend between the deepest part of the lake and its southern shoreline, secondary normal faults run parallel to the Sölöz Fault on land. These faults can be observed on the seismic reflection profiles (Figures 5: Section K7, K2B and K8). The main fault (i.e., NAFMS) extends along the deepest part of the southern trough. It is almost vertical or dips steeply northward (Figures 5: Section K7 and K8). This fault exercised the most control over the evolution of the southern trough. These two faults extending along the southern coast on land and along the southern trough in the lake, may show two successive evolutionary phases.

The Northern Fault is another vertical fault observed at the northern margin of the northern trough. It is oriented N83°E and runs ~10° oblique to the NAFMS in the lake. The fault corresponds to dextral P-shear or secondary synthetic shear faults (Figure 6c, d). A wide and shallow antiformal structure lies between the northern and southern troughs, extending parallel to the northern Fault. These folds developed between two dextral strike-slip faults (Figure 6b, d). Other fault systems consistent with our proposed orientation on Lake İznik and which run parallel to the northern Fault, are the dextral Demirtaş-Kıblepınar Fault in the Bursa Basin (BB) south of Lake İznik and the Adliye-Mesruriye Fault, situated on the northern block east of Lake İznik. Both of these are dextral strike-slip faults (Figure 6a) and show 1–2 km pre-Late Pliocene total morphological displacements. The Demirtaş-Kıblepınar and the Adliye-Mesruriye faults are interpreted as P-shear or secondary synthetic shear faults which developed as a single fault at an early stage of the evolution of the NAFMS. This single fault (Demirtaş-Kıblepınar-Adliye-Mesruriye Fault) was cut through by the NAFMS during the evolution of the North Anatolian Fault and has been shifted dextrally by ~8 km. The northwest–southeast-trending Orhangazi Fault is one of the active tectonic elements in the evolution of the Lake İznik Basin. Its extensional character is also consistent with the dominant dextral shear regime in the region (Figure 6b, d).

Historical Earthquakes and Instrumental Seismicity

Historical records on natural disasters show that many destructive earthquakes occurred in the Lake İznik region during the last 2000 years. They provide an opportunity to investigate the tectonic processes in the region. The historic city of İznik (Nicaea) on the eastern shore of Lake İznik (Ascania) was founded by Antigonus I, king of Macedonia, in the 4th century BC, and later flourished under the Romans (Koyunluoğlu 1935) The city has been the capital of the Byzantine Empire, the Seljuk Turks and then the Ottoman Empire. An ancient harbour at the city of Gemlik (Kios) was founded by the Militians in 630 BC and administered by Hittites, Bithynians, Romans, Byzantine and Ottoman Empires, remaining as one of the ancient centres of politics, economics and culture (Koyunluoğlu 1935). Therefore, historical earthquakes and other hazards in these regions and their effects have been well documented throughout history by many chroniclers, historians, priests, etc. Modern earthquake catalogues, based on these historical documents (e.g., Ergin *et al.* 1967; Soysal *et al.* 1981; Guidoboni *et al.* 1994; Ambraseys & Finkel 1995; Ambraseys 2000), show that the Lake İznik Basin and its surrounding region have suffered several destructive earthquakes during the historical period (Table 1). Some important and well-documented data are as follows:

29 AD November 24: the most severe damage was around the historic city of İznik, where most of the buildings were destroyed.

362 AD December 02: a major earthquake, also felt in İstanbul, totally destroyed the ancient city of İzmit (Nicomedia) at the eastern end of the Gulf of İzmit and most of İznik (Nicaea). It is said that the near-by springs dried up.

368 AD October 11: strong lethal shock with epicentre near Lake İznik destroyed Nicaea and its

Table 1. Historical earthquakes around the Lake Iznik region. 1– Ergin *et al.* (1967) ; 2– Soysal *et al.* (1981); 3– Ambraseys & Finkel (1995); 4– Guidoboni *et al.* (1994); 5– Ambraseys (2000), 6– Ambraseys (2002).

Date	Reported Locality	°N	°E	Intensity	References
24.11.0029	İznik, İzmit	40.4	29.7	X	1, 2, 3, 4
02.01.0069	İznik, İzmit	40.4	29.7	VII	1, 2, 3, 4
120–123	Nicomedia	40.5	30.1	(VIII) Ms= 7.4	6
0128–0129	İznik, Zeytinbağ, Mudanya	40.4	29.4	(VIII)	2, 3
03.05.0180	İznik (Nicomedia)	40.6	30.6	Ms= 7.3	6
00.00.0268	İznik	40.7	29.9	Ms= 7.3	6
02.12.0362	İznik (Nicaea)	40.7	29.6	VI	1, 2
11.10.0368	İznik	40.4	29.7	(VII) Ms= 6.4	2, 3, 4
00.00.0378	İznik	40.4	29.7	VI	2
00.00.0715	İznik	40.4	29.7	IX	1, 2, 3
23.09.0985	İznik, Bandırma, Erdek	40.4	28.9	(VIII)	1, 2
29.09.1064	İznik, Bandırma, İstanbul	40.4	28.9	IX	2
29.12.1854	South coast of Lake İznik	40.4	29.5	Ms= 4.5	5
17.09.1857	Gemlik, İznik, Bursa	40.4	29.2	VI, Ms= 5.4	1, 3, 5
06.11.1863	Gemlik, Umurbey, İznik	40.4	29.1	IX, Ms= 5.0	1, 2, 3, 5
21.01.1895	İznik	40.4	29.7	V	1, 2
14.03.1897	Gemlik, Bursa	40.4	29.1	V	2

surroundings in Bithynia, as reported in the Ecclesiastical History of Socrates Scholasticus (Guidoboni *et al.* 1994). In a chronological work *Chronicon Paschale* (7th century AD), a destructive earthquake was reported in İznik, which is famous in ecclesiastical history for the two Councils of Nicaea, during the 4th year of 287th Olympics (Guidoboni *et al.* 1994). In an Ethiopic version of the chronicle of John Nikiu, a 7th century writer, refers to seismic sea-wave of 358 (Guidoboni *et al.* 1994). This earthquake also caused major damage along the coastal area between Gemlik (Kios) and Mudanya in the west.

1065 AD September: a local earthquake around Lake İznik affected the region once more following the central Marmara earthquake of September, 1063, which had caused important damage in the city of Nicaea two years previously.

1854 AD December 29: A very strong earthquake shook the south coast of Lake İznik and did some damage to the villages of Mehmeçik and Pamukcık (Ambraseys 2000).

1857 AD September 17: A small earthquake occurred between Lake İznik and the Gulf of Gemlik, causing damage at the ports (Ambraseys 2000). The ruined villages between Gemlik and İznik indicate a fault segment crossing Gemlik.

1863 AD November 06: a tremor caused damage around Lake İznik and at Gemlik (I_o= IX). More than 40 houses in the village of Umurbey, near Gemlik, were ruined (Ambraseys 2000). On the basis of damage, the earthquake is believed to have been caused by movement on the fault bounding the southern shore of Lake İznik.

The instrumental seismicity (1940–2008) obtained from the catalogues of Kandilli Observatory (KOERİ) shows 616 earthquakes with a scatter of epicenters of 30 small (M= 4–4.9) and 3 moderate (M= 5–5.9) earthquakes around the western side of the lake (Figure 7). Earthquake activity is strikingly low in a specific area around the northern and southern troughs and increases gradually along the NAFMS towards the Gulf of Gemlik. The segment of the NAFMS in Lake İznik is undergoing a significant seismic quiescence period.

The moment tensor analyses of three microseismic events on the NAFMS (Gürbüz *et al.* 2000) indicate mechanical solutions consistent with the faults we have delineated in the study area (Figures 6 & 7). On the basis of the GPS slip vectors, the relative velocity of the Armutlu Peninsula relative to the Mudanya block (i.e., on the NAFMS, is 2±1 mm/year; Straub *et al.* 1997). Considering that the age of the NAFMS between the Armutlu Peninsula and the Mudanya block is ~3.5 Ma, or

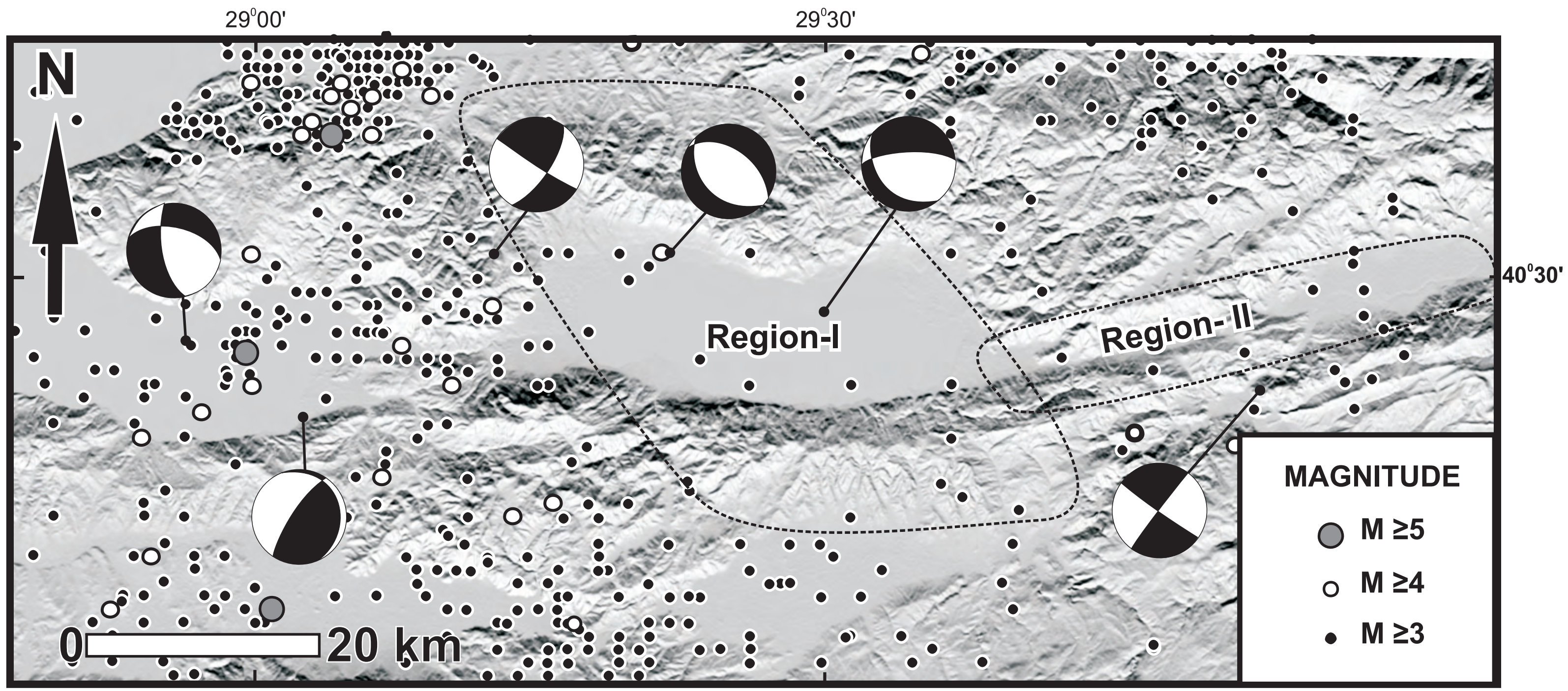

Figure 7. Seismic activity of the Lake İznik Basin and surroundings. Data is provided from the catalogues of Kandilli Observatory (KOERI, April 2008). Geographic distribution of the individual focal mechanism solutions obtained from Gürbüz *et al.* (2000) was superimposed. Circle size represents earthquake magnitude. Figure drawn using the GMT software (Wessel & Smith 1998).

the same age as the northern strand of the North Anatolian Fault along the northern margin of the Armutlu Peninsula (Alpar & Yaltırak 2002), the total displacement of the NAFMS was calculated to be 7–8 km in the Gulf of Gemlik (Yaltırak & Alpar 2002). These authors further proposed a recurrence interval of ~2500 years for large earthquakes (M≥7) with displacements of up to 5 m. This long interval of time is also supported by palaeoseismological studies (Uçarkuş 2002), which only found evidence for a single 2000 year old event in the 3–6 m deep trenches at the western side of the Lake İznik.

Discussion and Conclusion

We have delineated three separate faults in Lake İznik, a tectonic freshwater lake flooding three distinct sub-basins. They are (a) the NAFMS, passing through the deeper southern trough; (b) the northern Fault, a strike-slip fault with a normal component that bounds the shallower and smaller northern trough (55 m); and finally (c) the N05ºE-trending left-lateral western Fault on the western slope of the western flat (WF).

The Orhangazi Fault on land is a normal fault, while the Boyalıca and İznik faults along the northeast margin of the lake are normal faults with a right-lateral component of movement. As an oblique fault with a dominant normal component, the Sölöz Fault acts as a releasing bend. To the east, it is formed by *en-échelon* faults between the coastal alluvial plains and the basement. The deep southern trough has formed under the control of the releasing bend character of the Sölöz Fault, and was later cut through by the NAFMS. At present, the NAFMS also cuts through the Sölöz Delta and extends to the Gulf of Gemlik. A very similar tectonic setting has been outlined in the Gulf of İzmit between the eastern Hersek (or Karamürsel) trough and the Hersek Delta (Alpar & Yaltırak 2002, 2003). The relative position of the Sölöz Fault is similar to those normal oblique faults bordering the Armutlu Peninsula in the north (Gökten 2001; Alpar & Yaltırak 2002). The thesis that the NAFMS crosses the southern shore area of Lake İznik on land(e.g., Ikeda *et al.* 1989, 1991; Barka 1992, 1993) should be revised according to our findings presented in this study, as the right-lateral strike-slip fault passes through the deep southern trough in Lake İznik.

Considering the tectonic frame described above together with the length and width of the Lake İznik basin, it is obvious that this lake could not be developed by only the NAFMS itself. There are several ways of forming such a big basin. First such a big and wide basin could be evolved within a pull-apart system. One characteristic feature of pull-apart basins is that the strike-slip faults controlling the basin are separate segments (Rodgers 1980). A basin develops between these two independent segments due to the offset between them. Based on the experimental results obtained by Dooley & McClay (1997), the shape of the basin developed in the tensional offset area between the related strike-slip faults is normally rhombohedric. If so, in order to produce a pull-apart basin in the Lake İznik region, the southern fault zone should step over northward and therefore should bound the southern margin of the Armutlu Peninsula in the west. However, there are no faults supporting such a mechanism. Another scenario for the evolution of the Lake İznik basin is development of a graben caused by an oblique transtensional regime associated with strike-slip faulting. If so, however, other graben developments should be present both at the margin near Pamukova along the NAFMS, and also in the west. This scenario is impossible because no grabens have developed in these places even if there is no evident change of fault orientation. We propose instead that the main Lake İznik trough predated the evolution of the NAFMS. Similar problems with the basinal geometries developed on branches of the NAF are also often encountered in the Sea of Marmara region. Yaltırak (2002) defined superimposed basins and fault systems evolved due to intersection of the younger NAF and older TEF system. The study area is a W–E extensional zone developed during the final closure of the Rhodope-Pontide Ocean at the end of the Oligocene (Genç & Yılmaz 1985). This zone was probably affected by the TEF system which was active in the region between the Early Miocene and Early Pliocene. We consider that the NAFMS, which followed the main axis of an intermontane tectonic depression in this zone towards the Sea of Marmara, contributed to the development of the Lake İznik basin. The elevation of the upper Miocene deposits observed in Umurbey and on the fault scarps along the Yalova-Orhangazi highway, is about 200 m above the bottom of the lake. This elevation difference and high erosional features observed in the upper Miocene deposits support the idea that the palaeo-İznik basin was developed before the NAF. If so, the Lake İznik basin is more likely to be a superimposed basin than a product of the other tectonic models.

Historical documents show that the strongest earthquake in the study area occurred in 368 AD. However, there was no seismic activity during the instrumental period in some parts of the study area, which can be outlined as two different regions. Depending on the affected regions, namely İzmit and İznik, the epicenters of the 362 AD and 368 AD earthquakes should be located within the regions II and I, respectively (Figure 7). Meanwhile the historical earthquakes of 29 AD 1065 AD and 1863 AD were local events around Lake İznik and possibly related to movement on local faults.

The calculation that a 7–8 km shift on the NAFMS in the Gulf of Gemlik occurred during the last 3.7–2.6 Ma depends on the shift between the northern and southern segments of the northwest-trending Thrace-Eskişehir Fault (Figure 6, Displacement X: Yaltırak & Alpar 2002). In this study two different situations similar to that observed in the Gulf of Gemlik are in question. The first one is the 8 km displacement observed between two NW–SE-oriented escarpments bounding the northeast of the Gemlik coastal alluvial plain (Figure 6, Displacement Y), and those at the north-eastern embankment of the Gençali Delta. The latter is an 8 km displacement observed at the south-eastern corner of Lake İznik between the NE–SW-trending Demirtaş-Kıblepınar and Adliye-Mesruriye Faults (Figure 6, Displacement Z). A relative slip rate of 2 mm/year suggests that an earthquake with a displacement of 4–5 m on the NAFMS, will occur with a 2000–2500-year frequency. This back-of-the-envelope calculation is in agreement with the previous findings obtained using different methods (e.g., Barka 1993; Yoshioka & Kuşçu 1994; Uçarkuş 2002; Yaltırak & Alpar 2002).

The tectonic setting in the Lake İznik region between the villages of Mekece and Gemlik and its main structural element, the NAFMS, exhibit similar characteristic features to the basins of the Gulf of Gemlik and Pamukova previously studied by Yaltırak & Alpar (2002) and Yaltırak (2002). The basement rocks in these basins are upper Miocene–lower Pliocene. In contrast, the ages of the NAFMS and other parallel tectonic features are Pliocene and post-Pliocene. In view of the elevation of the terraces around Lake İznik, we suggest that the faults observed in and around Lake İznik, with their morphological influence on the depositional sequences, have had much less effect on the elevation of the terraces than the changes in the lake water level. Besides the idea that the highest terraces record the highest lake level, regional uplift in the lake region may have aided the deep incision of the Karsak Pass discharging the lake water into the Gulf of Gemlik, simultaneously with the tectonic uplift of above-mentioned high-altitude terraces. This scenario implies that the palaeo-lake level during the recent glacial period (12–24 Kyr) was not higher, but instead was ~40 m lower than the present lake level. The maximum range of lake level changes can be estimated as 65 m, since the maximum elevation of the lake terraces and minimum lake level are 100–110 m and 45 m, respectively. Hence, establishing the timing of the deep incision of the Karsak Pass and the lake drainage into the Gulf of Gemlik will be very important to an understanding of why these terraces are elevated, whether due to tectonic uplift or climate changes.

Acknowledgements

The authors wish to thank Denizhan Vardar for his assistance in field studies. We are also grateful for historical earthquake data supplied by Yıldız Altınok and for useful recommendations made by the referees Ergun Gökten and Erhan Altunel for improving the earlier version of this manuscript. This research was supported by the Research Foundation of İstanbul University (Projects 423/13092005 and UDP-426/22022005) allocated to K.Ö. John A. Winchester edited English of the final text.

References

Akartuna, M. 1968. *Armutlu Yarımadasının Jeolojisi* [Geology of Armutlu Peninsula]. İstanbul Üniversitesi, Fen Fakültesi Monografi **20** [in Turkish].

Alpar, B., Öztürk, K., Adatepe, F., Demirel, S. & Balkis, N. 2003. Sparker in lakes; reflection data from Lake İznik. *Turkish Journal of Marine Sciences* **9**, 195–206.

Alpar, B. & Yaltirak, C. 2002. Characteristic features of the North Anatolian Fault in the Eastern Marmara region and its tectonic evolution. *Marine Geology* **190**, 329–350.

Alpar, B. & Yaltirak, C. 2003. Reply: Characteristic features of the North Anatolian Fault in the Eastern Marmara region and its tectonic evolution. *Marine Geology* **194**, 203–208.

AMBRASEYS, N.N. 2000. The seismicity of the Marmara Sea area 1800–1899. *Journal of Earthquake Engineering* 4, 377–401.

AMBRASEYS, N.N. 2002. The seismic activity of the Marmara Sea region over the last 2000 years. *Bulletin of the Seismological Society of America* 92, 1–18.

AMBRASEYS, N.N. & FINKEL, C.F. 1995. *Seismicity of Turkey and Adjacent Areas: A Historical Eeview, 1500–1800*. Eren Yayıncılık ve Kitapçılık Ltd.

ARDEL, A. 1953. İznik Depresyonu ve Gölü [İznik depression and lake]. *İstanbul Üniversitesi Coğrafya Enstitüsü Dergisi* 2, 210–225.

BARGU, S. 1982. The geology of İznik-Yenişehir (Bursa)-Osmaneli (Bilecik) area. *İstanbul University Yerbilimleri Dergisi* 3, 191–234.

BARGU, S. & SAKINÇ, M., 1990. The geology and structural characteristics of the area between Gulf of İzmit and Lake İznik. *İstanbul University, Engineering Faculty Bulletin of Earth Sciences* 6, 45–76 [in Turkish with English abstract].

BARKA, A.A. 1992. The North Anatolian Fault Zone. *Annales Tectonicae* 6, 164–195.

BARKA, A. 1993. *Kuzey Anadolu Fayının Sapanca-İzmit ve Geyve-İznik Kolları Üzerinde Paleosismolojik Araştırmalar [Palaeoseismological Research on the Sapanca-İzmit and Geyve-İznik Branches of the North Anatolian Fault]*. TÜBİTAK Project Report no. TBAG 1013/YBAG 0021 [in Turkish with English abstract, unpublished].

BARKA, A.A. & KADINKY-CADE, K. 1988. Strike-slip fault geometry in Turkey and its influence on earthquake activity. *Tectonics* 7, 663–684.

BARKA, A.A. & KUŞÇU, İ. 1996. Extends of the North Anatolian Fault in the İzmit, Gemlik and Bandırma bays. *Turkish Journal of Marine Sciences* 2, 93–106.

BARTLETT, W.L., FREIDMAN, M. & LOGAN, J.M. 1981. Experimental folding and faulting of rocks under confining pressure. Part IX Wrench faults in limestone layers. *Tectonophysics* 79, 255–277.

BOZKURT, E. 2001. Neotectonics of Turkey – a synthesis. *Geodinamica Acta* 14, 3–30.

BUDAKOĞLU, M. 1999. *İznik Gölü Hidrojeokimyası ve Sonuçların Jeoistatistik Değerlendirilmesi [Hydrogeochemistry of Lake İznik and Geostatistical Evaluation of the Results].* PhD Thesis, İstanbul Teknik Üniversitesi, Fen Bilimleri Enstitüsü, İstanbul [in Turkish with English abstract, unpublished].

CHAPUT, E. 1936. Voyages d'études géologique et géomorphogénique en Turqie. Mémoires Institut Français Archeologic de İstanbul. II f. Paris.

DOOLEY, T. & MCCLAY, K. 1997. Analogue modelling of pull-apart basins. American Association of Petroleum Geologists Bulletin 81, 1804–1826.

ECE, İ.Ö. 1990. Stratigraphy of the Tertiary sedimentary rocks in Gemlik (Bursa) region. *Turkish Association of Petroleum Geologist Bulletin* 2, 123–134 [in Turkish with English abstract].

EISENLOHR, T. 1995. *Die Thermalwässer der Armutlu-Halbinsel (NW-Türkei) und deren Beziehung zu Geologie und aktiver Tektonik*. ETH, Zürich [English summary].

EMRE, Ö., ERKAL, T., TCHEPALYGA, A., KAZANCI, N., KEÇER, M. & ÜNAY, E. 1998. Neogene–Quaternary evolution of the Eastern Marmara Region, Northwest Turkey. *Mineral Research and Exploration Institute (MTA) of Turkey Bulletin* 120, 119–145.

ERGİN, K., GÜÇLÜ, U. & UZ, Z. 1967. *Türkiye ve Civarının Deprem Kataloğu (M.S. 11 yılından 1964 sonuna kadar) [Earthquake Catalogue of Turkey and Its Surroundings (From 11 BC to End of 1964]*. İTÜ Maden Fakültesi Arz Fiziği Enstitüsü Publications no. 24, İstanbul.

FRANZ, S.O., ÜLGEN, U.B., DÖNER, L. & ÇAĞATAY, M.N. 2007. Paleoclimatic changes during the Late Holocene recorded in sediments from Lake İznik (NW Turkey). *Limnogeology: Tales of Evolving Earth, 4th International Limnogeology Congress – Barcelona 2007, S15-O5*, 85–86.

GENÇ, Ş.C. 1993. *İznik-İnegöl (Bursa) Arasındaki Tektonik Birliklerin Jeolojik ve Petrolojik İncelenmesi [Geologic and Petrologic Investigation of Tectonic Units in the Area Between İznik and İnegöl (Bursa)]*. PhD Thesis, İstanbul Technical University [in Turkish with English abstract, unpublished].

GENÇ, Ş., AKINCI, H. & BILEN, A. 1986. *İznik-Uludağ Arasında Kalan Alanın Jeolojisi [Geology of the area between İznik and Uludağ]*. Mineral Research and Exploration Institute (MTA) of Turkey Report no. 7852 [in Turkish, unpublished].

GENÇ, Ş.C. & YILMAZ, Y. 1995. Evolution of the Triassic continental margin, northwest Anatolia. *Tectonophysics* 243, 193–207.

GÖKTEN, E. 2001. Altınova (Hersek Deltası güneyi – Yalova) dolayının neotektonik özellikleri [Neotectonic characteristics of Altınova (south of Hersek delta – Yalova] region]. *ATAG-4 Makaleler Kitabı*, 1–15.

GÖNCÜOĞLU, M.C., ERENDİL, M., TEKELİ, O., AKSAY, A., KUŞÇU, İ. & ÜRGÜN, B.M. 1992. Introduction to the geology of Armutlu Peninsula. *ISGB–92, Guide Book*. Mineral Research and Exploration Institute (MTA) of Turkey Publication, Ankara, 26–35.

GUIDOBONI, E., COMASTRI, A. & TRAINA, G. 1994. *Catalogue of Ancient Earthquakes in the Mediterranean Area up to the 10th Century.* Istituto nazionale di geofisica pubblicazione. Rome.

GÜRBÜZ, C., AKTAR, M., EYİDOĞAN, H., CISTERNAS, A., HAESSLER, H., BARKA, A., ERGİN, M., TÜRKELLİ, N., POLAT, A., ÜÇER, S.B., KÜLELİ, S., BARIŞ, S., KAYPAK, B., BEKLER, T., ZOR, E., BIÇMEN, F. & YÖRÜK, A. 2000. The seismotectonics of the Marmara region (Turkey): results from a microseismic experiment. *Tectonophysics* 316, 1–17.

IMBACH, T. 1992. *Thermalwaesser von Bursa. Geologische und hydrogeolosiche Untersuchungen am Berg Uludağ (NW Türkei)* Diss, ETH Zürich, Nr. 9988.

IKEDA, Y., SUZUKI, Y. & HERECE, E. 1989. Late Holocene activity of the North Anatolian fault zone in the Orhangazi plain, Northwestern Turkey. *In:* HONKURA, Y. & IŞIKARA, A. (Eds), *Multidisciplinary Research on Fault Activity in the Western Part of the North Anatolian Fault Zone*, 16–30.

IKEDA, Y., HERECE, E., SVGAI, T. & IŞIKARA, A.M. 1991. Post glacial crustal deformation associated with slip on the Western part of the North Anatolian Fault Zone in the İznik Lake Basin, Turkey. *Bulletin of the Department of Geography University of Tokyo* 23, 13–23.

KALAFAT, D. 1995. *Anadolu'nun Tektonik Yapılarının Deprem Mekanizmaları Açısından İrdelenmesi İstanbul Universitesi Deniz Bilimleri ve İşletmeciliği Enstitüsü* [*Discussion of the Anatolian Tectonic Structures for the Earthquake Mechanism*]. PhD Thesis, İstanbul Universitesi, Deniz Bilimleri ve İşletmeciliği Enstitüsü [in Turkish with English abstract, unpublished].

KOÇYİĞİT, A. 1988. Tectonic setting of the Geyve Basin: age and total displacement of the Geyve Fault Zone. Middle East Technical University. *Journal of Pure and Applied Sciences* 21, 81–104

KOERI *Catalogue* http://www.koeri.boun.edu.tr, April 2008.

KOYUNLUOĞLU, A.M.T., 1935. *İznik ve Bursa Tarihi [History of İznik and Bursa]*. Bursa Vilayet Matbaası.

RODGERS, D.A. 1980. Analysis of pull-apart basin development produced by en-écheolon strike-slip faults. *In*: BALANCE, P.F. & READING, H.G. (Eds), *Sedimentation in Oblique-slip Mobile Zones*. International Association of Sedimentologists Special Publications 4, 37–43.

SOYSAL, H., SİPAHİOĞLU, S., KOLÇAK, D. & ALTINOK, Y. 1981. *Türkiye ve Çevresinin Tarihsel Deprem Kataloğu [Earthquake Catalogue of Turkey and Its Surroundings]*. TÜBİTAK, Proje no.TBAG 341 [in Turkish with English abstract, unpublished].

STRAUB, C., KAHLE, H.G. & SCHINDLER, C. 1997. GPS and geologic estimates of the tectonic activity in the Marmara Sea region, NW Anatolia. *Journal of Geophysical Researc-Solid Earth* B12, 27587–27601.

ŞENGÖR, A.M.C. 1979. The North Anatolian transform fault: its age, offset and tectonic significance. *Journal of the Geological Society, London* 136, 263–282.

ŞENGÖR, A.M.C. & YILMAZ, Y. 1981. Tethyan evolution of Turkey: a plate tectonic approach. *Tectonophyiscs* 75, 181–241.

TANOĞLU, A. & ERİNÇ, S. 1956. Garsak boğazı ve Eski Sakarya [*Garsak strait and old Sakarya*]. *İstanbul Üniversitesi Coğrafya Enstitüsü Dergisi* 4, 17–31 [in Turkish].

TAYMAZ, T. 1990. *Earthquake Source Parameters in the Eastern Mediterranean Region*. PhD Thesis, Cambridge University, Cambridge [unpublished].

TAYMAZ, T. 1999. Seismotectonics of the Marmara region: Source characteristics of 1999 Gölcük-Sapanca-Düzce earthquakes. *Proceedings of ITU-IAHS, International Conference on the Kocaeli Earthquake 17 August 1999, İstanbul*, 55–78.

TAYMAZ, T. 2000. Seismotectonics of the Marmara region: source characteristics of 1999 Gölcük-Sapanca-Düzce earthquakes. *In*: BARKA, A.A., KOZACI, O., AYÜZ, S.H. & ALTUNEL, E. (eds), *1999 İzmit-Düzce Earthquakes: Preliminary Results*. İstanbul Technical University Publications, İstanbul, 79–97.

TCHALENKO, J.S. 1970. Similarities between shear zones of different magnitudes. *Geological Society of America Bulletin* 81, 1625–1640.

TCHALENKO, J.S. & AMBRASEYS, M.N. 1970. Structural analysis of Dasht-e Bayaz (Iran) earthquake fractures. *Geological Society of America Bulletin* 60, 2018–2102.

TSUKUDA, E., HERECE, E. & KUŞÇU, İ. 1988. *Some Geological Evidence on Activity of the Western Anatolian Fault, Geyve, İznik, Gemlik Area*. ITIT Project 8513, 68–91.

UÇARKUŞ, G. 2002. *Gemlik Fay Zonunun Aktif Tektoniği [Active Tectonics of Gemlik Fault Zone]*. MSc Thesis, İTÜ Avrasya Yerbilimleri Enstitüsü [in Turkish with English abstract, unpublished].

ÜLGEN, U.B., FRANZ, S.O., ÇAĞATAY, M.N. & THEIN, J. 2007. Environmental and climatic history of Lake İznik (NW Turkey) – Preliminary results from a short core study. *Limnogeology: Tales of Evolving Earth, 4th International Limnogeology Congress – Barcelona 2007, FRI-P54*, p. 205.

WESSEL, P. & SMITH, W.H.F. 1998. New, improved version of generic mapping tools released. *EOS Transactions AGU* 79 (47), p. 579.

WILCOX, R.E., HARDING, T.P. & SEELY, D.R. 1973. Basic wrench tectonics. *American Association of Petroleum Geologists Bulletin* 57, 74–96.

YALTIRAK, C. 2002. Tectonic evolution of the Marmara Sea and its surroundings. *Marine Geology* 190, 493–530.

YALTIRAK, C. & ALPAR, B. 2002. Evolution of the NAF Middle segment and shallow seismic investigation of the Southestern Sea of Marmara (Gemlik Bay). *Marine Geology* 190, 307–327.

YOSHIOKA, T. & KUŞÇU, İ. 1994. Late Holocene faulting events on the İznik – Mekece fault in the western part of the North Anatolian fault zone, Turkey. *Bulletin of Geological Survey of Japan* 45, 677–685.