*Turkish J. Marine Sciences 5(3): 111-130 (1999)*

# Underwater Signatures of the Kocaeli Earthquake (August 17th 1999)

# 17 Ağustos 1999 Kocaeli Depreminin Deniz Tabanı ve Güncel Çökeller Üzerindeki Etkileri

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**Abstract**

The fault rupture of the Kocaeli Earthquake ($M_w$ 7.4, at 03:02 on August 17th, 1999) was well defined on land. In the present study, single-channel, high resolution seismic reflection data were used to characterise the underwater fault signatures of the Kocaeli Earthquake in the Izmit Bay and at the eastern Marmara Sea. Some personal opinions are also given about the speculations for a possible (<30 years) and devastating (>magnitude 8) earthquake in the Marmara Sea.

**Keywords:** Marmara, Izmit Bay, earthquake, seismic exploration

## Introduction

An earthquake of magnitude $M_w$ 7.4 occurred on the North Anatolian Fault Zone, one of the well known seismic right lateral strike-slip fault of the World, with a macroseismic epicenter 11 km SE of Izmit in the western part of Turkey on August 17th, 1999 at 03:02am. It was commonly termed as the Kocaeli Earthquake. Different workers use different names as well, such as Izmit, Gölcük or Marmara Earthquake. Its predominant focal mechanism shows a dextral transcurrent movement.

The Kocaeli Earthquake was the last one of a series of westward migrating earthquakes on the fault starting from 1939 Erzincan Earthquake in the eastern section of the fault. Historical records show that the similar migrations took place in the past. Field observations indicated that some parts of the fault rupture were under the sea. Along the Sapanca-Gölcük fault segment, many buildings slid down to sea bottom and sea invaded the shore and submarine cracks along the fault line were observed by scuba divers.

The Marmara Sea (278 x 80 km) forms a complex structure with shelf break at about 110 m. Modern bathymetric data show three central basins (1152 - 1276 m) separating the northern (2-13 km) and southern (~32 km) shelves. Easternmost, Izmit Bay which occupies E-W position (53 x 2-10 km) forms a narrow depressional marine realm consisting of three main basins with two straits. The deepest part of the Izmit Bay is 204 m.

The resultant suture after the Oligocene-collision of the Rhodop-Pontid Block with the Sakarya Zone is now largely replaced by the North Anatolian Fault Zone (NAFZ). The NAFZ is the most prominent active fault zone (30-80 km in length) in Turkey and has been the source of numerous large earthquakes throughout the history. The NAFZ is a relatively simple, narrow and right-lateral transform across most of Turkey and became active in late Miocene-Pliocene (Şengör and Yılmaz, 1991; Perinçek, 1991; Barka, 1992; Okay and Tansel, 1992; Okay and Görür, 1995). The NAFZ splays into three strands to the west of about 30.5E (Şengör et al., 1985). The northern strand passes through the Izmit Bay, traverses the Marmara Sea and reaches to the Saros Gulf.

***Marmara Sea Region***

Several researchers considered that the Marmara Sea region is a graben structure (i.e. Crampin and Evans, 1986). To explain the structure of the northern strand of the NAFZ in the Marmara Sea, Barka and Kadinsky-Cade (1988) and Wong et al. (1995) have developed similar models, that considers right stepping en echelon strike-slip segments giving rise to small open basins and blocks as pull-apart structures.

The Marmara Basin is segmented into a series of rhomboidal or wedge-shape NE-SW oriented small sub-basins. The presence of these deep marine sub-basins in the modern Marmara Sea is mainly related with the dextral movement of the NAF along its northern strand.

Both strike-slip and pure normal faulting earthquakes occur in the region revealing that normal faulting plays an important role in the recent tectonic evolution of the Marmara Sea. The interaction between the NAF and the present N-S extensional tectonic regime of the Aegean developed this complex basement which consists various paleotectonic units (Ketin, 1948; Saltık, 1974; Brinkman, 1976; Şengör, 1979; Hancock and Barka, 1981; Sümengen et al., 1987; Şentürk et al., 1987; Adatepe, 1988; Alpar, 1988; Siyako, et al., 1989; Akgün and Ergün, 1995; Sakınç et al., 1995; Ergün et al., 1995; Ergün and Özel, 1995; Yaltırak, 1996; Barka, 1997).

The Marmara sub-basins are separated by structurally controlled saddles rising about 600 m above their surroundings (Barka and Kadinsky-Cade, 1988; Smith et. al., 1995). The sub-basins are internally cut by numerous steeply dipping faults (Wong et al., 1995). The westernmost of the deep basins is the fault-bend Tekirdağ Basin which was filled Pliocene-Quaternary syn-transform sediments of over 2500 metres in thickness (Okay et al., 1998, 1999).

Such a morphology is a result of splaying of the NAF at its western end in northwest Anatolia, where a N-S extension occurs (Dewey and Şengör, 1979; Görür et al., 1995). The deformation caused by this N-S extension across the northern Marmara Sea is taken up by a series of splays from the Çınarcık Fault which enters into the sea in the east. These splays are the features bounding the basins (Kuşçu et al., 1999).

***Izmit Bay***

The basins of the Izmit Bay were filled with mainly continental siliclastic material resulting from fluvial and littoral processes. The average sedimentation rate was calculated as 20 cm / 1000 year with a maximum of 150 cm / 1000 year for deepest parts (Ergin and Yörük, 1990). Deltaic fans developed in front of the rivers where the currents and waves are weak (Alpar and Güneysu, 1999).The Plio-Quaternary deposits are ~25-30 m thick and overlay the basement (Özhan et al., 1985). This deposition is considered to take place under the influence of the NAF.

The tectonic basins in the Izmit Bay were created by the E-W compressional and N-S tensional forces resulted as a response to the kinematical block displacements at active zones (Barka and Kadinsky-Cade 1988; Kurtuluş, 1990; Barka, 1992; Wong, 1995). Recent faults affect the actual basin-fill deposits in the Izmit Bay and form a negative flower structure (Sakınç and Bargu, 1989; Seymen, 1995) at the seabed. Barka and Kuşçu (1996) describes the best model representing the structural geology of the Izmit Bay as a pull-apart model. According to their model, strike-slip fault segments, which are laterally (echelon) descending towards right, create three small basins; western, central (Karamürsel) and eastern (Izmit) basins. The grabens are considered to lie at overlapping sections of the faults which display an en-echelon pattern (Koral and Öncel, 1995; Şenöz, 1998).

Consequently, the highly industrialised Marmara Region is under high earthquake risk. The main objectives of this paper are to describe the bottom and subbottom signatures of the Kocaeli Earthquake and to establish near surface tectonic settings of the study areas, based on the analysis of high resolution subbottom seismic profiling data.

## Material and Method

Following the Kocaeli Earthquake, single-channel high-resolution digital seismic reflection profiles were acquired (Figure 1) using 1.25 kJ multi-electrode sparkarray and a 11-element, 10-m-long surface-towed hydrophone streamer. The seismic source is less than one meter in length with 30 discharging electrodes (6 kV and 30 mF), spaced about 5 cm apart. Sampling interval was ¼ ms, record window length was 250 ms (twtt) and shot interval was 2 sec (about 4.1 m). These parameters provided details on sedimentary deposits up to 150 m below the seabed. Positioning was carried out by using an integrated GPS with an accuracy of ± 20 m.

## Conclusions

The fault rupture was well defined by many workers on land from Gölyaka to the Hersek Point. The fault rupture (Sapanca-Gölcük segment) enters into the sea at the easternmost part of the Izmit Bay. The seismic profiles recorded at the Başiskele area show the ongoing tectonic deformation in the sea with a well defined seismic pattern (Figure 2). There can be seen gas plumes in the water column coming from weak and discontinuous seismic reflections which may represent different depositional environments. When the NAF became active in late Miocene, the Izmit Bay was representing a fluvio-lacustrine environment (Seymen, 1995; Meriç, 1995). The faults in the Izmit Bay cut different depositional environments (brackish-deltaic, continental, marine and shallow marine) developed under the effects of regional climatic fluctuations and active tectonism from late Pliocene to late Holocene. Due to the reduced modern current velocities in the lower layer, eastern and partly central sub-basins

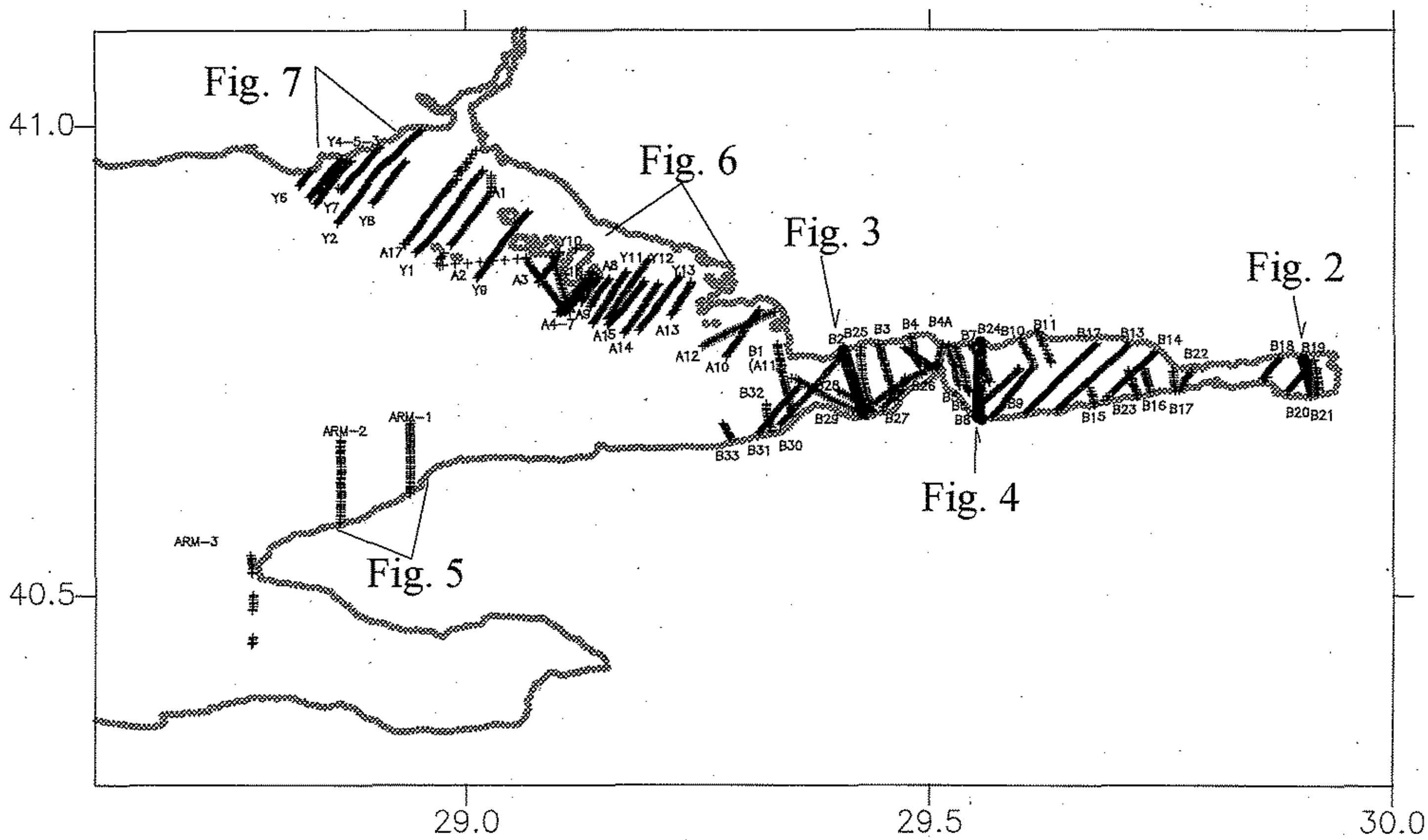


Figure 1. Seismic location map

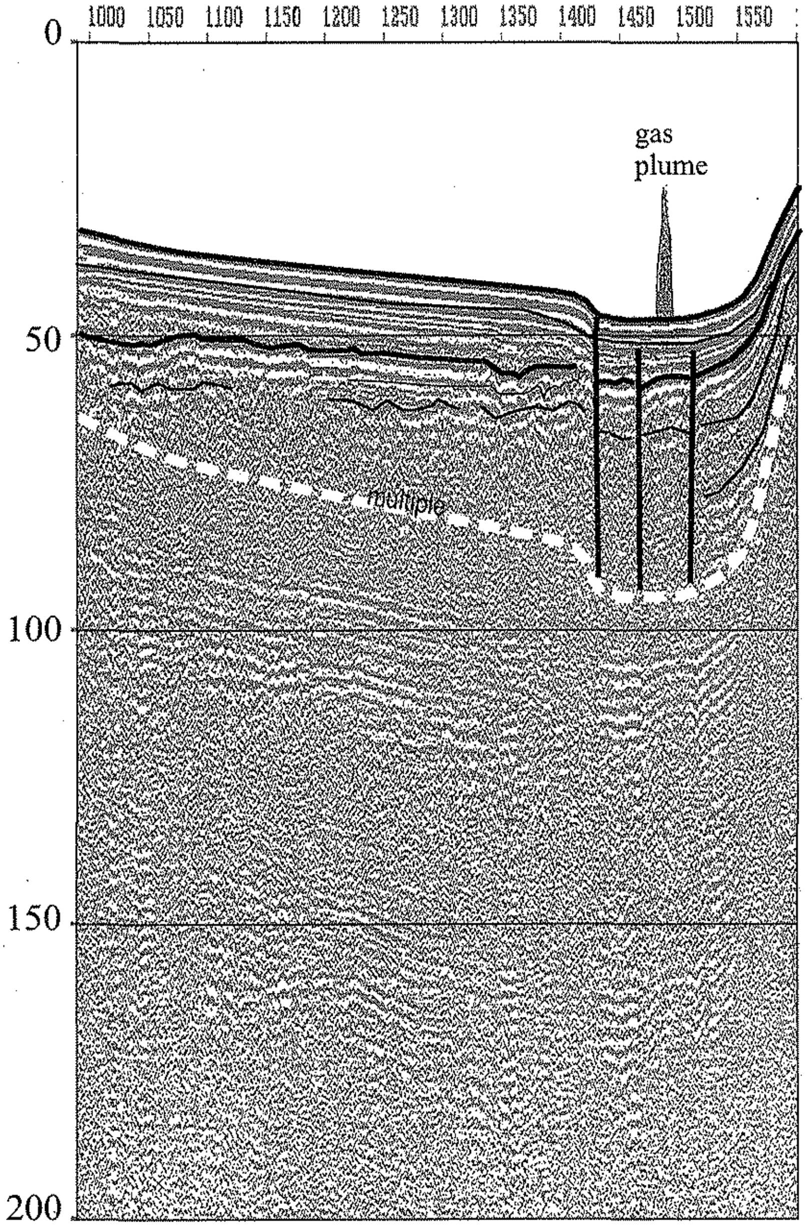


Figure 2. Interpreted line drawing of sparker profile (B20) in the Izmit Basin (Başiskele area). See Fig. 1 for location.

of the Izmit Bay are depositional areas for fine grained material which forms cap rock for the underlying gas-charged sediments.

It is well-known that the subaqueous sedimentary units in the Izmit Bay are charged with gas and the Holocene posttrangressional marine deposits acts as a cap layer over the gas-charged sediments. The gas-charged sediments are generally placed in the central parts of the basins, especially where the gulf becomes wider (personal communication with Mehmet Şimşek). The gas could have been produced by bacterial fermentation reactions during the early diagenesis. These reactions produce large amounts of methane and carbon dioxide as a result of microbial degradation of organic matter in the sediments. Following the Kocaeli Earthquake, many gas seepage's have been observed on the seabed. The most prominent of them was about one km NW of Topçular (Figure 3). where significant gas bubbles have been observed on the sea surface. During the cruise, the lateral distance between the blocks was measured as 5 m wide on the echo-sounder. The gas plumes are sometimes very thick and diverted from vertical by currents (Figure 4).

Tsunamis have been reported in the Marmara Sea and the surrounding area from antiquity to present (Soysal, 1985; Altınok and Ersoy, 1998). Large waves produced by an earthquake or a submarine landslide can overrun nearby coastal areas in a matter of minutes. During the Kocaeli Earthquake, a considerably damaging tsunami hit both the northern and southern sides of the bay in one minute. Even the tsunami was not very large, subsidence and coastal landslides have left a substantial portion of the towns of Gölcük, Değirmendere and Karamürsel inundated with sea water (Altınok et al., 1999, this volume). Precise observation of tsunami runups is rather important in order to discriminate the most plausible cause of the tsunami; tectonics, submarine landslide or such kind of subsidence events. Submarine landslides, which often accompany large earthquakes, can disturb the overlying water column as sediment and rock slump downslope and are redistributed across the sea floor. Submarine landslides disturb the water from above, as momentum from falling debris is transferred to the water into which the debris falls. Therefore, slump-generated tsunamis dissipate quickly and rarely affect coastlines distant from the source area. Therefore, the Kocaeli Tsunami should not be a slump-generated tsunami. This is confirmed by our seismic data as well. There is not any apparent submarine landslides on the seismic sections, except a small slump close to the deepest part (see Fig. 2a in Altınok et al., 1999). So, one can say that the dextral segments extending in the sea floor should have contributed to the tsunami

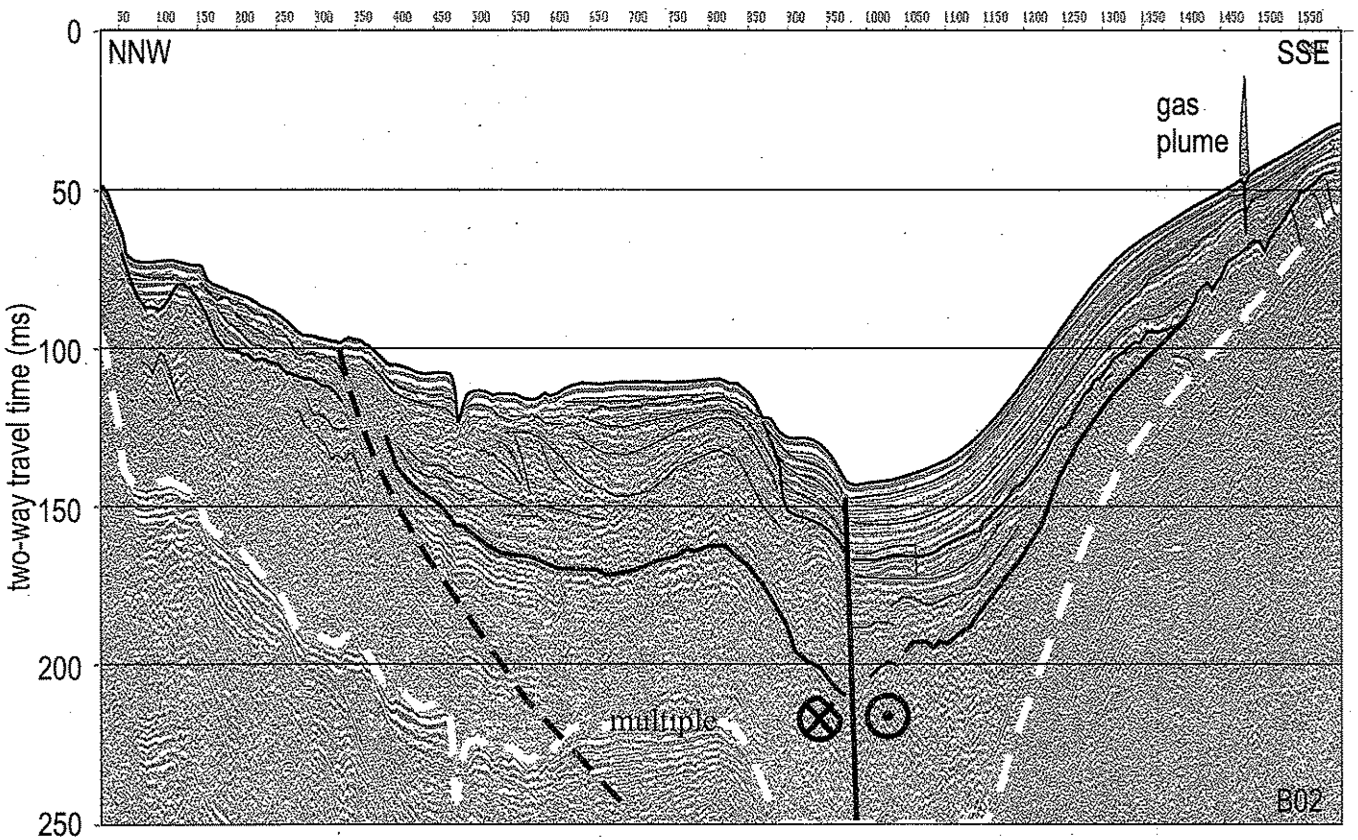


Figure 3. Interpreted line drawing of sparker profile (B02) showing gas plumes. See Fig. 1 for location.

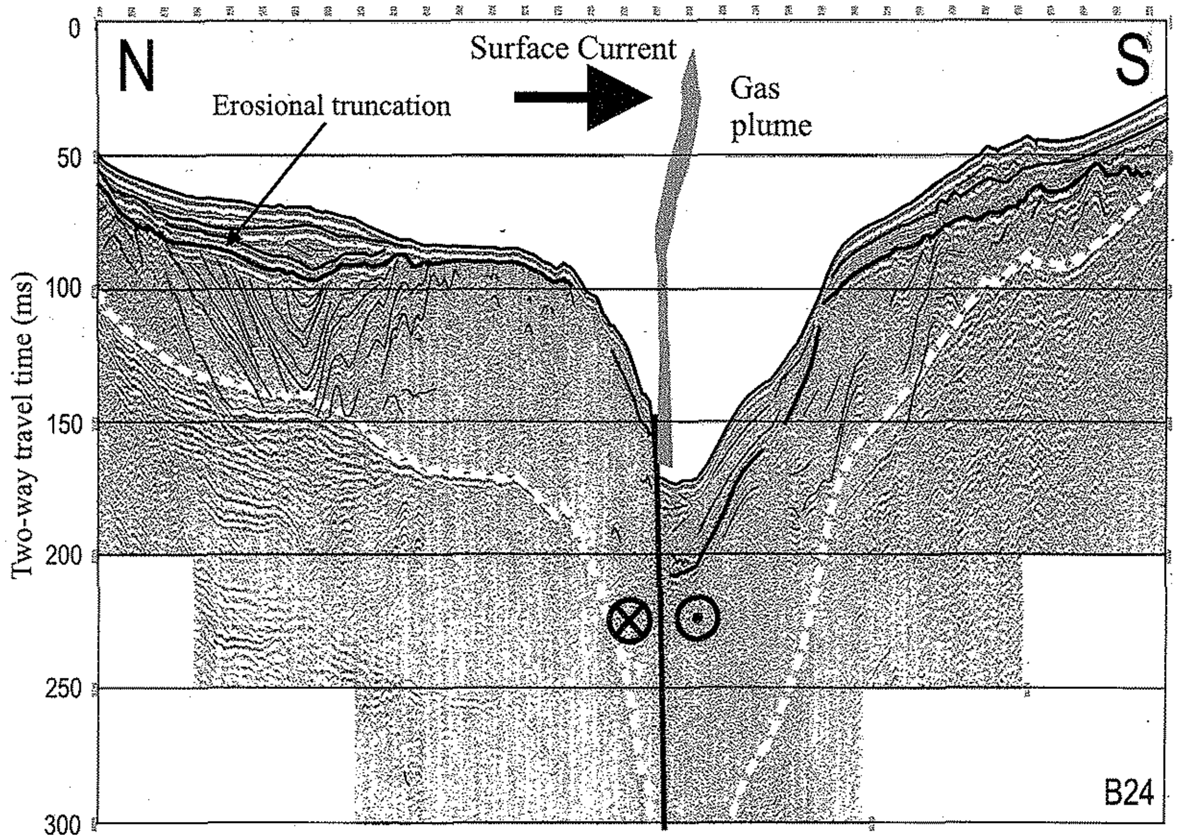


Figure 4. Interpreted line drawing of sparker profile (B24) showing how the gas plume follows current vectors. See Fig. 1 for location.

generation. When the Kocaeli Earthquake occured beneath the sea and large areas of the sea floor subsided, then the water above the deformed area was displaced from its equilibrium position and the waves were formed as the displaced water mass. On the other hand, the subsidence events along the southern coasts (Kavaklı, Değirmendere and Karamürsel) are probably the result of the tectonic deformation along the shores (see also Altınok et al., 1999).

It is well-known that the stress loading is the largest at the two ends of the ruptured fault. According to the aftershock distribution, the western end of the fault is offshore of Esenköy. There are some seabed ruptures on the seismic sections in that area (Figure 5). The fiber optic cable of *Hesfibel* between the Yalova and Yassıada has been broken and burnt 8 km offshore Yalova (personal communication with Cem Değirmenciler). These findings may explain why no ground ruptures were observed on land along the Yalova fault segment. These seabed ruptures may possibly be connected with the *en echelon* faults between the northern coasts of Imralı and Marmara islands defining the northern edge of the southern shelf.

The Pendik Fault with a strike slip character between the Tuzla Peninsula and the islands of Sedef and Balıkçı (Figure 6) is possibly caused by a historical big earthquake occurred in the deep basins of the Marmara Sea. The Pendik Fault is possibly responsible for the cut of the telephone cable lying between Kartal and Çanakkale, which was determined by Eginitis (1894), the director of the Observatory of Athens, who was invited by the Sultan Abdülhamit (II) following the 1894 earthquake (Gündoğdu, 1991).

The fault maps prepared by the MTA's or TPAO's scientists represent the mid-depth ranges (up to 5 km). From conventional seismic data, synthetic / antithetic faults and flower structures within the sedimentary infill are evident. In this depth range, the NAF zone splays into three (or four) strands. Barka and Kuşçu (1996) suggested that there was higher earthquake risk along the northern strand, based on the fact the GPS slip rate was higher along the northern strand (from Izmit Bay to Saros Gulf) than that along the middle strand. Considering that the GPS observations establish a 24±4 mm/a deep slip rate on the North Anatolian fault (Straub and Kahle, 1994, 1996, 1997) and also the right lateral displacement offset of the Kocaeli Earthquake to be 4.4 m, it can be calculated that the energy introduced by the Kocaeli Earthquake can be compensated in 180±40 years.

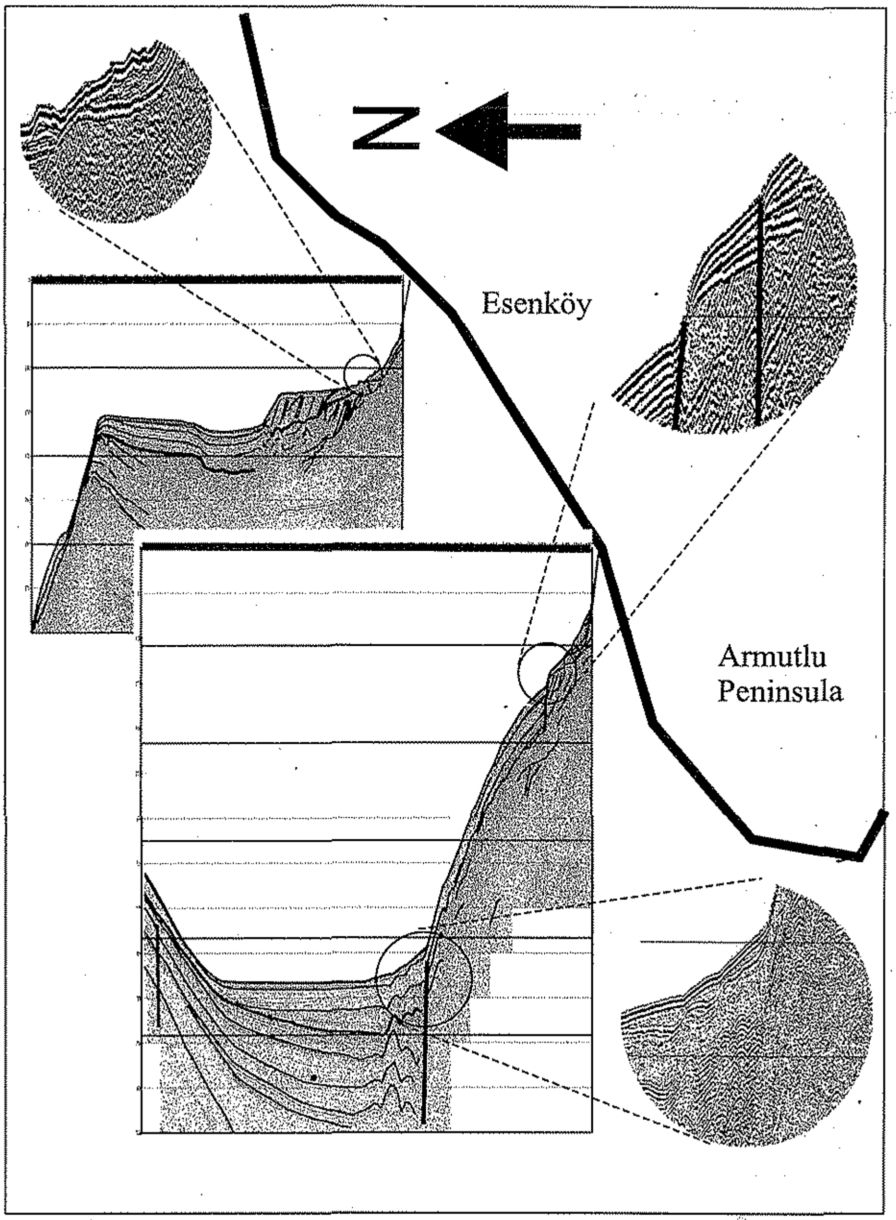


Figure 5. Structural block diagram of the western end of the fault rupture at the sea bottom (Esenköy). Viewing direction is from W to E.

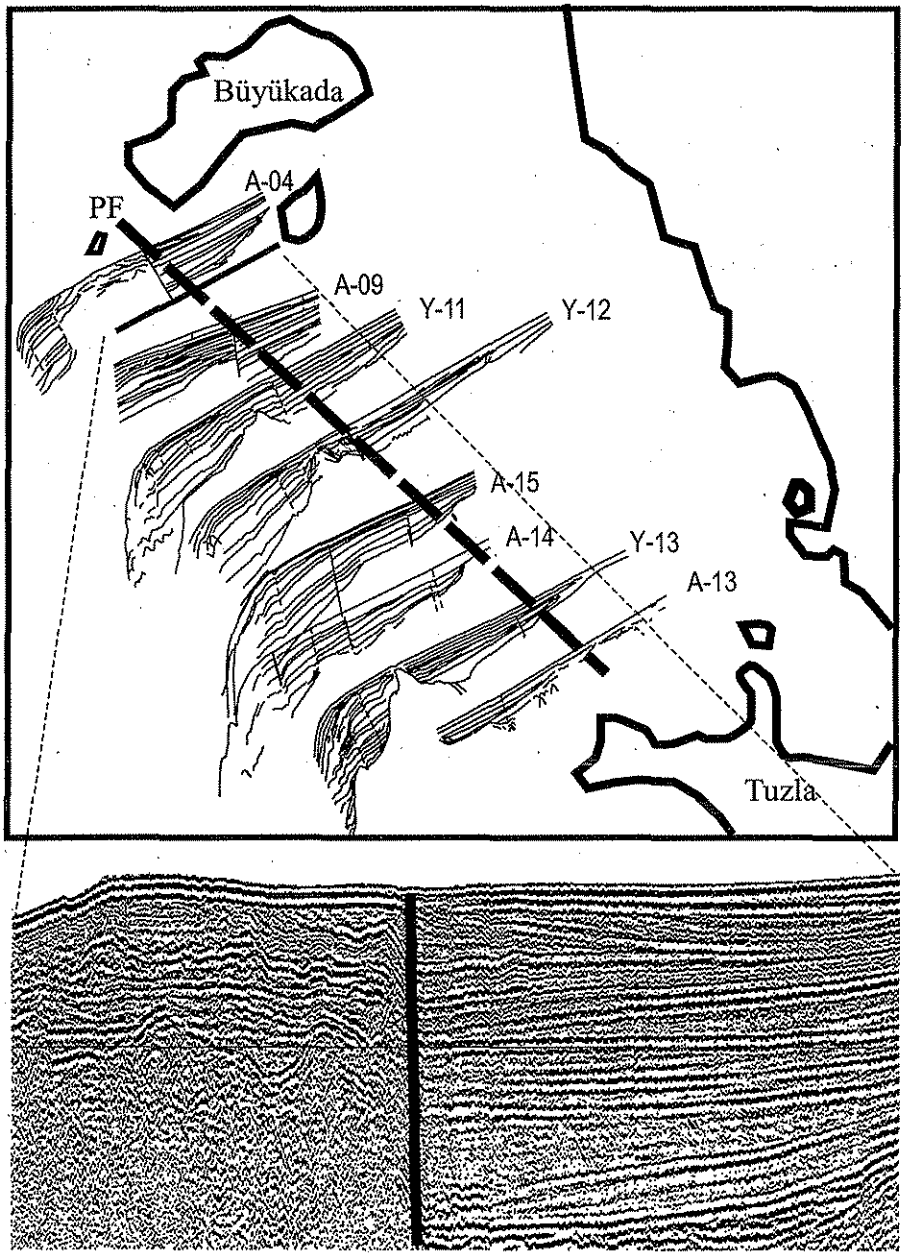


Figure 6. Structural block diagram of the Pendik Fault. Viewing direction is from SE to NW.

However, 6-7 km below the surface, the fault plane (not a zone anymore) is believed to be a single plain. This is not a new idea of the author! This fault plane (the North Anatolian Fault) occupies a certain position under the rhomboidal deep marine sub-basins in the modern Marmara Sea and also under the deepest parts of the Saros Gulf, close to the northern margin, but not along the northern coasts of the Gelibolu Peninsula (Fig 10 in Yaltırak et al., in press). Therefore the Ganos Fault is one of the shallower branches of the North Anatolian Fault. The steep slopes along the northern margin of the Marmara Sea (Fig. 3 in Aksu et al., 1999) are the geomorphic evidences of this sight. In fact, there is literally no shelf area in front of the Ganos Mountain where very steep slopes continue down to >1000 m water depth. The Moho discontinuity in the Marmara region, which gets deeper from north to south as defined by Özer et al., (1996) using azimuthal anomalies computed from the particle motion diagrams, may play an important role in this configuration.

The NAF or the segments of the NAFZ will evidently be triggered off in future. However, the author hardly believes that a single earthquake (Le Pichon, 1999) will rupture the fault from east (Hersek or Esenköy) to west (Gaziköy, where the seismic energy discharged on August 9$^{th}$, 1912; Ambraseys and Finkel, 1987) all along the Marmara Sea. It seems to be rather difficult, because there should be another old fault system cutting the Marmara Sea in NW-SE direction (Yaltırak et al., 1998; Yaltırak et al., in press). This old fault system, which can be partly seen from the conventional oil seismic studies in the Ergene Basin (Thrace), underlies the present N-S extensional tectonic regime and possibly aged as 60 my B.P. This old fault system, which should be chopped up internally by numerous faults, might form a natural barrier in the Marmara Sea and might prevent the NAF to break the Marmara at one time. This assumption can be tested with a piece of paper thorned in the middle. One can not tear such a piece of paper at an oblique angle from one end to other. Consequently, it may be considered the rupture speed (about 3 km/s) can not overcome the remnants of the old NW-SE fault (or a half-graben ?) system lying deeps of the Marmara sub-basins. On the other hand, such kind of sticking processes of the NAF to the old NW-SE fault underneath the Marmara deeps may cause some seismic activities at the coastal sections of the old NW-SE fault (especially along the Marmara coasts of the Thrace such as Ambarlı and Yeşilköy). Offshore part of the Halkalı (or Ayamama) River (which is placed in a valley caused by the old fault or graben system) is one of such kind of places where gas plumes were observed on the seismic sections following the Kocaeli Earthquake (Figure 7). The author believes that such kind of gas plumes

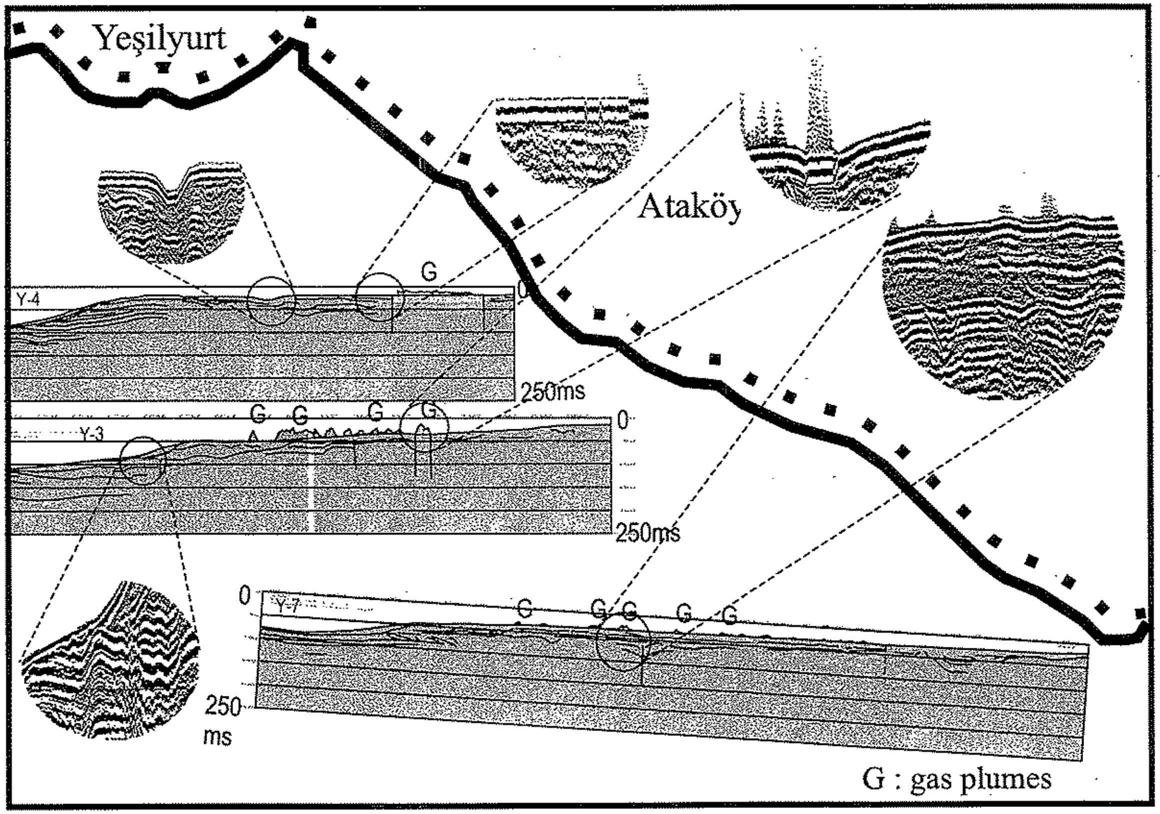


Figure 7. Structural block diagram showing the gas plumes along the western coasts of Istanbul. Viewing direction is from E to W.

were caused by stress transfer of the Kocaeli Earthquake on the old NW-SE fault.

Additional offshore studies will refine details of the underwater geological effects and seismological parameters of this major earthquake.

**Özet**

Bu çalışmada, İzmit Körfezi, Armutlu Yarımadası kuzeyi, Tuzla Körfezi, Adalar ve İstanbul'un güneybatı kıyıları boyunca yapılan sığ sismik çalışmalarının ışığında 17 Ağustos 1999 Kocaeli Depreminin ($M_s$ 7.4) deniz tabanı ve dip altında yarattığı olası yapısal değişimler incelenmiştir. Son zamanların spekülasyon konusu olan ve 30 yıl kadar yakında olduğu iddia edilen olası büyük Marmara depremi hakkında bazı görüşler sunulmaktadır. Bu görüşler kişisel olup, konu ile ilgili disiplinler tarafından sınanmalıdır.

**Acknowledgements**

This paper would not be carried out without the financial support of Prof. Dr. Ertuğrul Doğan who made everything out of nothing. I wish to express my sincere thanks to Assoc. Prof. Dr. Yıldız Altıok for her proposals based on the unusual geomorphic feature of the Balıkçı island, to Assoc. Prof. Dr. Berkan Ecevitoğlu for his technical hints on data acquisition, to Dr. Oğuz Gündoğdu for his pessimism about coming seismic hazards which caused us increase the number of seismic lines, to Mr. Şahin Akkargan for his onland work expressing dignity, to Col. Nazım Çubukçu for his historical data support, to Mr. Mehmet Şimşek for his comments about the gas charged sediments in the Izmit Bay before the Kocaeli Earthquake, to Mr. Sabri Bal for his operational and technical support and to the officers and crew of the research vessel RV Arar for their guidance, comments and assistance in data acquisition.

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*Received 22.11.1999*

*Accepted 18.12.1999*