

## **Evolution of the Hersek Delta (Izmit Bay)**

### **Hersek Deltasının (İzmit Körfezi) oluşumu**

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#### **Abstract**

The Hersek Delta which was developed by the alluvial deposits carried by the Yalakdere River is an important morphological element in the middle of the southern coasts of the İzmit Bay. In the present study, field observations, detailed bathymetric data and analyses of single-channel, high resolution seismic reflection data are used to characterise the stratal geometry and seismic stratigraphy of the Hersek Delta. The tectonised acoustic basement (unit F) is overlain by a sedimentary cover composed of 4 main seismic units (A, B, C and D/E from top to bottom). The absence of late Pleistocene aged unit C at the eastern part of the Hersek Delta implies that the waters of the Marmara Sea could not spill over the Hersek Pass during the sea level maximum (~60 m relative to modern sea level) occurred ~25 kyr BP. During Holocene and at present, the development of the Hersek Delta continues with positive and negative accelerations under the control of tectonics and climatic changes.

**Keywords:** Hersek Delta, İzmit Bay, Marmara Sea, Plio-Quaternary, seismic stratigraphy, evolution

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## Introduction

The İzmit 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 İzmit Bay is formed by three small tectonic basins; namely, western, central (Karamürsel Basin) and eastern (İzmit Basin) basins. These basins are separated by two narrow water passages. The water passage (Hersek Pass) between the western and Karamürsel basins is separated by the restriction produced by the growth of the Hersek Delta. The Hersek Pass is 2.7 km wide with an average depth of 55 m.

The sea water circulation of the İzmit Bay is well known (Oğuz and Sur, 1986). The Black Sea origin surface water entering into the İzmit Bay splits into two branches near the Hersek Point; its main branch enters into the inner basins of the İzmit Bay with a reduced current velocity whereas other branch turns back along the northern coasts. Therefore the current speed in front of Hersek Point is faster than the westward surface currents in front of Kaba Point. Contrary to the surface currents, the Mediterranean origin bottom layer follows an anticyclonic route in the İzmit Bay.

The distribution of suspended particulate matter (SPM) in the İzmit Bay is mainly controlled by the seasonal variations of its two-layered waters. The SPM concentration was found to be higher in the lower layers throughout the year (Algan, et al., 1999). The authors explained this finding due to higher SPM input into the bay than the output.

Even the depositional conditions are different, the basins were filled with mainly continental siliclastic material resulting from fluvial and littoral processes. Due to the reduced current velocities in the lower layer, the İzmit and Karamürsel Basins are depositional areas for fine grained material. The western basin, on the other hand, is subjected to accumulation of silt-sized sediments (Eryılmaz et al., 1995; Algan, et al., 1999).

As it is seen, except extreme meteorologic and oceanographic conditions, the water circulation in the İzmit Bay is not sufficient for prominent sediments transportation. Under these circumstances, deltaic successions may occur at the mouths of the streams, if the seabed morphology is convenient as well. There are no any important deltaic developments along the notably high northern coasts.

The Hersek Delta, on the other hand, is a large (~25 km<sup>2</sup>) morphological element in the middle of the southern coasts of the bay. It was developed by the alluvial deposits carried by the Yalakdere River (Figure 1).

Geologic maps of various scales are available for the study area and its surroundings. In general, large-scale maps were used in favour of smaller-scale maps, and preference was given to the more recently published map of MTA (1987). According to the surface geologic information obtained mainly from published and unpublished geologic maps, most of the sediments of the Hersek Delta came from Palaeozoic conglomerate, sandstone, limestone; Triassic conglomerate and sandstone; upper Cretaceous conglomerate, sandstone, limestone and marl; Eocene flysch; Pliocene conglomerate, sandstone, clays and marl; and also from varying age andesite, basalt, gneiss, mica schist and amphibolite.

Onshore, the Pamukova metamorphic rocks (Precambrian) form the basement in the area. Overlying the basement, Silurian, Triassic (Ballıkaya fm.), Cretaceous (Kocakır and Sarihama limestone, Bakacak fm.), Paleocene–Eocene (İncebel Fm., Sarısu volcanic rocks) and Plio-Quaternary sediments are dominant (Figure 1).

The North Anatolian Fault (NAF) is the most important tectonic element in the study area. It splits into three strands at the eastern part of the Marmara Sea and its northern strand lies to the İzmit Bay in the west. The transpressional and transextensional regimes of the North Anatolian Fault (NAF), which has a dextral displacement about 1500 km, affected the İzmit Bay during the neotectonic period (Crampin and Evans 1986; Barka and Kadinsky Cade, 1988).

The deposits which were affected by the NAF in the İzmit Bay represent a brackish water environment during Sarmatian-Pontian and a fluviolacustrine environment during the end of late Miocene and early Pleistocene (Özhan et al., 1985; Sakınç and Bargu, 1989; Seymen, 1995). Using paleontological data, Meriç (1995) defined different depositional environments developed under the effects of regional climatic fluctuations and active tectonism from late Pliocene to late Holocene. In the beginning of late Pleistocene, brackish-deltaic and continental environments were dominant. The highly saline Mediterranean waters invaded the area during late Pleistocene and deposited marine clastics. From late Pleistocene to present shallow marine conditions are dominant.

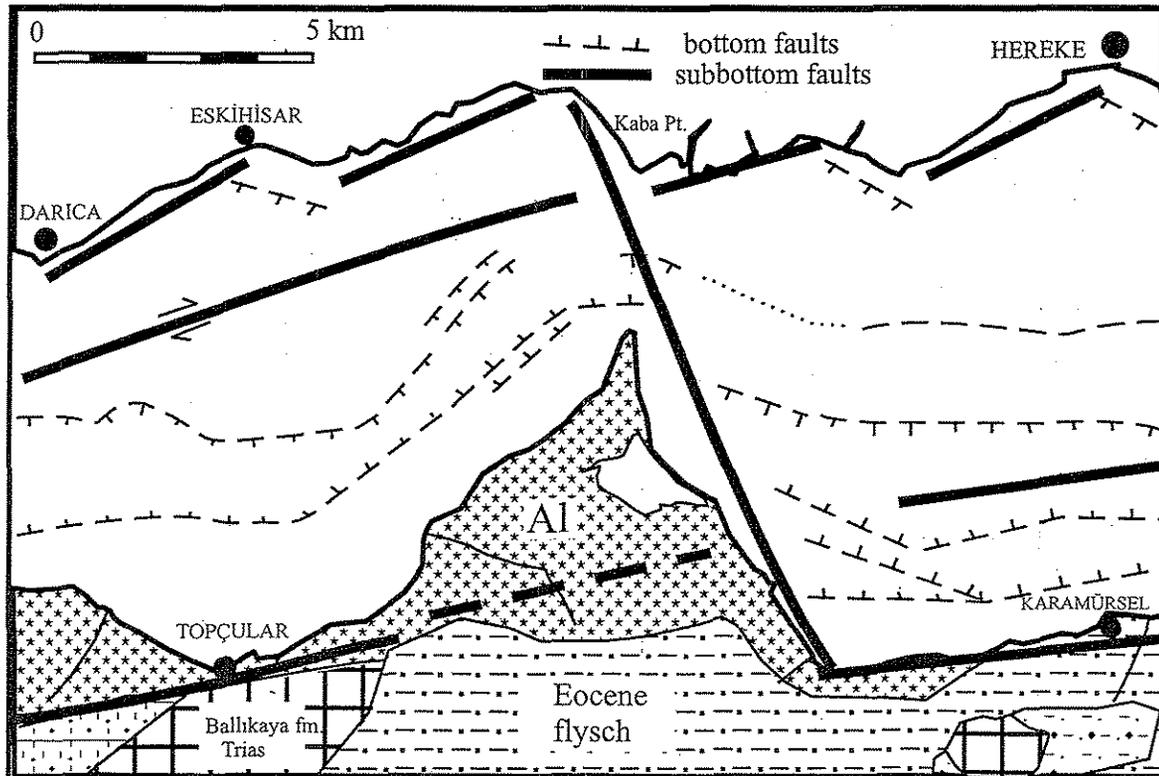


Figure 1. Geology and structural elements of the Hersek Delta, İzmit Bay. Compiled from Seymen, 1995; Kurtuluş 1990; Koral and Öncel, 1995; Barka and Kuşçu, 1996 with moderate modifications based on this study. The faults which have fingerprints on sea floor and/or on very near subsurface sediments were drawn as dashed and ticked.

The modern sea bottom is mainly covered by mud with small amount of carbonate. The average sedimentation rate was calculated as 20 cm / 1000 yr with a maximum of 150 cm / 1000 yr for deepest parts (Ergin and Yörük, 1990).

The geological formations in the area, which were developed under the control of young epirogenic movements and faults during late Pleistocene and Holocene, are generally in good harmony with the sedimentary units (Figure 1). Active tectonism, caused by normal and lateral faults, also affects the actual basin-fill deposits in the İzmit Bay (Özhan et al., 1985; Sakınç and Bargu, 1989; Koral and Öncel, 1995; Seymen, 1995).

The tectonic basins in the İzmit 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; Wong, 1995). These faults form a negative flower fault at the seabed.

According to Barka and Kuşçu (1996), the best model representing the structural geology of the İzmit Bay is the pull-apart model. According to model, strike-slip fault segments, which are laterally (echelon) descending towards right, create three small basins; western, central (Karamürsel) and eastern (İzmit) basins.

In this paper, possible evolution of the Hersek Delta and the sedimentary record of water levels are described based on detailed bathymetry, onshore geomorphic features and offshore shallow seismic data.

### **Material and Method**

From onshore observations we have prepared a detailed geomorphology map showing many features not previously documented. Single-channel digital seismic reflection profiles were acquired in front of the Hersek Delta (Figure 1). High-resolution profiles were collected 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 length was 250 ms two-way travel time (TWT) and shot interval was 2 sec (about 4.1 m). These parameters locally provide details on sedimentary deposits up to 60 m below the seabed. Positioning was carried out by using an integrated GPS system with an accuracy of  $\pm 20$  m. Finally, pre-existing navigation maps, some local single-beam bathymetry data and our seismic data have

facilitated the preparation of a detailed bathymetry map. Two-way travel times are converted to depths below sea level using a typical interval velocity of 1500 m/s.

## Results

Geomorphological evolution of the Hersek Delta is related with the sediments carried by the Yalakdere River at the south. The Yalakdere River issues into the İzmit Bay at the west of Altınova. There is a large plateau expanded until the Dumanlı Mountains, 20-km south of the Hersek Delta. This plateau is an erosion area developed in late Pliocene by the Yalakdere River and its tributaries (Karadere and Yağcıdere at its west) which cut the Pliocene deposits. Many relicts of suspended valleys have been observed on the plateau surface (Figure 2).

The Hersek Delta consists of different lithologies, such as basalt, andesite, dolerite, gneiss, mica schist, amphibolite, sandstone, limestone, clay, marl and flysch, coming from the plateau surface via the streams.

The Yalakdere River has formed an epigenetic gorge on the Eocene flysch between the Subaşı and Kaytazdere villages just before the Hersek plain (Figure 2). Just at the northern part of this gorge, marine terraces take place between Subaşı and Kaytazdere villages (Hoşgören, 1995). These terraces are placed at 12-18, 42-48 and 68-74 m elevations (Göney, 1964). According to Göney (1964), the 68-74 m terrace is a production of the long-lasting transgression occurred after Sicilian while other terraces placed at lower altitudes belong to younger interglacial periods. The 68-74 m terrace was developed on the Altınova formation, as it was named by Sakiñç and Bargu (1989). Due to the NAF, the deposits of the late Pleistocene (Tyrhenian) unit, which should be placed at 18-20 m or 25-30 m elevations, lifted to 68-74 m elevations (Sakiñç and Bargu, 1989). TL (Thermo-luminescence), U/th and <sup>14</sup>C dating methods applied on the *ostrea edulis* fossils indicate an age of 260-40 kyr BP for this unit (Palluska et al., 1989; Sakiñç and Bargu, 1989). Sakiñç and Yaltırak (1997), depending on their studies along the coastal area of the Marmara Sea and the Saros Bay, suggested that all of the terraces raised under the control of the compressional forces along the tectonically active edges of the Marmara Sea. Therefore, tectonic movements have had effects on the positions of the terraces which are relatively above the modern sea level.

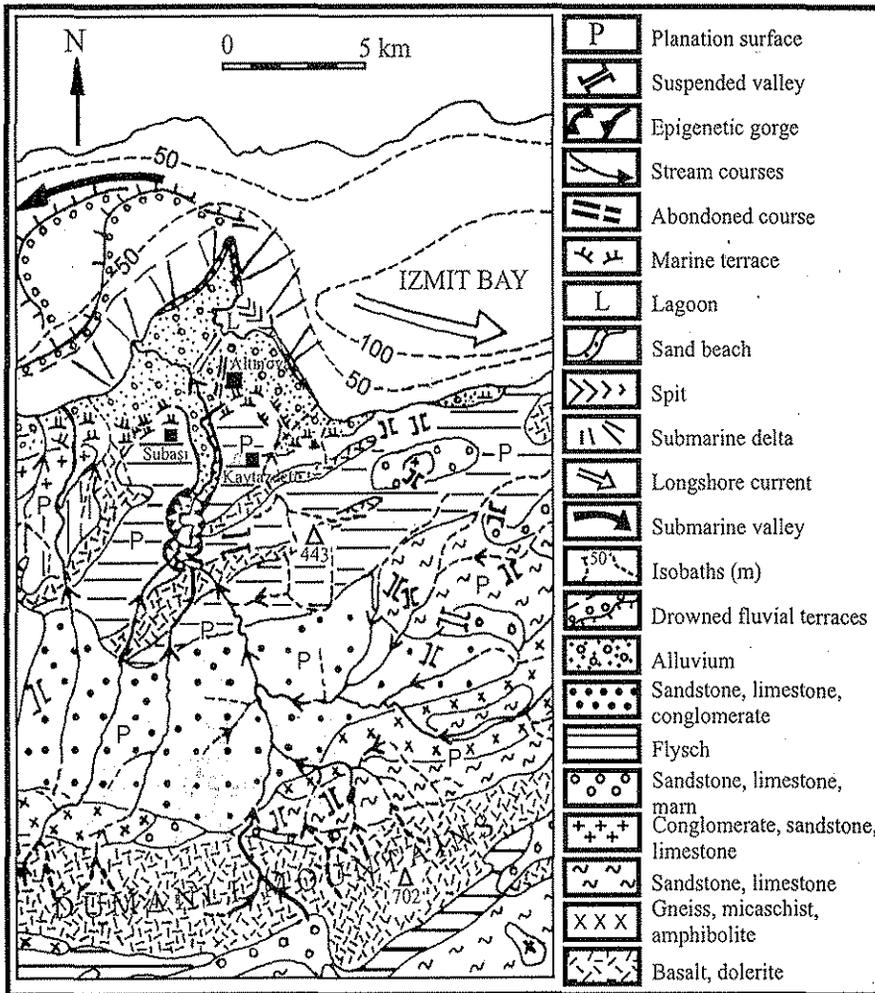


Figure 2. Geomorphological map of the study area.

A deltaic plain takes place northward in front of these marine terraces. There is a lagoon at the eastern part of this deltaic plain which is about 4.5 km long between the Altınova village and the Hersek Point. At the south of this lagoon lake, remnants of ancient stream channels have been observed.

The detailed isopach map of the study area provides a useful tool to recognise the physiographic elements and the main morphosedimentary features (Figure 3). The littoral cordon of deltaic plain is covered by sandy beach facies which was mainly deposited by along-the-shore (EW) oriented currents where the Yalakdere River lost its physical influence. The morphology of this beach unit (sand and gravel), which also makes the lagoon lake shut by forming a NW-SE oriented spit (Figure 2), can be followed until 5-m water depth in the detailed isopach map (Figure 3).

In the same isopach map, deltaic structure show thicker areas of accumulation and the underwater topography of the Hersek Delta extends until 45 m water depth (Figure 3). Comparison of the seismic profiles recorded in the vicinity of prodelta (Figure 4) with the isopach map show that the prodelta exhibits a different geomorphic appearance from the underwater topography of the Hersek Delta. This appearance is in a form of terrace plain extending stepwise towards the basement of the gulf and it is evident at the NW of the prodelta (Seismic Line 4a in Figure 4a). The stepwise terraces between -58.25 and -71.55 m depths (relative to modern sea level) and the coarse fluvial gravel deposits at these levels (Ediger and Ergin, 1995), may indicate a EW trending valley at the basement of İzmit Bay in which a high-energy stream was flowing initially. Ediger and Ergin (1995), based on the ESR (Electron Spin Resonance) dating of the mollusc shells placed under the gravel deposits (Çetin et al., 1995), concluded that the starting depositional age of these gravel deposits is  $254 \pm 34$  kyr BP. Successive mud and sand layers with varying thicknesses are placed on top of the gravel deposits and they indicate changing energy conditions, possibly caused by faulting activities.

The beach rocks which were cut between -43.5 and -35.0 m (relative to modern sea level) in the drill holes at the Hersek Pass indicate steady sea level conditions emerged after rapid post-glacial rises. Since these levels contain abundant continental material composed of mainly gravel, Ediger and Ergin (1995) suggested that the Hersek Delta came up with after the last glacial stage. Intercalating materials with varying thickness such as sand, clay, silt and shells overly the beach rocks up to the seabed.

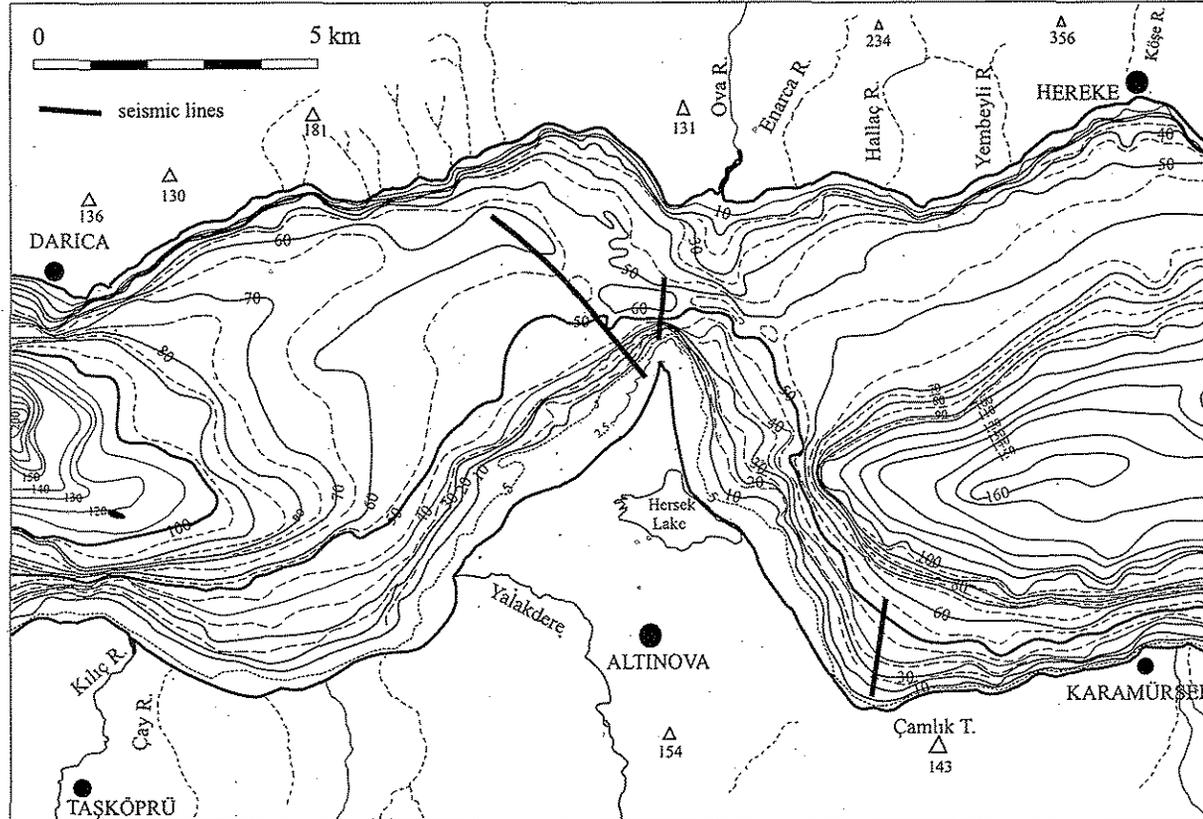


Figure 3. Detailed bathymetry of the vicinity of the Hersek Delta compiled using navigation maps and high-resolution seismic data. Isobaths are in metres. Streams, main heights and seismic lines were also added.

The sedimentary deposits imaged in sparker records collected in the vicinity of the Hersek Delta can be divided into five main seismic units (Figure 4).

#### Western Basin (Seismic Line 4a)

On the seismic Line 4a, late Quaternary sediments averages 35 to 40-m-thick and unconformably overlie the bedrock which have been affected by the active faults extending along the bay (Figure 4a). Considering the lithologic data obtained from borehole logs, the topmost unit consists of fossiliferous sand (unit A) and takes place near coastline. The reflections underlying the sand-prone deposits of unit A possibly belong to soft organic mud with small amount of sand on occasion (unit B1 and B2). These shallow marine sediments, which were deposited during last post-Würm transgression and named as Holocene deposits, overly thin late Pleistocene sediments (unit C). Unit C is composed of (sandy) silty clay. Underlying the deposits of thin unit C, older stratified deposits (clayey silty sand) of unit D must be deposited 50-135 kyr BP during which minor sea-level changes occurred between Riss and Würm glacial stages.

It is well known from borehole logs that thin and discontinuous sandy rock fragments (unit E) are placed under the deposits of unit D. However, in most seismic profiles unit E cannot be readily resolved (Figure 4a).

All of these units unconformably overly acoustic basement (unit F). The basement is composed of consolidated, largely stratified and slightly folded reflections, suggesting a sedimentary character. At its top, unit F is marked by a prominent unconformity which has been identified at different depths. The active faults extending along the İzmit Bay cut the acoustic basement (Figure 4a). The deposits of unit F possibly corresponds to hard silty clay and clay layers as cored near Hersek Point (possibly early-middle Pleistocene).

The late Pliocene and Pleistocene deposits in the İzmit Bay have a maximum thickness of 120 m. The ESR dating, which was applied to mollusk shells cut in the borehole KS2 drilled at the apex of the Hersek Point, indicated possible ages of  $6.6 \pm 0.7$  kyr BP and  $817 \pm 105$  kyr BP for -3 and -50 m (relative to modern sea level) depths, respectively (Çetin et al., 1995). Paleontological findings give late upper Pliocene age for the bottom end (-112 m) of this borehole (Toker and Şengüler 1995). It is also known from MTA's conventional seismic data, that some horizontal and cross-stratified sediments (possibly Triassic) are placed at deeper parts (Akgün and Ergün, 1995).

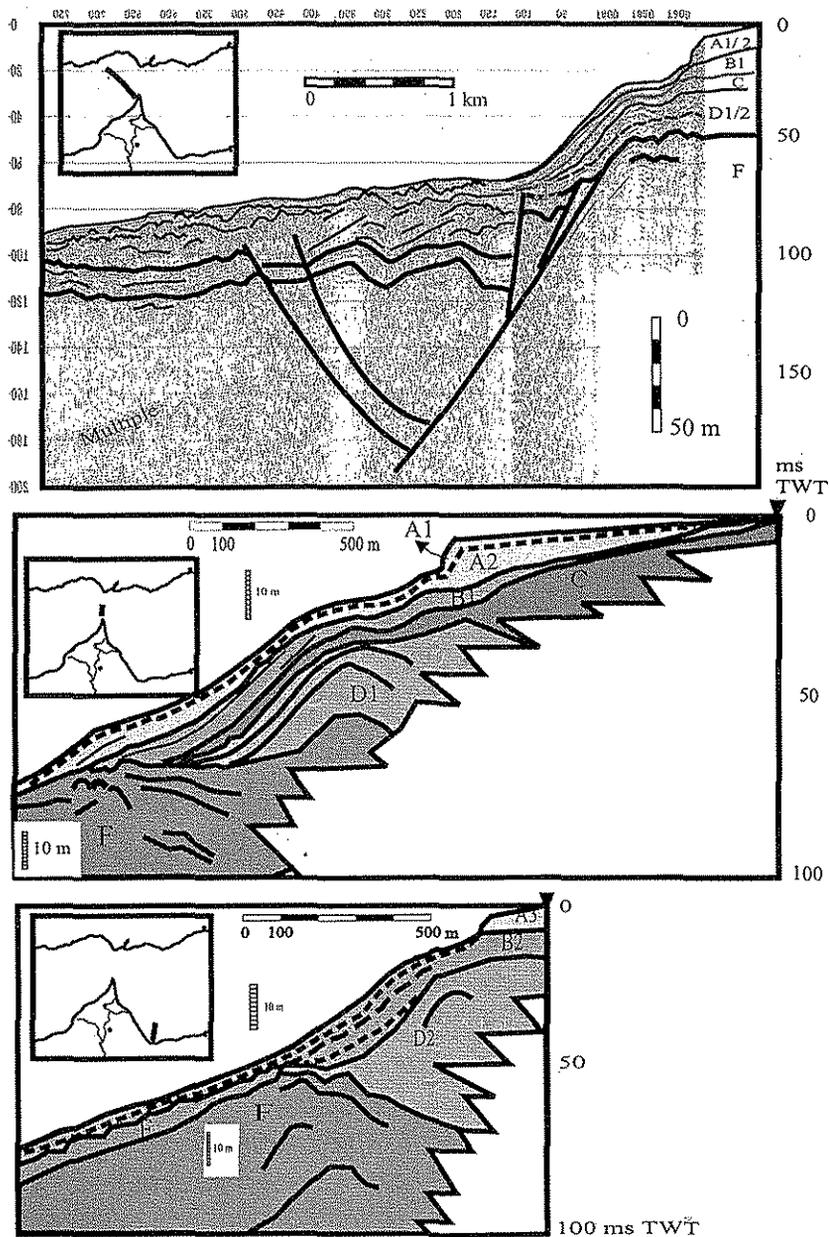


Figure 4. Interpreted line drawings of sparker profiles showing the distribution of the seismic units. A1: loose sandy shells, A2: shelly sand or sandy shell, A3: shelly gravel and sand, B1: soft silty clay or soft clay, B2: shelly silty clay with sandy silty clay bands, C: thick silty clay or sandy silty clay with silty sand bands, D1: clayey silty sand, D2: clayey silty sand with gravel bands, E: sandy gravel, F: folded layers of hard silty clay or clay. See Fig. 3 for location.

### Delta Apex (Seismic Line 4b)

The seabed near the coastline on the seismic Line 4b, where the bottom is generally covered by shells and sands, is rather shallow (< 5 m). This is due to the thick uppermost deposits (unit A) of the present-day Hersek Delta (Figure 4b). Its generally continuous reflections with highly reflective amplitudes represent coarse grained sediments and shell. The upper part of unit A consists of loose sandy shells (unit A1) while its lower part consists of denser sands with shells (unit A2). Unit A has a maximum thickness of about 7 m at shallow waters (Figure 4b). Considering that this unit deposited during the last 1000-2000 years, deposition rate during this period should be very high.

Parallel and semi-parallel reflections observed underlying unit A correspond to Holocene shallow marine soft silty sands of unit B1. This unit averages 2 to 4 m thick and its inner parallel reflections become more evident with increasing depth.

According to seismic data, unit C (late Pleistocene) is composed of fine grained but more consolidated materials compared to unit B1. From lithologic data from borehole logs, unit C consists of consolidated silty clay and sandy silty clay containing semi-consolidated silty sand bands.

Underlying deposits of unit C, unit D1 has concordant inner reflections and consists of clayey-silty sands. Unit D1 must be deposited during minor sea-level changes between Riss and Würm glacial stages (20-135 kyr BP).

All of these units (A-D) unconformably overly a bedrock (unit F). Unit F is marked by a prominent unconformity at its top. According to its seismic characteristics, the bedrock is hard and homogenous with slightly folded inner reflections. This unit possibly corresponds to hard silty clay cut by the drill holes and probably to early middle Pleistocene age.

### Karamürsel Basin (Seismic Line 4c)

Even though mud is dominant for deeper parts more than 10-20 m, the sea floor at the Hersek Pass is covered by sand and muddy sand. Along southern shores of the Karamürsel Basin at the east of the Hersek Delta, a narrow (~200 m) band of sea floor with water depths less than 5 m consists of gravel, sand and fossil shells (Eryılmaz et al., 1995). This unit was named as unit A3 on seismic section (Figure 4c).

Close to the shoreline, the parallel reflections underlying unit A3 represent the deposits of unit B2 which are composed of unconsolidated

fossiliferous silty clays and sandy silty clay bands. Unit B2 is thicker (13 m) around the high-gradient sea floor and it becomes thinner (3 m) at the offshore end of the section (Figure 4c). This unit should be deposited during last 12 kyr following the last glacial maximum.

Underlying the deposits of unit B2, the deposits of units D2 (close to shore) and unit E (offshore) take place. Unit D2, which has a varying thickness with slightly folded inner reflections dipping offshore, corresponds to clayey silty sand layer (with gravel bands) observed in boreholes. Traced northwards, unit D2, which should be possibly deposited between Riss and Würm interglacial period, rapidly thins to less than 2 m and laterally passes into unit E.

Unit E, which is not observed on the seismic sections 4a and 4b, averages about 4 to 5 m thick on seismic line 4c. It is known from lithologic data obtained from borehole logs that unit E consists of rich sandy gravel levels. Such kind of levels which are composed of eroded and rounded continental clastics indicate relatively high-energy depositional environments. Therefore, we may interpret unit E as a base conglomerate which was deposited during sea-level lowstand. Hence the position of unit E may show the ancient coastline during this sea-level lowstand (possibly 25-120 kyr BP).

The lowermost unit with slightly folded inner reflections constitutes the acoustic basement (unit F) which is marked by a prominent unconformity at its top. It has been identified at different depths. This homogenate unit (hard clay) is probably early middle Pleistocene age. From conventional seismic data, Bargu and Yüksel give a thickness of 120 m for this unit.

## **Conclusions**

İzmit Bay is a tectonically active depositional area. Due to insufficient current conditions, the material carried by streams may cause deltaic developments mainly along the southern coastline where the seabed conditions are convenient. The most important of them is the Hersek Delta. The detailed investigation of the seismic sequences observed at the underwater prolongation of the Hersek Delta reveals intervening hydrodynamic and tectonic conditions during late Quaternary.

A narrow sandy band of sea floor lie adjacent to the southern coasts of the İzmit Bay. Under normal conditions, it laterally passes to muddy sand. However, the sea floor is covered by broad variety of material (from mud to gravel) in the Hersek Pass where the Hersek Delta was rapidly developed with the alluvium carried by the rushing Yalakdere

River. This rapid sedimentation rate may also explain why the basement at the Hersek Delta is deeper than that at the northern part of the İzmit Bay.

Regional tectonics (pull-apart basins, Figure 1) is very important in the evolution of the Hersek Delta. Ediger and Ergin (1995) suggest a 40 m vertical displacement for the fault placed just north of the Hersek Delta. The seismic data used in this study indicate two faults with smaller vertical displacements (Figure 4a). These faults are responsible for the coastline changes and the developments of Hersek and Kılıç deltas. Besides regional tectonics, the eastward direction of the surface currents, which are faster along the southern shores, is also an important factor for the development of the Hersek Delta.

The existence of the Pliocene conglomerates indicate that the fluvial activity lasts from late Miocene to present. The Yalakdere River and its tributaries speeded up their erosional activities beginning from late Pliocene. As a consequence of the tectonic activities which is effective from Pleistocene to present, they dig out their valleys deeper. The sediments carried by the Yalakdere River deposited into the fluvio-lacustrine environment which was existed in the middle of İzmit Bay during early Pleistocene. The seismic unit, which was dated as early middle Pleistocene (unit F in Figure 4), is interpreted to represent fluvial deposition of fan-shaped sediments.

The Yalakdere River continued its depositional activities into the fluvio-lacustrine environment between Riss-Würm interglacial period. Units E and D (middle-upper Pleistocene) and unit C (30-24 kyr BP, late Pleistocene) were deposited (Figure 4).

Unit C is absent on the seismic Line 4c (Figure 4c). This indicates that the sediments of unit C which mainly consists of consolidated silty/sandy clay with silty sand bands were not deposited, if not eroded, at the east of the Hersek Delta, possibly all over the Karamürsel Basin. This may indicate a cessation of sea level rise at about -60 m relative to modern sea level just prior to the last glacial stage during late Pleistocene (~25 kyr BP). Therefore, the waters of the Marmara Sea could not reach to the Paleo-Karamürsel Lake by spilling over the water passage between the western and Karamürsel basins (Figure 5).

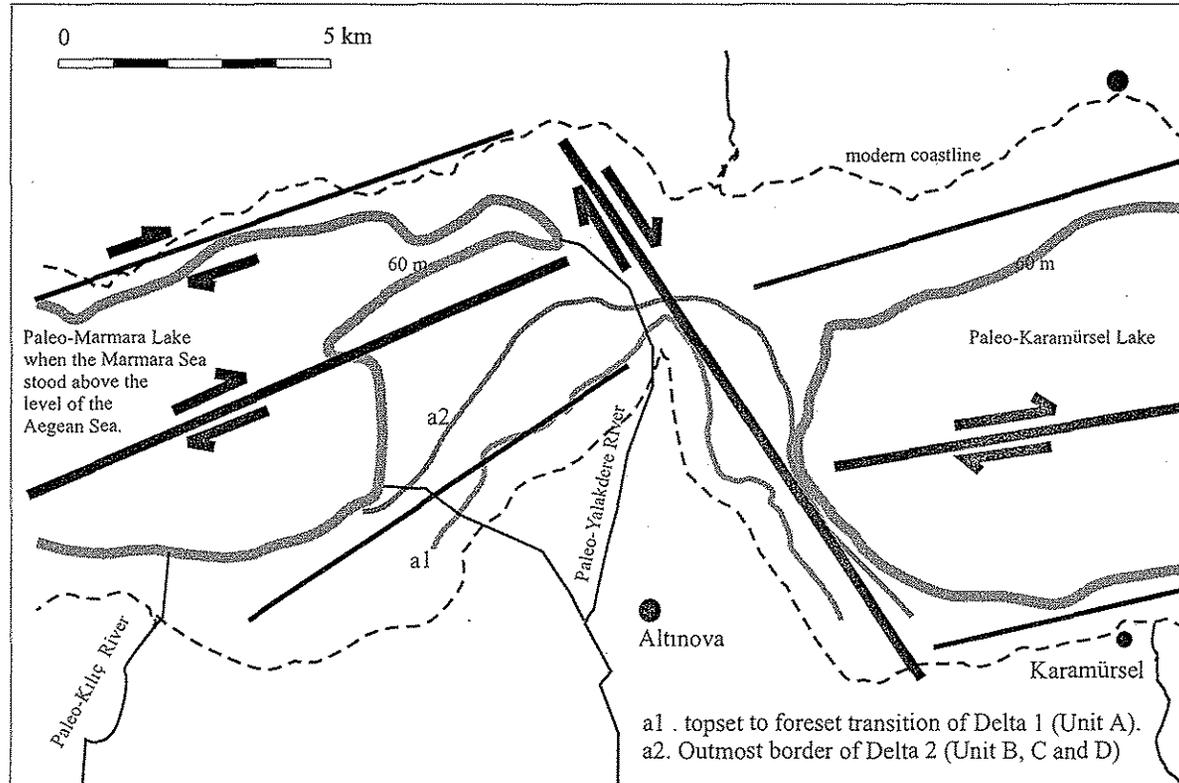


Figure 5. Possible paleo-shoreline at 25 kyr BP just following the cessation of Aegean sea-level rise at about 60 m relative to modern sea level. Beside tectonic activity, the Hersek Delta may also play an important role in preventing the Marmara Sea waters to spill over into the Paleo-Karamürsel Lake.

During the early deglaciation stage following the last glacial maximum, the Mediterranean seawater invaded the Marmara Sea. The sea level started to rise at ~11 kyr BP in the İzmit Bay causing transgression of shelves and lowstand deltas. At ~9.5 kyr BP, glacial meltwater temporarily stored in the Black Sea lake flowed toward the Aegean Sea until ~7 kyr BP (Aksu et al., 1999).

The Hersek Delta continued its development during mild and wet periods (5-6 kyr BP, climatic optimum) when the Turkish straits were completed their developments (Erol, 1990; Erol and Çetin, 1995). Depending on the climatic oscillations and tectonic activities, the Hersek Delta continues its development with oscillating intensities from the beginning of Holocene (soft silty clay deposits of units B1 and B2, Figure 4) until present (shell, gravel and sandy deposits of units A1-3, Figure 4).

### Özet

Bu çalışmada, jeolojik, jeomorfolojik, batimetrik ve sığ sismik çalışmalarının ışığında, Yalacdere'nin taşıdığı sediment yükünün körfez tabanında birikimi neticesinde İzmit Körfezi güney kıyısının ortasında önemli bir morfolojik yapı oluşturan Hersek Deltasının yapısal özellikleri, oluşumu ve gelişimi incelenmiştir. Bu gelişimde, yerel tektoniğin de büyük önemi vardır. Sismik kesitlerde akustik temel olarak gözlenen ve tektonik hareketlerden etkilenmiş F sismik birimi üzerinde Hersek Deltasına ait 4 ayrı çökel paketi (yukardan aşağı A, B, C ve D/E) ayırıt edilmiştir. Hersek Deltasının doğusunda geç Pleistosen yaşlı C sismik biriminin gözlenememesi, yaklaşık 25,000 yıl önce günümüz deniz düzeyinden yaklaşık 60 m aşağıda yer alan Marmara Denizi sularının (yüksek deniz düzeyi) Hersek önündeki eşiği aşamayıarak Eski Karamürsel Basenine geçemediği şeklinde değerlendirilmiştir. Hersek Deltasının gelişimi iklim oynamaları ve tektonik etkisiyle artan ve azalan hızlarda devam etmektedir.

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