

RESEARCH ARTICLE

Sea bottom features of eastern İzmit Bay and entrance zone of the North Anatolian Fault in the northeastern Marmara Sea

Vedat Ediger^{1*}, Ali Cankurtaranlar¹, Onur Akyol²

ORCID IDs: V.E. 0000-0003-4388-7951; A.C. 0000-0002-6044-5111;
O.A. 0000-0003-3956-1449

¹ TÜBİTAK MAM Earth and Marine Sciences Institute, P.O. Box 21, 41470 Gebze, Kocaeli, TURKEY

² TÜBİTAK MAM Environment and Cleaner Production Institute, P.O. Box 21, 41470, Gebze, Kocaeli, TURKEY

*Corresponding author: vedat.ediger.55@gmail.com

Abstract

The main purpose of this study is to investigate the North Anatolian Fault (NAF) entrance into İzmit Bay. Upper Quaternary submarine features (gas seeps, gas bearing sediments, pockmarks, mud volcanos, sediment structures and faults) and alongation of the NAF from land to İzmit Bay are investigated by using water depth data, high-resolution shallow seismic profiles, side scan sonar images, and borehole logs. The presence of acoustic anomalies in the Late Quaternary sequences was observed intensely and these anomalies were interpreted as gas bearing sediments. As a result of earthquakes and / or mass movements, the amount of buried gas accumulated along the sediment column may have increased or displaced. In this study, five different gas bearing layers are classified and their distribution patterns are mapped. It has been determined that the active faults in the region that shaped the coastal zone and sea floor morphology of the İzmit Bay are in two different groups. The first group consists of right-lateral strike-slip faults that run along the north and south slopes of the east depression and are in the east-west direction. The secondary group of faults have normal fault characteristics. These secondary faults are parallel to the depth contour lines of the deltas.

Keywords: Late-Quaternary, shallow seismic, side scan sonar, gas bearing sediments, pockmark, mud volcano

Received: 17.02.2021, **Accepted:** 04.04.2021

Introduction

İzmit Bay is located in the east of the Marmara Sea and comprises three basins: the western, central and eastern basins (Figure 1). Basins are separated by two shallow sills located to the north of Hersek Peninsula (54m depth) and north of Gölcük (33m depth). The study area is located at the eastern end of İzmit Bay. High resolution shallow depth sounding records, seismic profiles, side scan sonar (SSS) images and sea bottom drilling cores were obtained along the eastern edge of the bay. The use of intensive and diverse geological and geophysical data has increased the sensitivity and importance of this work.

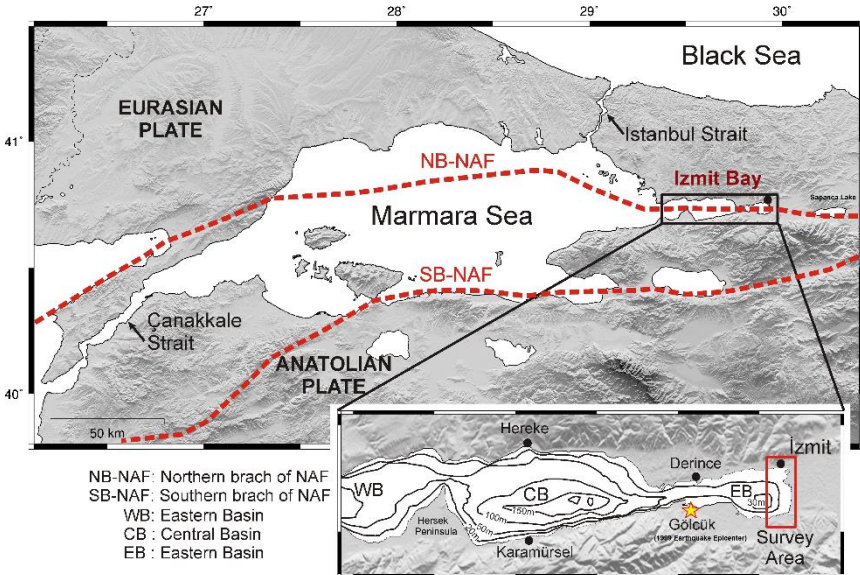


Figure 1. Map showing the location of the study area at the easternmost corner of İzmit Bay (Fault lines are simplified from Okay *et al.* 2000)

Over the last two decades plenty of seismic reflection surveys have been carried out in İzmit Bay. These surveys have provided the basis for detailed information about the stratigraphy and structure of the bay. Considering the importance of the study area to the country's economy, industry and maritime transport, it reveals the importance of knowing the geological and sedimentary characteristics of the bay in detail. The knowledge accumulation in this direction will contribute to the efforts to reduce the pressure of natural disasters on both the economy and social life.

Up to now, research on the eastern corner of the bay related to the North Anatolian Fault (NAF) do not cover the critical transition zone between the land and sea. The most important characteristic of this study is that the sea side of the transitional zone between land and sea was studied in detail. Thus, it is considered

that the results of our work will provide important contributions to the research to be done on the extension of the NAF into İzmit Bay and its extension to the Marmara Sea from the Bay. In addition, the present work contains detailed findings about the sea bottom structures and the gas bearing sedimentary layers. In this article, the structures of the sediment layers in the eastern corner of İzmit Bay were investigated by using some previous studies and a set of new marine data. This study mainly focuses on the eastern coastal region of the bay. The main focus of this article is to investigate the seabed structures and presence of gas bearing sedimentary unit in the area. As a result, the areal distributions of the seabed structures and the entry points of the NAF to the bay were determined and mapped by the integrated interpretation of all data.

Structural features

İzmit Bay is a narrow and elongated basin extending towards the east of Marmara Sea under the structural control of the NAF (Figure 1). The northern branch of the NAF enters the eastern Marmara Sea through İzmit Bay. NAF is an active right-lateral strike-slip fault in northern Anatolia which runs along the transform boundary between the Eurasian and Anatolian plates (Ketin 1948). The fault extends westward from a İzmit Bay junction with the East Anatolian Fault (EAF) at the Karlıova Triple Junction (KTJ) in eastern Turkey, across northern Turkey, into İzmit Bay, Marmara Sea and Aegean Sea, respectively (Ketin 1969; Şengör *et al.* 1985; Şaroğlu 1988; Barka 1992). NAF split into two branches in the Marmara Region and this region acts as a transition zone between strike slip behavior of NAF and N-S extensional regime of western Anatolia (Gürer *et al.* 2003). The entrance of the northernmost branch of NAF to the Marmara Sea is at the southern side of İzmit Bay (Şengör 1979; Şengör *et al.* 1985; Barka 1992; Şaroğlu *et al.* 1992). This branch plays an important role in the structural formation of the bay. The sea bottom morphology of the bay was influenced by the neotectonic period movements affecting the morphology of the entire Anatolian plate. The controlling factor of the neo-tectonic movements in the region is formed by the influence of the NAF (Turoğlu 1998).

Numerous structural and sedimentological marine studies had been carried out in İzmit Bay prior to the 1999 İzmit earthquake. Geological and sedimentological characteristics of the region were investigated and mapped before the earthquake (Özhan *et al.* 1985; Özhan 1986; Kavukçu 1990; Barga and Yüksel 1993; Akgün and Ergün 1995; Koral and Öncel 1995; Barka and Kuşçu 1996; Barka and Reilinger 1997; Özhan and Bayrak 1998, and Şenöz 1998) (Figure 2). Although pre-earthquake surveys were performed as part of the Marmara Sea geology, the post-earthquake activity is mainly concentrated in the bay.

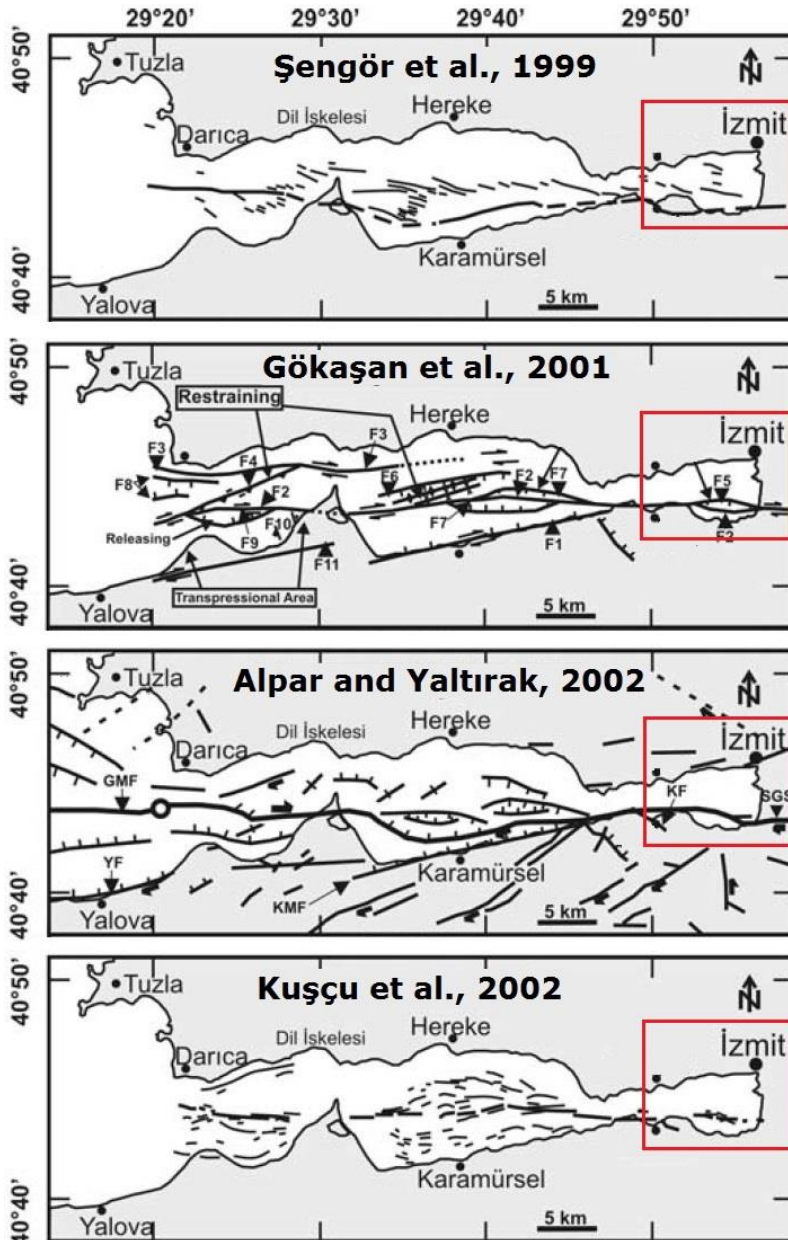


Figure 2. Structural maps produced as a result of previous researches in and around İzmit Bay. These maps were compiled from Okyar *et al.* (2008).

After the 1999 İzmit earthquake, various geological, geophysical and oceanographic studies were carried out in İzmit Bay and very detailed data were

collected (Alpar and Güneysu 1999; Şengör *et al.* 1999; Alpar and Yalıtırak 1999, 2000 and 2002; Gökaşan *et al.* 2001; Kuşçu *et al.* 2002; Okyar 2003; Cormier *et al.* 2006; Okyar *et al.* 2008; Kurt and Yücesoy 2009) (Figure 2). However, when these maps are examined carefully, it is clear that none of them concentrates especially on the eastern end of the bay and does not cover this zone.

Morphology

The length of the bay is approximately 35 km and the width varies between 1.5km (Derince - Gölcük) and 10 km (Hereke-Karamürsel). İzmit Bay is divided into western, central, and eastern three basins, considering the coastal structure and fault-controlled depressions (Güneysu 1999). The deepest point of the central basin is about 200 m (Okyar *et al.* 2008). Southern coastal zone of each of the three basins is steeper and narrower than the northern coastal zone. Partially narrow and shallow passages between these three basins and the NAF controlled depressions in southern regions are observed. Deep-basins near the southern shore were developed due to the seismic activity in Pliocene (Ergin and Yörük 1990). Tectono structural framework effects sediment erosion, transportation, deposition and gas removal are the geomorphological processes that shape the sea floor morphology of İzmit Bay (Ergin and Yörük 1990).

Sedimentology

Geological and geomorphological evolution of western, central and eastern basins, which are connected directly to each other through narrow passages and show little sedimentological difference. Detailed results about the characteristics of the sediment deposition along the coastal (Güneysu 1999) and marine (Okyar *et al.* 2008) areas of İzmit Bay have been given in previous studies.

The sediment thickness distribution in the bay show regional differences depending on the location of the coastal rivers, seabed erosion/deposition mechanism, and the sea bottom morphology (Figure 1). Okyar *et al.* (2008) concluded that the highest values of sediment thicknesses in the central and eastern basins were associated with fault lines passing through the area. In the middle part of the eastern basin, the average thickness of the Holocene sediments reaches 15 m. On the other hand, in the eastern part of the basin where the study area is located, the sediment thickness varies between 20m and 25m (Okyar *et al.* 2008).

According to Ergin and Yörük (1990), the middle and southern regions are dominated by silty sediments. Whereas, in the northern part where the industrial and settlement areas are intense, clay-sized material is predominant in the sea bottom. Geochemical analysis of the surface sediments of the eastern basin indicates that the organic carbon and calcium carbonate percentages decrease from the north where the housing and industrial settlements are intense to the south (Ergin and Yörük 1990).

Materials and Methods

Marine geological and geophysical data used in this study were collected by using DIPTAR shallow water research platform of R/V TÜBİTAK Marmara. Shallow seismic and SSS data were collected by using combined Edgetech 2000-DS system. Frequency range of source wavelet was chosen between the ranges of 2 kHz to 12 kHz after source test studies at the survey area. Images were collected (at 400 kHz sampling frequency) to cover areas of 80 m to the right and left sides of each SSS line. SSS studies were carried out in the north-south direction and at a distance of 75 m between the lines (50% coverage) (Figure 3). Leica GS-14 dual frequency geodetic GPS receiver was used during the acquisition of all marine data (the positional accuracy is about ± 2.5 cm in the horizontal plane).

From the research area, 121 sub bottom seismic profiles, 46 continuous SSS images, simultaneous multibeam depth data along all lines and 6 different core samples were collected (Figure 3). All these raw data were processed, examined, interpreted and mapped.

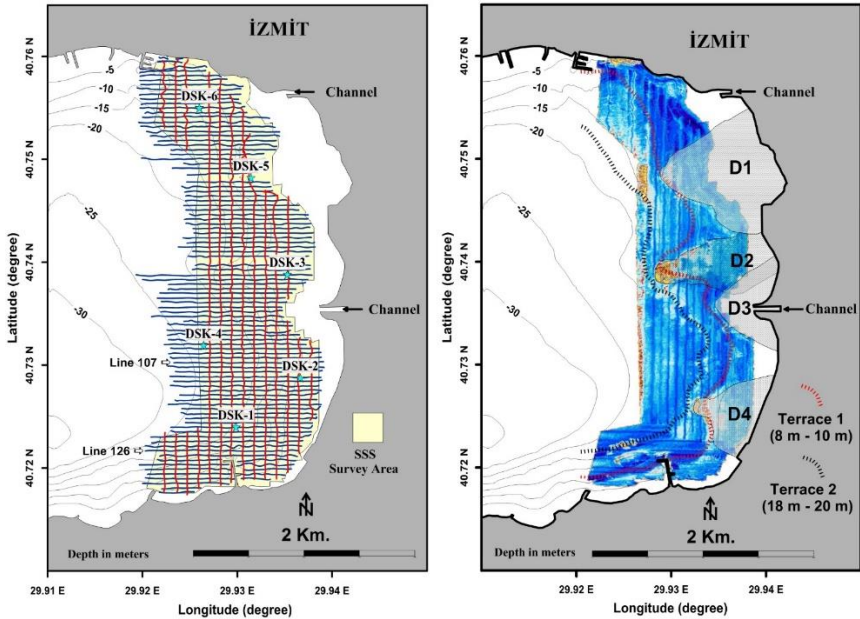


Figure 3. Track line of the high resolution seismic profiles (red and blue lines), SSS coverage area (yellow) and core locations (DSK 1-6) (at left). SSS mosaic images, coastal deltas (D1, D2, D3 and D4) and terraces (1 and 2) with depth contours (at right).

Standard methods discussed by Mitchum *et al.* (1977), Sangree and Widmier (1977, 1979), Vail *et al.* (1977) and Brown and Fisher (1979) were followed during the interpretation of seismic reflection data and the definition of reflection

characteristics of the bottom. Depth conversions from time sections were made using a sound velocity of 1500m/s for water and 1700m/s for sediments (Ediger and Ergin 1995).

When the density and coverage of the data obtained in this study are taken into consideration, it is understood that this research is the most extensive research in the eastern part of İzmit Bay.

Result and Discussion

Sea bottom morphology, deltas and terraces

Sea bottom morphology of the study area was investigated by using the bathymetric data and SSS images (Figure 3). Eastern depression of İzmit Bay is one of the basic sea bottom morphological features of the studied area. This depression has an asymmetry along the east-west axis of the eastern basin as well as different slopes on the northern and southern sides. Although the southern slopes of this depression have a steep morphological feature due to southern branch of the NAF, the northern slopes have a less sloping morphological structure due to the high sedimentation (Özhan *et al.* 1985; Ergin and Yörük 1990).

The average sedimentation rate in the area was calculated as 20cm/1000 year with a maximum of 150cm/1000 year for the deepest parts (Ergin and Yörük 1990). The Plio-Quaternary deposits are 25-30m thick and overlay the acoustic basement (Özhan *et al.* 1985). Due to the high sedimentation originating from the eastern coastal rivers, the eastern shelf of the study area was relatively shallow and wide (Figure 3). Deltaic fans developed in front of the eastern rivers where the currents and waves are weak and sedimentation is high (Alpar and Güneysu 1999). Bathymetric and SSS maps show that four different shapes of deltas were developed in the continental shelf and extended from the present coast to the westward (Figure 3). The places where rivers reach the sea, the amount of sediment loads of rivers and sea level changes due to global climate changes are the main factors affecting the shape and coverage areas of deltas.

SSS mosaic map shows two distinct post-glacial marine terraces at -9+1m and -19+1m depth of sea water (Figure 3). Based on previous studies related to the sea level change of the Marmara Sea, it is assumed that these marine terraces are probably younger than 8,500 years BP (Ediger *et al.* 2018).

Seismic interpretation and evidence of shallow gas

An extensive area, which is characterized by poor seismic reflection pattern and low seismic penetration, was revealed as a result of very high resolution reflection seismic surveys on the eastern corner of İzmit Bay (Figure 4). It was most likely resulted from scattering of the acoustic energy by interstitial gas in the sediment (Schubel 1974). In general, some morphological structures of the seabed may be

indicative of gas removals from the seabed. The presence of pockmarks and mud volcanoes in the study area gave the impression that these morphological structures were formed by the effect of gas exits along the fault line and along the local cracks. In general, gases that are thought to rise towards the seabed within the porous deltaic units appear to be trapped beneath the low porous cover units and parallel to the boundary line of these units (Figures 4 and 5). Nevertheless, more quantitative studies in which acoustic properties of gas bearing sediments were examined based on seismic investigations are very rare in this studied area. Indicators considered to be related to gas in seismic profiles were acoustic turbidity and blanking, phase reversal and strong multiple reflections (Figure 4).

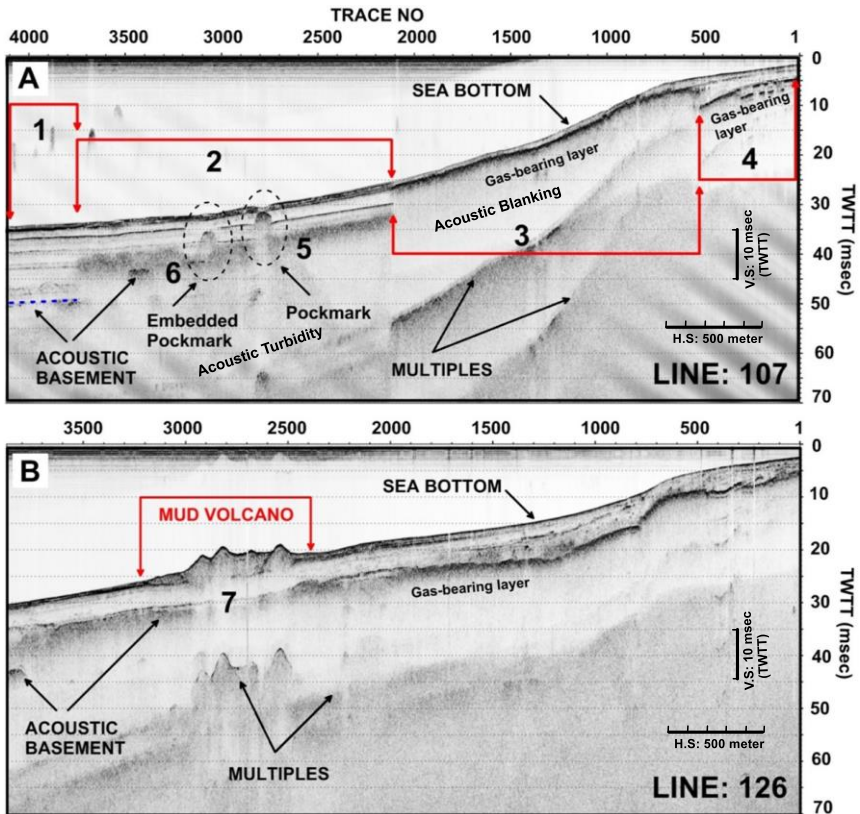


Figure 4. The internal structure of the acoustic basement and the Late Quaternary sediments deposited on it, observed in the deepest part of the seismic reflection profiles 107 and 126 (see Figure 3 for location).

Gas-free layers (1), Gas in deeper layers (2), Gas in shallow layers (3), Gas in the bottom and between the layers of the top set deltaic deposits (4), Pockmark (5) and embedded pockmark (6), mud volcano (7), acoustic basement and multiples.

Acoustic turbidity, which is defined as diffuse and chaotic seismic energy covering almost all deep reflections, is the most prominent gas-related anomaly

Origin and areal distribution of gas

Seismic data showed the presence of gas charged sediments at different layers and depths along the seafloor (Figure 4). The accumulation of gas in the layers may be due to differences in the gas bearing properties of these smelly sediments (Figure 5). It is thought that as a result of the high pressure resulting from high sedimentation and regional tectonic movements, the gases may have concentrated in the sediments close to the surface and formed pock marks (Yun *et al.* 1999). It is thought that the migration pathways that allow gases to concentrate in sediments may be along stratigraphic layers (Orange *et al.* 2002), along weak zones resulting from faults, and within porous sediments (Judd and Sim 1998).

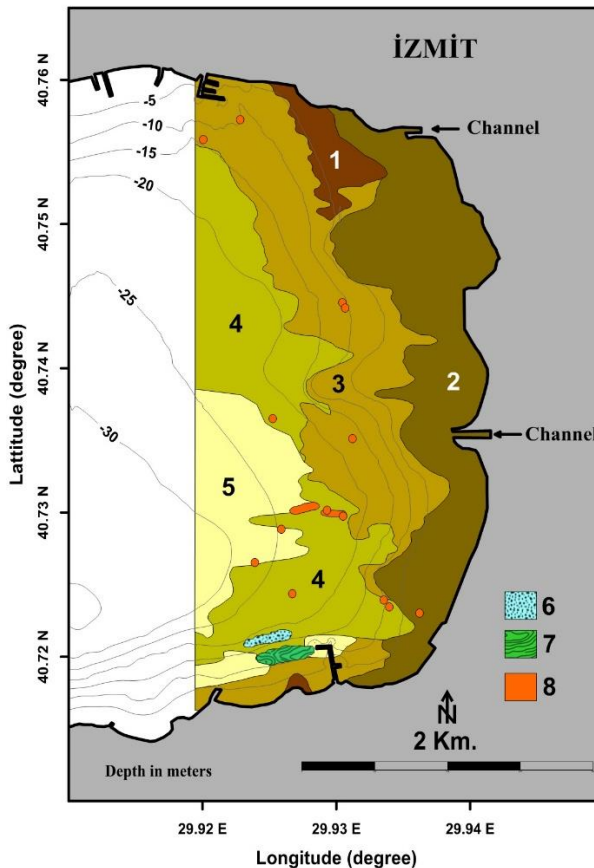


Figure 6. Distribution of gas bearing sedimentary layers mapped by using their stratigraphic locations and areal distributions

- 1: Gas-free layers, 2: Gas in deeper layers, 3: Gas in shallow layers, 4: Gas in the bottom and between the layers of the top set deltaic deposits, 5: Gaseous fields reaching the sea floor, 6: Pockmarks, 7: Rock outcrop and 8: Mud volcano.

On 17 August 1999, a major earthquake of M_w 7.4, whose epicentre was located near the pockmark field, appears that has probably activated the pockmarks and mud volcano (Kuşçu *et al.* 2005). As a result of the interpretation of the seismic sections, an active pockmark area extending in the E-W direction in the study area was identified and mapped (Figure 6).

Origin and distribution of gas in shallow marine sediments has probably two principal potential sources: (1) biogenic gas produced by bacterial degradation of organic matter at low temperatures, and (2) thermogenic gas produced by high-temperature degradation and cracking of organic compounds at considerable burial depths (Schoell 1988). Gases detected at different levels and characteristics within the Holocene sediments (Kvenvolden *et al.* 1981; Okyar and Ediger 1999). Anthropogenic (industrial and domestic) materials originating from the intensive settlement areas along the northern coast contain organic matter in high concentrations (Yaşar *et al.* 2001; Tolun *et al.* 2012). Thus, the high source of organic matter in surface sediments is likely to be anthropogenic (Figure 6). In addition, a high organic productivity in the Marmara Sea during the Quaternary, a high inflow of terrigenous organic carbon by many coastal rivers in combination with a good preservation of organic matter due to hydrogen sulphite saturation of the water column may have resulted in the generation of considerable amounts of biogenic gas in shallow subsurface sediments (Figure 4).

The geology and morphology of the study area shows some possible deep thermogenic sources of gas along the NAF zone and organically rich shallow biogenic sources of gas along the other part of the survey area. It was found that the clay dominant levels of cores DSK-5 and DSK-6 drilled in the regions close to the coastal areas (Figures 3 and 5) had a bad smell. Organic materials in the water column are stored together on the seabed during the rapid sedimentation of mud dominated sediments. Therefore, it is thought that biogenic gases are the cause of the smell of the sediments. However, the main origin of the gas observed at different levels was associated with the presence of Late Pleistocene - Early Holocene aged peat bearing layers observed in the drilling cores (Figure 5).

As shown in the seismic sections, different levels of gas bearing sediments observed in different sediment layers (Figure 4) may be indicative of large-scale organic carbon deposition in the basin (Okyar and Ediger 1999). The gas bearing areas are classified according to the depth at which the gas is observed in the sediment layers. Thus, gas bearing layers were identified, classified and mapped under five different categories (Figure 6). In the northern and southern corners, the areas where the gases reach the uppermost sediment layers were identified and called as Area 5 (Figure 6). In Area 4, gas bearing sedimentary units were observed between the deltaic strata near the coastal zone (Figure 6). The areas where the gas bearing layers were observed deeper than the surface are called Area 3, the relatively deeper gas bearing areas are called Area 2 and the non-gas bearing areas are called as Area 1 (Figures 4 and 6). In addition, mud volcanoes

and pock marks which may have been caused by sudden and intense gas leakage during fault activations in the south of the bay were observed and mapped (Figures 4 and 6).

The boundaries of these areas probably bounded by regional faults, gas quantities and / or different sediment characteristics (grain size and porosity). On the map, when the depths of the gas bearing layers from the seabed were examined, it was seen that there was relative deepening from the north to south and east to west of the basin (Figure 6). Mud volcanoes (Area 8), rocky hills (Area 7) and pits (Area 6) were other basic features of the basin (Figure 6).

Faults and E-W extension of the NAF

The NAF, which crosses the eastern basin in the east-west direction and located to the south of the basin, played an important role in shaping the morphology of the eastern basin. The basin therefore had an elliptical and asymmetrical shape (max. depth -42m). The basement structures of the area were mapped by interpreting the shallow seismic sections collected from the region (Figure 7). When the structural features of the seabed of the research area were examined, the presence of two main fault groups was determined. Normal faults to the north of the southern basin were classified as normal faults group and strike-slip deep faults to the south were classified as NAF group. (Figures 7 and 8).

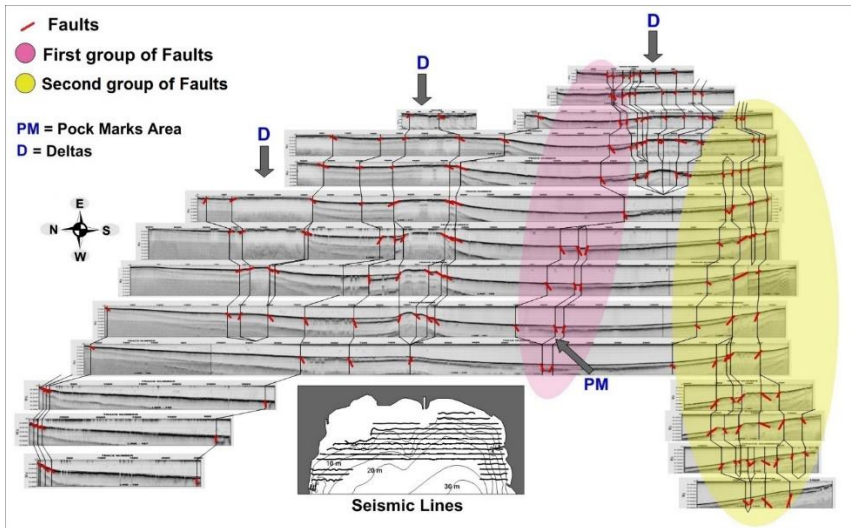


Figure 7. Sequential display of seismic sections (lines) extending in the north-south direction. Faults, pockmarks, deltas and their correlations are presented.

The presence of gas in pock marks (some buried) and along the sediment columns on the sea floor is probably controlled by small-scale normal faults along the delta slopes. Generally, the presence of these faults in delta slopes is a result of high

sedimentation rates and submarine landslides (Katz *et al.* 2015). The presence of gases in fine-grained unconsolidated deltaic sediments may have led to increased pore pressure, reduced shear resistance, and ultimately to the formation of normal fault group (Figure 8). It was observed that these faults generally extend parallel to the depth contours of the deltas (Figure 8).

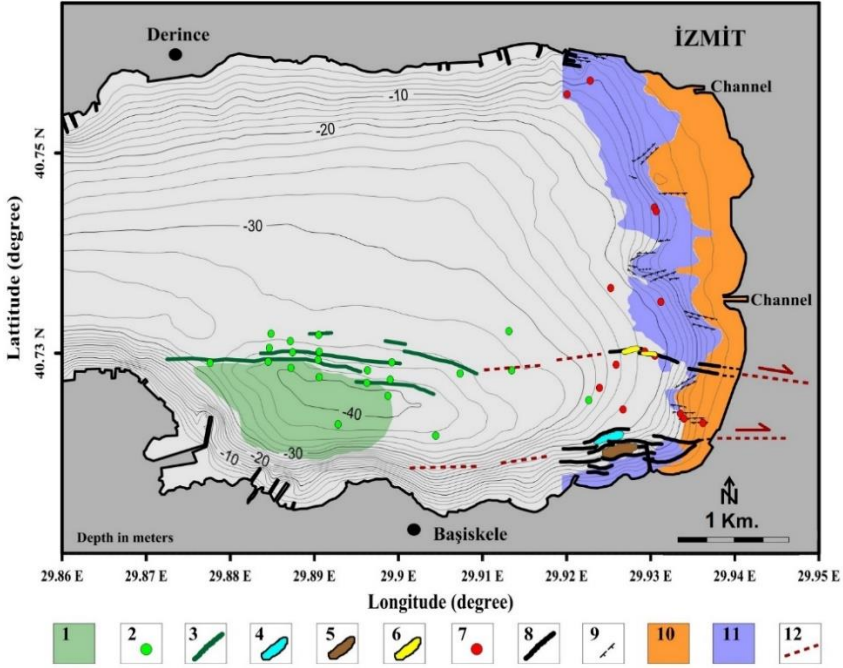


Figure 8. The sea bottom structural features and their areal distributions obtained by this and some previous studies

- 1: Gaseous area (Kuşçu *et al.* 2002 and 2005), 2: Pockmarks (Kuşçu *et al.* 2002 and 2005), 3: Faults (Kuşçu *et al.* 2002 and 2005), 4: Mud volcanos, 5: Rocky outcrop, 6: Pockmark channels, 7: Pockmarks, 8: NAF extensions (strike-slip faults, NAF group), 9: Active recent normal faults (normal faults group), 10: Topset delta (partially gaseous area), 11: Gaseous area (near surface), 12: Probable elongation of faults (two sectors of NAF).

In general, scientific research conducted before the 1999 earthquake (Figure 1) did not cover the eastern basin of the bay (Figure 2) (Özhan *et al.* 1985; Kavukçu 1990; Barga and Yüksel 1993; Barka and Kuşçu 1996). On the other hand, the fact that the 1999 earthquake epicenter was close to the eastern basin of the gulf increased the number of scientific studies in this basin (Şengör *et al.* 1999; Göktaşan *et al.* 2001; Alpar and Yalıtırak 2002; Kuşçu *et al.* 2002). However, the results obtained from previous studies performed after the 1999 earthquake did not cover the area where the NAF entered the bay. After this study, the most eastern parts of the NAF's entry into İzmit Bay were investigated in detail and the results were complementary to the previous studies.

The second group of strike-slip deep faults were examined under two branches as southern and northern faults. NAF was divided into two parts before entering the bay. It was determined that first branch of the fault followed the southern slope edge and the second branch of the fault followed the northern slope edge of the eastern depression of İzmit Bay.

The southern branch of the second group of fault was clearly identified by the localities of the mud volcanoes and slip surface of fault observed in rocky area (Figures 7 and 8). As a result of our studies and in some previous studies it was found that the fault extends parallel to the southern boundary of the depression (Şengör *et al.* 1999; Gökaşan *et al.* 2001) along the east-west direction. The northern branch of the NAF is interpreted by correlating the E-W extension of the normal fault group in the seismic sections (Figure 7) and the horizontal boundaries of the gas bearing structures (pock mark). The NAF's northern entrance to the bay, which we have obtained as a result of this study, has been mentioned in some previous studies (Gökaşan *et al.* 2001; Alpar and Yalıtırak, 2002; Kuşçu *et al.* 2002).

Thus, the pockmark and the normal fault sequences forming the northern slopes of the eastern basin determined the northern branch of the NAF, and the strike-slip faults forming the southern slopes of the basin determined the southern branch of the NAF (Figure 8). Main NAF zone, which is to extend approximately along the E-W direction along İzmit Bay, is an active, right-lateral strike-slip fault with normal component.

As a result of this research, which is a pioneering study for the region, the entry zone of the NAF to the bay has been investigated in detail as much as possible. Thus, the most eastern part of the bay, which has not been studied in detail until now, has been investigated and the extension of the NAF from land to the bay have been identified.

Although this study was a pioneering study for the region, there were some important constrains arising from the shallow morphology of the research area. It is a fact that the integration of the results obtained from the previous researches with the results of the current study may contribute to the interpretation of some unknowns about the region. Until now, sufficiently high quality seismic refraction profiles from the eastern basin have not been obtained due to the shallow water depth. As the eastern basin is shallow, it limits the mobility of research vessels and makes it difficult to control the hydrophone and sparker systems. Therefore, in this study seismic reflection data were collected instead of seismic refraction data.

The most important deficiency in this region is that a reliable connection has not been established in previous studies between the NAF zones detected on land and those detected in marine environment. Therefore, for future land studies, it is

recommended to perform a seismic refraction survey along the north-south direction on land between Izmit Bay and Sapanca Lake (Figure 1). Thus, as a result of this proposed study and the present study, the entrance zone of the NAF from the land to Izmit Bay will be studied and the uncertainty on this issue will be cleared.

Acknowledgments

We thank the captain, the crew of the R/V TÜBİTAK Marmara and the researchers of the TÜBİTAK MAM for their efforts during data acquisition. The acquisition of data reported in this study has been carried out in the framework of contracts from the İzmit Metropolitan municipality. The first figure was prepared using the Generic Mapping Tools (GMT) software (Wessel & Smith, 1998). We are grateful to reviewers Prof. Dr. Mahmut Okyar and Prof. Dr. Emin Demirbağ for valuable comments during the revision of our manuscript.

İzmit Körfezi doğusunun deniz tabanı özellikleri ve Kuzey Anadolu Fayının Marmara Denizi'ne kuzeydoğu giriş zonu

Öz

Bu çalışmanın temel amacı, İzmit Körfezi'ne Kuzey Anadolu Fayı (KAF)'nın girişini incelemektir. Üst Kuvaterner denizaltı özellikleri (gaz sızıntıları, gaz içeren çökeltiler, pokmaklar, çamur volkanları, tortu yapıları ve faylar) ve KAF'ın karadan İzmit Körfezi'ne kadar olan uzanımı su derinlik verileri, yüksek çözünürlüklü sığ sismik profilleri, yandan taramalı sonar görüntüleri ve sondaj günlükleri kullanılarak incelenmesidir. Geç-Kuvaterner çökelleri içerisinde akustik anomalilerin varlığı yoğun bir şekilde gözlenmiş ve bu anomaliler gaz ihtiva eden sedimanlar olarak yorumlanmıştır. Depremler ve/veya kütle hareketlerinin bir sonucu olarak, tortular boyunca biriken gömülü gaz miktarı artmış veya yer değiştirmiş olabileceği düşünülmektedir. Bu çalışmada, beş farklı gaz taşıyan katman sınıflandırılmış ve dağılım şekilleri haritalanmıştır. İzmit Körfezi'nin kıyı kuşağını ve deniz tabanı morfolojisini şekillendiren bölgedeki aktif fayların iki farklı grupta olduğu tespit edilmiştir. Birinci grup doğu çukurluğunun kuzey ve güney yamaçları boyunca uzanan ve doğu-batı doğrultusunda olan sağ-yanal ve doğrultu atımlı faylardan oluşmaktadır. İkincil faylar grubu ise, normal fay özelliklerine sahiptir. Bu ikincil faylar, deltaların derinlik kontur çizgilerine paralel olarak uzanmaktadır.

Anahtar kelimeler: Geç-Kuvaterner, sığ sismik, yandan taramalı sonar, gaz içerikli sedimanlar, pokmark, çamur volkanı

References

Akgün, M., Ergün, M. (1995) Structure of the İzmit Bay and the evaluation of its connection with the North Anatolian Fault (NAF). *Jeofizik* 9(10): 65-69.

Alpar, B., Güneysu, C. (1999) Evolution of the Hersek Delta (İzmit Bay). *Turkish J Mar Sci* 5: 57-74.

Alpar, B., Yalırak, C. (1999) Properties of the North Anatolian Fault in the İzmit Bay and affects of the 17 August 1999 Earthquake. Proceeding book of the third meeting of the Active Tectonic Research Group. 04-05 November 1999 in SCÜ. www.atag.itu.edu.tr. (in Turkish).

Alpar, B., Yalırak, C. (2000) Anatomy of the North Anatolian Fault in the İzmit Bay and related effects of 17 August 1999 Earthquake. In: Articles of the Active Tectonic Research Group: III Workshop, 4-5 November 1999 (eds., Tatar, O., Kavak, K.S., Özden, S.), Cumhuriyet University, Sivas, Turkey, pp. 51-58.

Alpar, B., Yalırak, C. (2002) Characteristic features of the North Anatolian Fault in the Eastern Marmara region and its tectonic evolution. *Marine Geology* 190: 329-350.

Bargu, S., Yüksel, F.A. (1993) Stratigraphic, structural features and distribution of thicknesses of Quaternary seabed sediments of Izmit Bay. *Turkiye Jeoloji Kurultayı Bülteni* 8: 169-187 (in Turkish).

Barka, A.A. (1992) The North Anatolian fault zone. *Annales Tectoncae* Special Issue 6: 164-195.

Barka, A., Kuşçu, I. (1996) Extents of the North Anatolian Fault in the İzmit, Gemlik and Bandırma Bays. *Turk J Mar Sci* 2: 93-106.

Barka, A.A., Reilinger, R. (1997) Active tectonics of the Eastern Mediterranean region deduced from GPS, neotectonic and seismicity data. *Annale de Geofisica* 40: 587-610.

Brown, L.F. Jr., Fisher, W.L. (1979) Seismic Stratigraphic Interpretation and Petroleum Exploration. American Association of Petroleum Geologists Continuing Education Course Note Series 16, Tulsa, Oklahoma.

Cormier, M.H., Seeber, L., McHugh, C.M.G. (2006) North Anatolian fault in the Gulf of Izmit (Turkey): rapid vertical motion in response to minor bends of a nonvertical continental transform. *J Geophys Res Solid Earth* 111(B4): 1-25.

Ediger, V., Demirbağ, E., Ergintav, S., İnan, S., Saatçılar, R. (2018) Post-Glacial terraces of the Marmara Sea and water exchange periods. *Bulletin of the Mineral Research and Exploration* 157: 39-57.

Ediger, V., Ergin, M. (1995) Sedimentology of the Quaternary sequence in the Gulf of İzmit (Hersek Burnu-Kaba Burun). In: Quaternary Sequence in the Gulf of İzmit (ed., Meriç, E), Turkish Navy Press, pp: 241-250 (in Turkish).

Ergin, M., Yörük, R. (1990) Distribution and texture of the bottom sediments in a semi-enclosed coastal inlet, the İzmit Bay from the Eastern Sea of Marmara (Turkey). *Estuarine, Coastal and Shelf Science* 30: 647-654.

Gökaşan, E., Alpar, B., Gazioğlu, C., Yücel, Z.Y., Tok, B., Doğan, E., Güneysu, A.C. (2001) Active tectonics of the İzmit Gulf (NE Marmara Sea): From high resolution seismic and multi-beam bathymetry data. *Marine Geology* 175: 273-296.

Güneysu, C. (1999) The bathymetry of the İzmit Bay. *Turkish J Mar Sci* 5(3): 167-170.

Gürer, Ö.F., Kaymakçı, N., Çakır, Ş., Özburan, M. (2003) Neotectonics of the southeast Marmara region, NW Anatolia, Turkey. *Journal of Asian Earth Sciences* 21: 1041-1051.

Judd, A.G., Sim, R. (1998) Shallow gas migration mechanisms in deep water sediments. In: Offshore Site Investigation and Foundation Behaviour: New Frontiers. (eds., Arduş, D.A., Hobbs, R., Horsnell, M., Jardine, R., Long, D., Sommerville, J.) Soc Underwater Technol Lond, pp. 163-174.

Katz, O., Reuven, E., Aharonov, E. (2015) Submarine landslides and fault scarps along the eastern Mediterranean Israel continental-slope. *Marine Geology* 369: 100-115.

Kavukçu, S. (1990) Active fault investigation in İzmit Bay, Bandırma Bay and Erdek Bay of Marmara Sea. Proceedings of the Workshop on Historical Seismicity and Seismotectonics of the Mediterranean Region, International Atomic Energy Agency, Turkish Atomic Energy Authority, 10–12 October 1990, Istanbul, Turkey, pp: 238-265.

Ketin, İ. (1948) Uo ber die Tektonisch-mechanischen Folgerungen aus den grossen Anatolischen Erdbeben des letzten Dezenniums. *Geol Rundsch* 36: 77-83.

Ketin, İ. (1969) About the North Anatolian Fault. *Bull Miner Res Explor Inst* 76: 1-25 (in Turkish).

Koral, H., Öncel, A.O. (1995) The structural and seismic features of İzmit Bay. *Jeofizik* 9: 79-82.

Kurt, H., Yücesoy, E. (2009) Submarine structures in the Gulf of İzmit, based on multi channel seismic reflection and multibeam bathymetry. *Marine Geophysical Researches* 30(829): 73-84.

Kuşçu, I., Okamura, M., Matsuoka, H., Awata, Y. (2002) Active faults in the Bay of İzmit on the North Anatolian Fault, NW Turkey: a high-resolution shallow seismic study. *Marine Geology* 190: 421-443.

Kuşçu, I., Okamura, M., Matsuoka, H., Gökaşan, E., Awata, Y., Tur, H., Şimşek, M., Keçer, M. (2005) Seafloor gas seeps and sediment failures triggered by the August 17, 1999 earthquake in the Eastern part of the Gulf of İzmit, Sea of Marmara, NW Turkey. *Marine Geology* 215: 193-214.

Kvenvolden, K.A., Vogel, T.M., Gardner, J.V. (1981) Geochemical prospecting for hydrocarbons in the outer continental shelf, southern Bering Sea, Alaska. *Journal of Geochemical Exploration* (14): 209-219.

Mitchum, R.M., Jr., Vail, P.R., Sangree, J.B. (1977) Seismic stratigraphy and global changes of sea level, Part 6: stratigraphic interpretation of seismic reflection patterns in depositional sequences: Section 2 Application of Seismic Reflection Configuration to Stratigraphic Interpretation. In: *Seismic Stratigraphy-Applications to Hydrocarbon Exploration* (ed., Payton, C.E.), American Association of Petroleum Geologists Memoir 26, Tulsa, Oklahoma, pp. 117-133.

Okay, A.I., Kaslılar-Ozcan, A., İmren, C., Boztepe-Güney, A., Demirbag, E. (2000) Active faults and evolving strike-slip basins in the Marmara Sea, northwest Turkey: a multichannel seismic reflection study. *Tectonophysics* 321(2): 312-189.

Okyar, M. (2003) Comment on: “Characteristic features of the North Anatolian Fault in the eastern Marmara region and its tectonic evolution” by Alpar, B. and Yaltrak, C. [*Marine Geology* 190, 329–350] and by Gökaşan, E., Alpar, B., Gazioglu, C., Yücel, Z.Y., Tok, B., Doğan, E., Güneysu, C. [*Marine Geology* 194:197–202]. *Marine Geology* 194: 197-202.

Okyar, M., Ediger, V. (1999) Seismic evidence of shallow gas in the sediment on the shelf off Trabzon, southeastern Black Sea. *Cont Shelf Res* 19: 575-587.

Okyar, M., Pinar, A., Tezcan, D., Kamacı, Z. (2008) Late Quaternary seismic stratigraphy and active faults of the Bay of İzmit (NE Marmara Sea). *Mar Geophys Res* 29: 89-107.

Orange, D.L., Yun, J.W., Maher, N., Barry, J., Greene, G. (2002) Tracking California seafloor seeps with bathymetry, backscatter and ROVs. *Cont Shelf Res* 22: 2273-2290.

Özhan, G. (1986) Le prolongement et l'influence tectonique de la zone de Faille Nord Anatolienne dans la Baie D', İzmit. Rapports et Proces-Verbaux des Reunions Commission Internationale pour l'Exploration Scientifique de la Mer Mediterranee. 30 th Congress of CIESM. Palma Majorca 30(2): 82.

Özhan, G., Bayrak, D. (1998) A seismic review of the Plio-Quaternary sediments at the İzmit Bay. *Geol Bull Turk* 41: 5-164.

Özhan, G., Kavukçu, S., Çete, M., Kurtuluş, C. (1985) High Resolution Shallow Seismic Report of the İzmit Bay (Marmara Sea). Miner. Res. Explor. Inst. Ankara (in Turkish).

Sangree, J.B., Widmier, J.M. (1977) Seismic stratigraphy and global changes of sea level, Part 9: seismic interpretation of clastic depositional facies. In: Seismic Stratigraphy Applications to Hydrocarbon Exploration (ed., Payton, C.E.), American Association of Petroleum Geologists Memoir 26, Tulsa, Oklahoma, pp. 165-184.

Sangree, J.B., Widmier, J.M. (1979) Interpretation of depositional facies from seismic data. *Geophysics* 44: 131-160.

Schoell, M. (1988) Multiple origins of methane in the Earth. *Chemical Geology* 71(1-3): 1-10.

Schubel, J.R. (1974) Gas bubbles and the acoustically impenetrable, or turbid, character of some estuarine sediments. In: Natural Gases in Marine Sediments (ed., Kaplan, I.R.), Marine Science, Vol. 3. Springer, Boston, MA, pp. 275-298.

Şaroğlu, F. (1988) Age and pure offset of the North Anatolian Fault. *Middle East Tech Univ J Pure Appl Sci* 21: 65-79.

Şaroğlu, F., Emre, Ö., Kuşçu, İ. (1992) Active fault map of Turkey. General Directorate of Mineral Research and Exploration (MTA), Ankara, Turkey (in Turkish).

Şengör, A.M.C. (1979) The North Anatolian transform fault: its age, offset and tectonic significance. *J Geol Soc* 136: 263-282.

Şengör, A.M.C., Demirbağ, E., Tüysüz, O. (1999) Preliminary note on the structure of the Bay of İzmit: implications for the westerly prolongation of the North Anatolian Fault. In: Proceedings, ITU-IAHS International Conference on

the Kocaeli Earthquake, 17 August 1999 (eds., Karaca, M., Ural, D.N.), Istanbul Technical University Press, Istanbul, pp. 25-37.

Şengör, A.M.C., Görür, N., Şaroğlu, F. (1985) Strike-slip faulting and related basin formation in zones of tectonic escape: Turkey as a case study. In: Strike-slip Deformation, Basin Formation and Sedimentation (eds., Biddle, K.T., Christie-Blick, N.), Soc Econ Paleontol Mineral Spec Publ 37: 227-264.

Şenöz, M. (1998) Tectonically activated submarine basins of İzmit Bay sited in the extension zone of North Anatolian Fault. Progress in Marine Geological Studies in Turkey, TÜBİTAK-UNIVERSITY-MTA National Marine Geology Programme (Coordinator: Görür, N.), Workshop-IV, 14–15 May 1998, Istanbul, pp. 123-128.

Tolun, L.G., Ergenekon, S., Hocaoglu, S.M., Donertas, A.S., Cokacar, T., Husrevoglu, S., Polat-Beken, C., Baban, A. (2012) Socioeconomic response to water quality: a first experience in science and policy integration for the Izmit Bay coastal system. *Ecology and Society* 17(3): 40.

Turoğlu, H. (1998) The survey of the east coast fill of Izmit Bay in terms of engineering geomorphology. *İstanbul Üniversitesi Edebiyat Fakültesi Coğrafya Bölümü Coğrafya Dergisi*: 321-343 (in Turkish).

Vail, P.R., Mitchum, R.M. Jr., Thompson, S.III. (1977) Seismic stratigraphy and global changes of sea level, Part 3: relative changes of sea level from coastal onlap. In: Seismic Stratigraphy-Applications to Hydrocarbon Exploration (ed., Payton, C.E.), American Association of Petroleum Geologists Memoir 26, Tulsa, Oklahoma, pp. 63-81.

Yaşar, D., Aksu, AE., Uslu, O. (2001) Anthropogenic pollution in Izmit Bay: Heavy metal concentrations in surface sediments. *Turkish Journal of Engineering and Environmental Sciences* (TÜBİTAK) 25: 299-313.

Yun, J.W., Orange, D.L., Field, M.E. (1999) Subsurface gas offshore of northern California and its link to submarine geomorphology. *Mar Geol* 154: 357-368.