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Tsunami generation of the Kocaeli Earthquake (August 17th 1999) in the Izmit Bay; coastal observations, bathymetry and seismic data

Kocaeli Depreminin İzmit Körfezinde yarattığı tsunaminin, kıyı gözlemleri, batimetri ve sismik veriler ile değerlendirmesi

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Abstract

In the present study, coastal field observations, detailed bathymetric data and analyses of single-channel, high resolution seismic reflection data are used to characterise tsunami generated during the Kocaeli Earthquake (August, 17th 1999) in the Izmit Bay.

Keywords: Tsunami generation, Izmit Bay, Marmara Sea, seismic

Introduction

The Izmit Bay is a E-W trending (53 km long and 2-10 km wide) tectonically active basin. The sea-floor relief and coastal zone physiography lie in E-W direction. The Izmit Bay is formed by three small tectonic basins; western, central and eastern. These basins are separated from each other by shallow and narrow ridges. The water passage between the western and central basins (2.7 km wide with an average depth of 55 m) is separated by the restriction produced by the growth of the Hersek Delta.

Statigraphy

The stratigraphy of the İzmit Bay starts with 25-30 m thick recent sediments unconformably overlying the basement lithologies. The small tectonic basins of the Izmit Bay are covered mainly by fine-grained continental siliclastic material resulting from fluvial and littoral processes. The western basin is also subjected to accumulation of silt-sized sediments (Algan, et al, 1999). The average sedimentation rate was calculated as 20 cm Per 1000 year with a maximum of 150 cm Per 1000 year for deepest parts (Ergin and Yörük, 1990).

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The effect of active tectonic setting onshore the Izmit Bay has been described by Akartuna (1968) and Altınlı (1970). The tectonic basins in the Izmit Bay were created by the EW compressional and NS tensional forces resulted as a response to the kinematical block displacements at active zones (Barka and Kadinsky-Cade 1988; Kurtuluş, 1990; Barka, 1992).

The North Anatolian Fault Zone (NAFZ) has been the source of numerous large earthquakes throughout the history. It splits into three strands at the eastern part of the Marmara Sea. The northern strand passes through Izmit Bay, traverses Marmara Sea and reaches to the Saros Gulf (Barka and Kadinsky-Cade, 1988). The transpressional and transecstensional regimes of the NAFZ, which has a dextral displacement about 1500 km, affected the Izmit Bay during the neotectonic period (Crampin and Evans 1986). Active normal and lateral faults also affect the actual basin-fill deposits in the Izmit Bay (Özhan et al., 1985; Sakınç and Bargu, 1989; Koral and Öncel, 1995; Seymen, 1995).

According to Barka and Kuşçu (1996), the best structural model for the Izmit Bay is a pull-apart model in which strike-slip fault segments (laterally descending towards right) create the tectonic basins of the Izmit Bay.

The 17th August 1999 Earthquake and its damages

The Kocaeli earthquake (00:01:39.80 UTC, August 17th 1999) of magnitude Mw=7.4 occurred on the northern strand of the North Anatolian Fault Zone with a macroseismic epicenter near the town of Gölcük (40.702 N, 29.987 E). The earthquake originated at a depth of 17 km and caused right-lateral strike-slip movement on the fault. The field observations indicate that the earthquake produced at least 125 km of surface rupture and right-lateral offsets as large as 4.2 m with an average of 2.7 m.

Almost all the industrial facilities are located along the coastal area of the Izmit Bay. Damages which are concentrated within 20 km of Gölcük and ranging from small displacements to complete collapses have been reported to the coastal structures such as ports, jetties, cranes and the piping systems. Subsidence, coastal landslides and the sea water inundation were occurred at Kavaklı (Gölcük), Değirmendere and Karamürsel.

The aim of this paper is to describe the tsunami generated by the Kocaeli Earthquake based on coastal observations, bathymetry and offshore shallow seismic data. The surface ruptures of the Kocaeli Earthquake was investigated onshore around the Bay and offshore in the Karamürsel and Izmit basins. The seismic data gathered in this study have led us to propose a new tectonic model with which the source of the tsunami event can be explained.

Material and Method

Immediately after the Kocaeli Earthquake, more than 15 field expeditions have been arranged along the coastal area of the Izmit Bay. Tsunami events have been investigated at 35 localities along the coasts of Izmit Bay and more than 70 eyewitnesses have been interviewed. Some tsunami findings and onland geological observations have been tried to relate with the interpretation of the single-channel high-resolution digital (¼ ms) sparker (1.25 kJ) seismic reflection profiles with which the sedimentary deposits were cleared up to 150 m below the seabed with a positional accuracy of ±20 m. Available literature on the bathymetry and neotectonic studies have also been re-evaluated.

Results

Historical records reveal that more than 90 tsunamis had occurred along the Turkish coasts between the period covering 1410±100 BC and 1999 AD. Following the Kocaeli Earthquake and knowing that many of the historical tsunamis were clustered around the Izmit Bay, for example in 325, 24/08/358, 08/11/447, 26/09/488, 15/08/553, 15-16/08/555, 14/12/557, 715, 740, 19/04/1878, 10/05/1878 and 18/09/1963 (Soysal, 1985; Kuran and Yalçıner, 1993; Altınok and Ersoy, 1996-1997, 1998), the coastal line from Tuzla on the northern part to Çınarcık on the southern part (Figure 1) has been investigated for tsunami events. Because of the coastal subsidence which occurred between Seymen and Kavaklı (the localities 17 and 19 in Figure 1), the determination of the tsunami evidence could not be accomplished. These findings were getting lost through Yalova (the locality 33 in Figure 1).

The findings that help to detect the tsunami can be generally defined as retreat and inundation of the sea, maximum and minimum sea level elevations and runup heights (Table 1). Some findings of this survey are given below.

Receding and inundation of the sea

Along the north coast, at Tavşancıl (at the locality 5 in Figure 1), all water in the local port withdrew during the earthquake. In a very short period of time, the sea came back and flooded up to 25 m inland invading the first floor of the houses. At Şirinyalı (at the locality 7 in Figure 1), the first floors which are 5 m close to the sea were flooded. The wave carried the seabed living mussels into the houses damaging their doors and windows. At the Yarımca Yachting Club (at the locality 9 in Figure 1), the sea was at first receded 15-20 m and when it came back, uplifted the motor yacht 25 m and moved it 50 m. The second wave inundated 30 m on the shore.

In the Izmit Marina (at the locality 14 in Figure 1), the sea receded about 40 m and passing down the seaport, caused the coast become wet. Between the eastern part of the bay, where the fault rupture enters into the sea, and Seymen (at the locality 17 in Figure 1) at southern part, small disturbances, coming from northwest (Yalçıner et al., 1999), was observed.

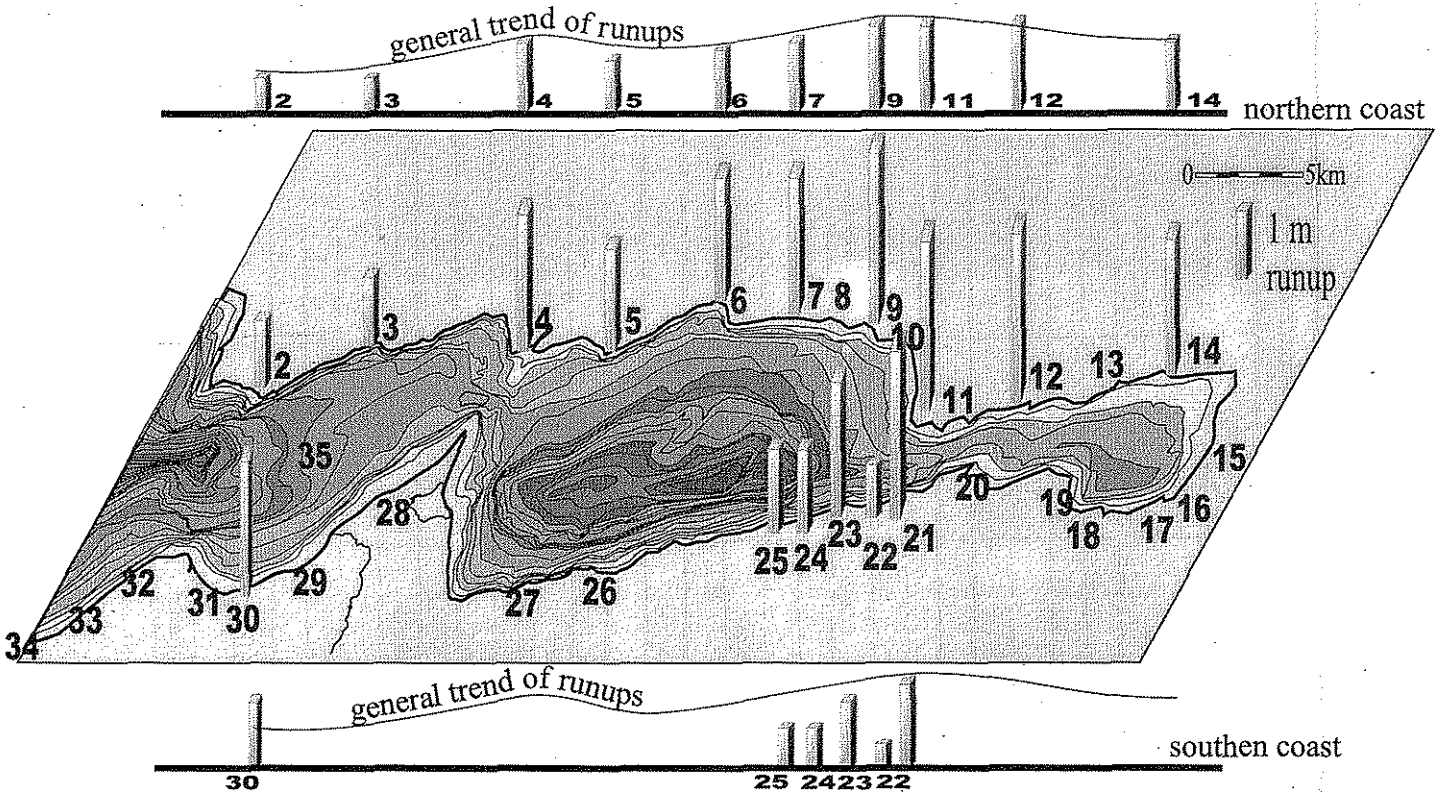

Figure 1. The tsunami runups superimposed on the bathymetry map of the Izmit Bay. See Table 1 for locations.

Table 1. Tsunami observations in the Izmit Bay. The signs (-, --, + and ++) preceding the values have different meanings; receding distance, minimum elevation, + inundation distance and, maximum elevation, respectively.

No	Locality	- receding distance (m) -- Minimum Elevation (m)	+ inundation distance (m) ++ Maximum Elevation (m)	runup (m)
2	Darıca		+ 4	> 1
3	Eskihisar		+ 15	> 1
4	Dilovası	-- 3	++ 2, 2.5	2
5	Tavşancıl	-	+ 25,30	1.5
6	Hereke		+ 30	1.80
7	Şirinyalı		+ 15	1
8	Kirazliyalı		+	2.5
9	Yarımca	- 15, 20	+ > 60	2.5
10	Körfez		+ 100	
11	Tüpraş			2.5
12	Derince Liman	- - ?	++ ?	2-2.5
13	Çene Suyu	- 80	+ 60	2
14	İzmit, Marina	- 40	+ 25	
17	Seymen	- 2 ?	+ 50	
19	Kavaklı		+ 300 ?	
21	Değirmendere	- 150 ?	+ 35 ?,++>10	2.5
22	Halidere	- 15, - - 1.5	+ 60	0.8
23	Ulaşlı		> 5	2
24	Ereğli (Güzelyalı)	- 10,15	+ 4	1.25
25	Defne Mahallesi	-	+ 4	1.5
26	Karamürsel	-	+	
27	Kaytazdere		+ 15 ?	
28	Hersek		+ >30	
29	Havuzdere	- ?	+	
30	Topçular	-	?	2 ?
35	Offshore Topçular	- - 30 ?	++ 30 ?	

At Değirmendere (locality 21 in Figure 1), the sea receded about 150 m away in a very short period of time (possibly less than 2 minutes) just before the earthquake and when it came back, it flooded up to 35 m inland since some mussel and dead fishes were seen in this inundation area. There was a subsidence along the coastline 250 m along the shore and 70 m width with two piers, a hotel, restaurant, cafe and 14 trees at Çınarlık Park. Bubbles were seen over the sea just after the earthquake.

At Halidere (locality 22 in Figure 1), the sea receded 10-15 m and then flooded up to 50 m inland where moss and jelly fishes have been observed. At Ulaşlı (locality 23 in Figure 1), the sea first receded and inundated more than 5 m. The wave dragged 7 people near the seaside and only 2 of them have been survived. The building of Ulaşlı Municipality and the restaurants along the coast sank into the sea together with cars, construction equipment and boats taken away by sea.

At Güzelyalı (locality 24 in Figure 1), at the onset of the earthquake, outside the breakwater, the sea rose up and then withdrew in the local port and boats stranded. When the sea came back, the inundation distance was about 5 m. Also at Karamürsel (locality 26 in Figure 1), the sea receded first and then inundated the shore. There was a coastal subsidence (20 m) along 800 m coastline. At Topçular (locality 30 in Figure 1), as usual, the sea receded first. Moss and dead fishes were found along the 70-100 m coastal band at the Aksa factory (Kılıç Delta, west of locality 30 in Figure 1), showing inundation.

Sea Level Elevations

Following observations were belong to the captains or the seamen on the boats during the earthquake.

Along the northern coasts of Izmit Bay, at Dilovası, Körfez, Derince and Izmit, (localities 4, 10, 12, 14 in Figure 1), the captains had experienced the motion of the wave. At the onset of the earthquake, at Dilovası Port (at the locality 4 in Figure 1), 1998 gross ton tanker "Nazan" with a draft of 4.5 m, along with the other ships (Greek Empros and Turkish Bora Mete) first fell down and then uplifted (within the range of ~3 m).

At the port of Derince (locality 12 in Figure 1), where the main cranes went off the rails due to horizontal and vertical movement of the caisson of up to 40 cm, two tugboats (1501 and 1503), boarding alongside a ship which was moored to the port, first dived on their bows as result of receding and then uplifted 2-2.5 m. The boat "Körfez-1" was mooring a fisherman wharf at Körfez (locality 10 in Figure 1) at around 3:00 a.m. at

that night. The captain had experienced that the boat bottom touched the sea floor and boat drifted back to the sea. In less than half a minute, the boat rose with the rising water and drifted to the fisherman wharf. The captain rescued the boat by giving a maximum engine power back. In Izmit Marina (locality 14 in Figure 1) the moored boats fell down 2 m, as well.

Along the northern coasts of Izmit Bay, at Değirmendere, Halidere, and Ulaşlı (localities 21-23 in Figure 1), the captains had experienced the motion of the wave. The passenger ship "Atatürk" (375 gross ton and 50 m in length) had been moored to the Değirmendere Pier and the fishing boat "Kırcılıoğlu-4" (300 gross ton and 36 m in length) was boarding alongside "Atatürk". Both were drifted with the receding of the sea. The captain of the fishing boat "Abonoz" which was near "Atatürk" and "Kırcılıoğlu-4" reported that "Kırcılıoğlu-4" was uplifted as high as a plane tree (more than 10 m) with the sea rise. The fishing boat "Kırcılıoğlu-4" uplifted two times above the "Atatürk" ship and then sank.

At the Halidere Pier (locality 22 in Figure 1), "Tatlısu Ship" (349 gross ton and with a drift of 4 m) fell down more than 1 m below the pier, hit the bottom, her shaft and propeller were damaged and robes were broken off.

At the Ulaşlı local port (locality 23 in Figure 1), the ship "Kırat" broke her robes off and fell down below the pier and then uplifted above its previous level. Meanwhile the ferryboat "Okmeydanı" was sailing with 10-knots speed from Topçular to Eskihisar (localities 30 and 3 in Figure 1), 2.6 miles far from Topçular, at the locality 35 (Figure 1) where the water depth was 90 m. The ferry fell down with the sea and the captain suddenly came across with a wave having 30-40 m height about 100 m away from bow. He then observed that the wave wall progressed towards Eskihisar (offshore Topçular in Table 1).

According to the eyewitness reports, the run-up and inundation measurements, the period of the tsunami is less than a minute. The arrival time is a few minutes to the northern coasts and a minute or so to the southern coasts (see also Yalçıner et al., 1999).

Bathymetry

The isopach map of Güneysu (1999) is the most detailed bathymetric map of the Izmit Bay drawn before the Kocaeli Earthquake. It provides a useful tool to recognise the physiographic elements and the main

morphosedimentary features. The northern margins are steep and the basins are asymmetric in geometry.

With the Kocaeli Earthquake, some depth changes should have been occurred. In our interviews, some depth changes have been reported from Ulaşlı and Değirmendere. A coastal slumping at Değirmendere caused about 20 m deepening. On the other hand, in front of the building of the Ulaşlı Municipality the sea deepened from 3 m to about 17 m. Such findings punctuate the importance of micro topographic surveys using swath sounding.

Seismic evidences

Seismic data show two main stratigraphic sequences (Figures 2a, b, c). The upper stratigraphic units are generally unconformable on the lower units. The upper units are less deformed and bear occasional slumps, probably triggered by active faulting. The lower units are deformed by faulting and folding and most probably noticing the opening of the bay.

Seismic profiles show that the 17thAugust fracture zone was located as two segments offshore of southern margins of the Izmit and Karamürsel basins. The western segment between Değirmendere and Hersek Point lies parallel to the shoreline (Figure 3). The eastern segment strikes E-W in the south of the Izmit Basin and continues eastward onland. The study of the onland fractures clearly demonstrates the strike-slip nature of this segment. Small pull-apart basins were developed between right step en echeleon faults.

Kavaklı fault

The rupture at Kavaklı (Gölcük) (Figure 4a) is 3.2 km (personal communication with Mr. Erdal Herece) with N60W orientation. It is an oblique normal fault. The north block of the faulting blocks has been downthrown by about 2 m with maximum of 2.5 m. These downthrown regions are now under the sea. Its strike-slip component is about 0.5 m with maximum of 1 m.

TÜPRAŞ fault

The faulting in the TÜPRAŞ Refinery area, in the north of the Bay (west of Derince) has been first documented by the authors. This fault strikes N80W and is located near the shore (Figure 4b). It is a normal fault with strike-slip component. Since both ends of this fault enter into the sea, its length is at least 200 m. The fractures developed are 30 cm to 1 m wide. Some of the small blocks between these open fractures were downthrown.

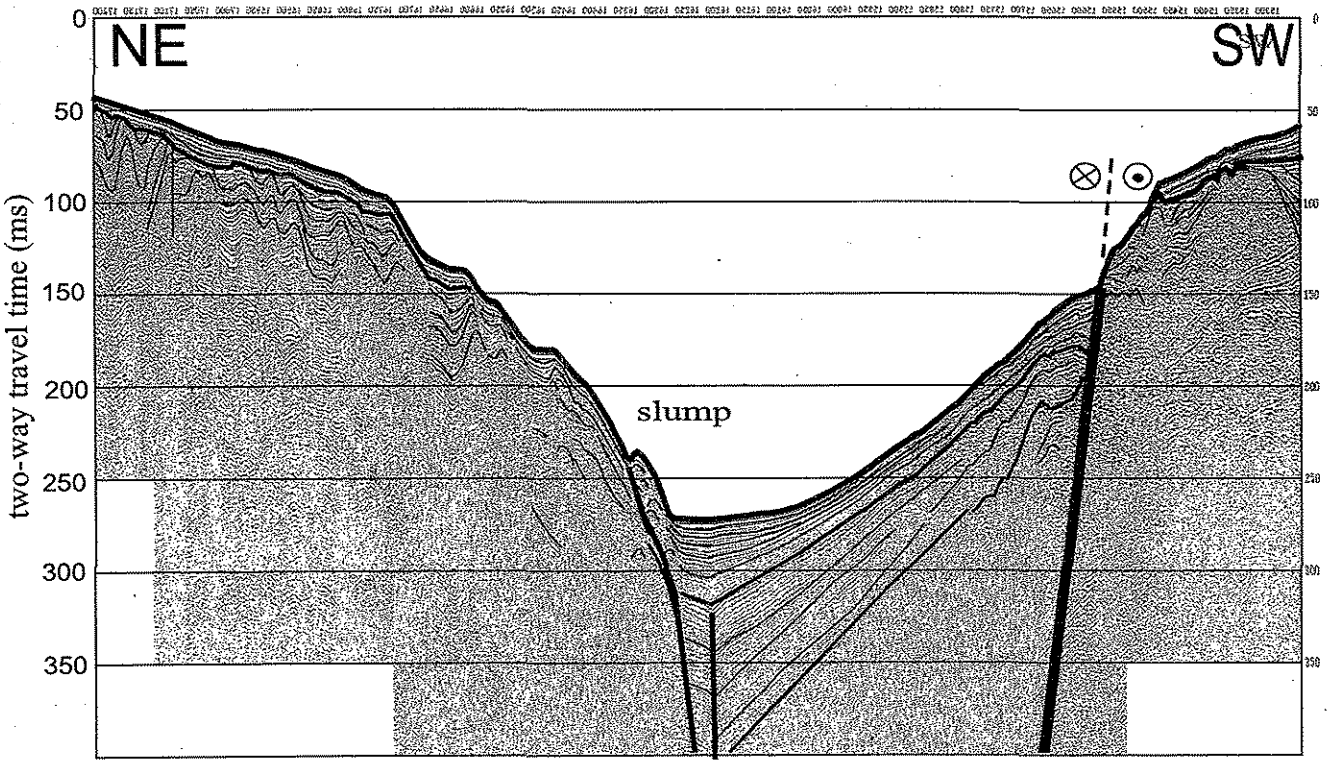

Figure 2 a. Interpreted line drawing of sparker profile B13 showing the layers, slump and faults.

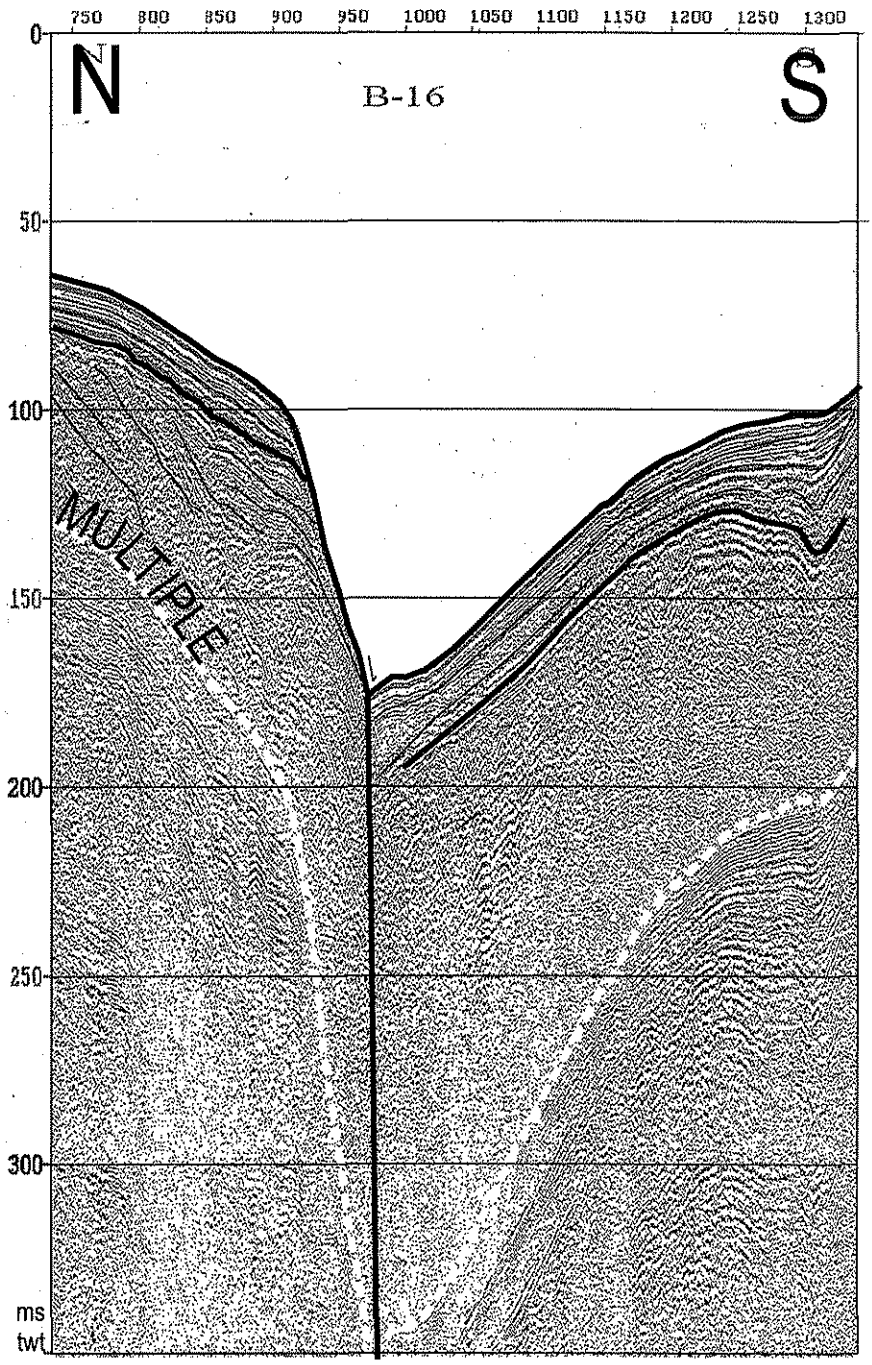

Figure 2 b. Interpreted line drawing of sparker profile B16 showing the the seismic layers and fault ruptures on the sea floor.

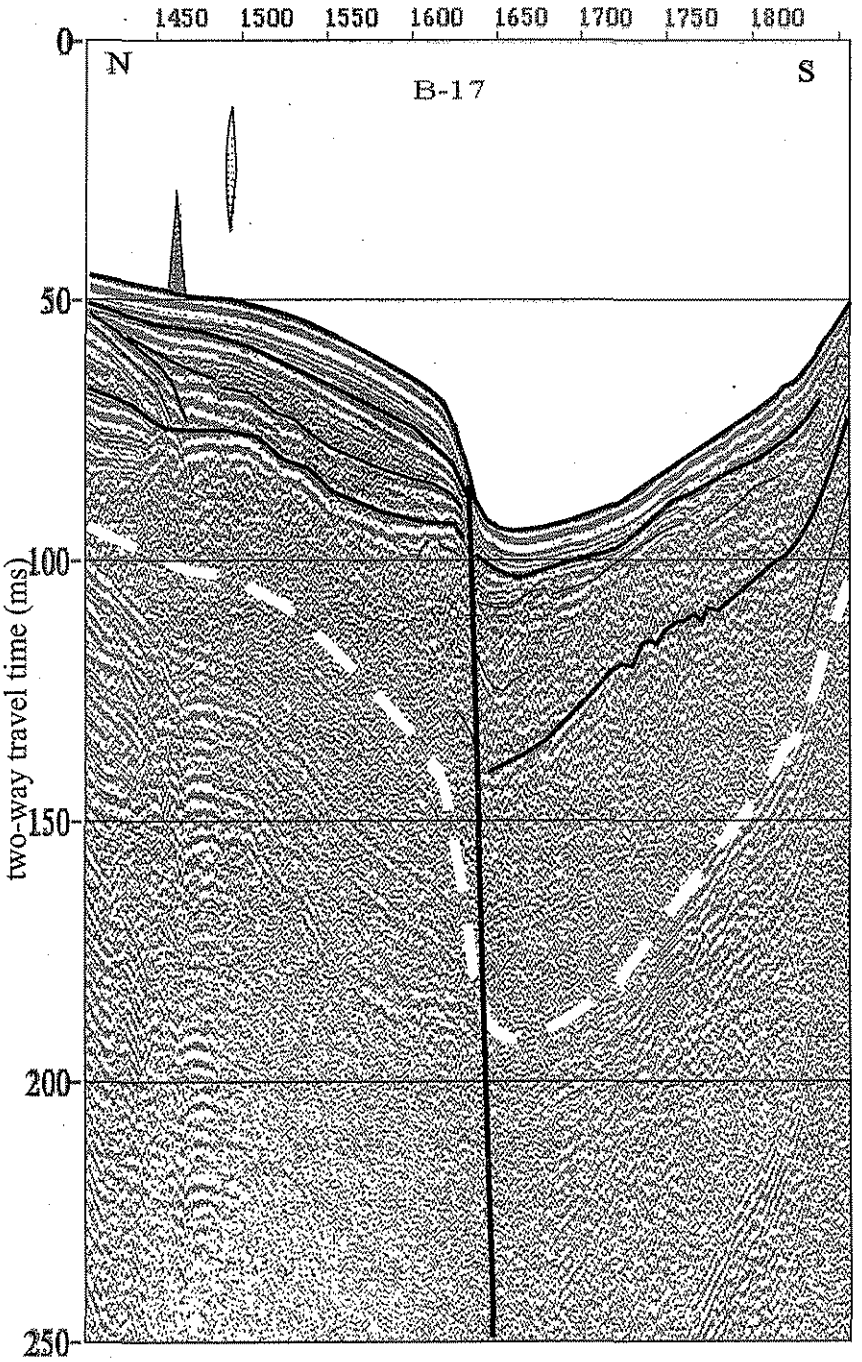

Figure 2 c. Interpreted line drawing of sparker profile B17 showing the seismic layers and fault ruptures on the sea floor. Dashed line stands for multiple. Gas sepages are evident.

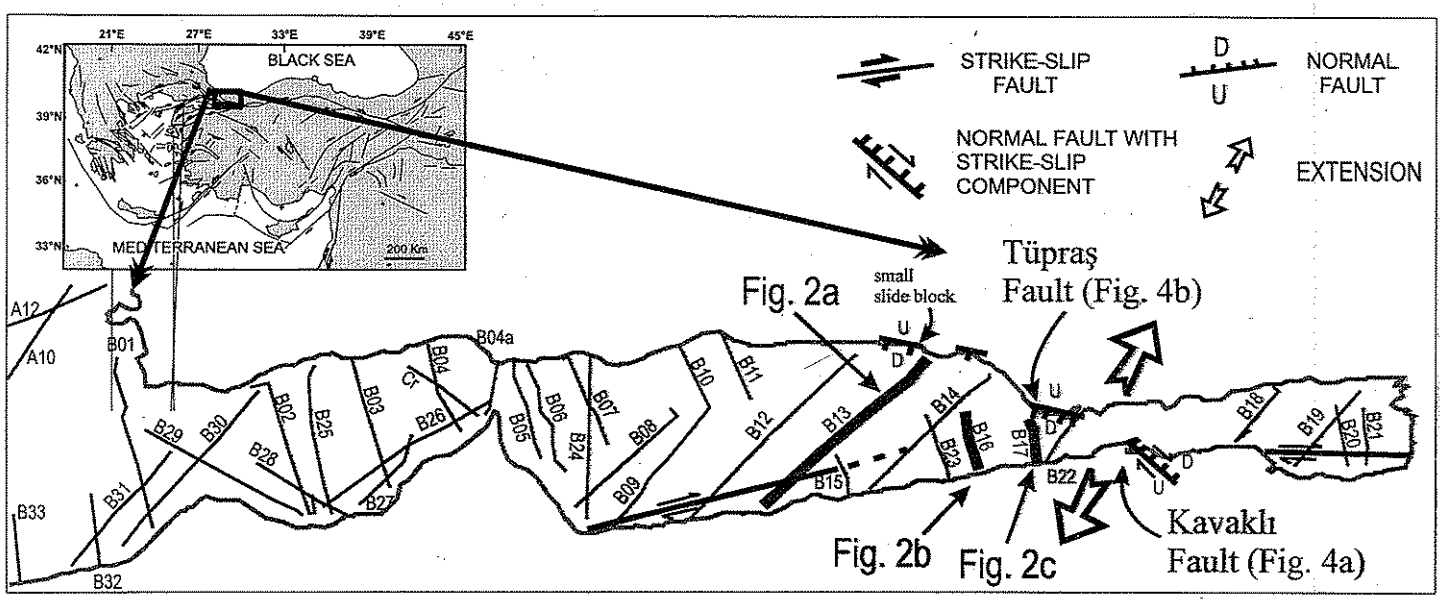

Figure 3. The fault ruptures on sea floor and/or on very near subsurface sediments. This map also shows the shallow seismic profiling tracks utilised in the text and shown in Figure 2.

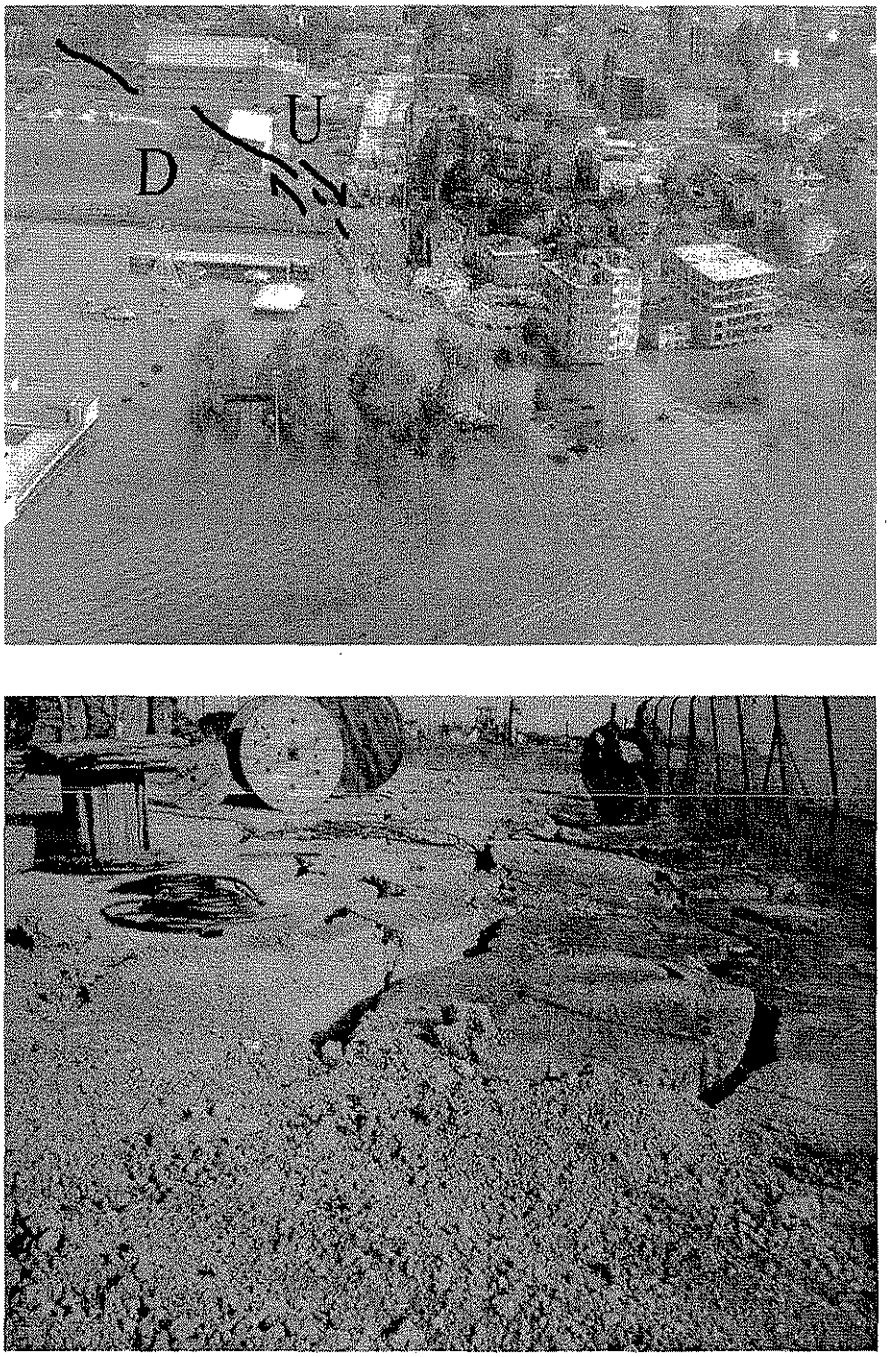

Figure 4. Pictures show the ruptures at (a) Kavaklı and (b) Tüpraş.

The south block of the faulting blocks has been downthrown by about 8 cm. Its strike-slip component is about 10 cm. The faulting caused a serious fire in the refinery. Gas plumes on Line B17 (Figure 2c) indicate possible sediment compression in that area which is close to the TÜPRAŞ fault.

Conclusion

Izmit Bay is a tectonically active depositional area. The basins in the bay area are asymmetric in geometry where the northern margins are steep. Seismic profiles show that this asymmetric geometry is a result of half graben formation. The seismic sequences reveal intervening hydrodynamic and tectonic conditions during late Quaternary. Sediments in the basin are thickest in the deepest part of the graben and gradually thin southward. The less deformed upper seismic units, which are unconformable on the lower units, bear occasional slumps. These may be new generated slumps triggered by the active faulting. This matter deserves further studying.

The subsidence of coastal zones and the wave motions caused deaths along the southern coasts (Altınok, 1999). Furthermore, sank or broken boats, lost persons and dragged objects show that the Kocaeli Earthquake generated tsunami with an average runup of 2.5 m. The most prominent evidence of the tsunami is the sea receding during the earthquake at both sides of the bay. However, Değirmendere case is an exception, where sea receding took place a very short period before the earthquake.

Since the period of the tsunami is less than a minute and the tsunami arrived to the northern coasts a few minutes later than to the southern coasts, the centre line of the tsunami source is lying along the central basin of the Izmit Bay closer to the southern coast. It is highly possible that this line follows the deepest parts of the basins.

The subsidence and slumpings at some localities along the southern coast such as Seymen-Kavaklı, Değirmendere, Ulaşlı and Karamürsel are not due to tsunami but they are probably the result of the tectonic deformation (flower structure) of the NAFZ. The normal faulting of the Kavaklı and TÜPRAŞ faults are the result of this tectonic deformation, indicating a NNE-SSW oriented extension (Figure 3).

As a consequence, the tsunami events occurred in the bay are mainly caused by the E-W trending tectonic deformation along the basin closer to the southern coast. The waves possibly became more complicated by local subsidence in coastal areas and underwater slumping.

Özet

İzmit Körfezi kıyıları boyunca yapılan tsunami gözlemleri, jeolojik incelenmeler ve yüksek çözünürlü sığ su sismik çalışmalarının ışığında 17 Ağustos Kocaeli Depremi ile ortaya çıkan tsunaminin oluşum yeri ve mekanizması incelenmiştir.

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