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Structural Features of the Tuzla Region, Istanbul

İstanbul-Tuzla Bölgesinin Yapısal Özellikleri

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Abstract

All known earthquakes which affected İstanbul are originated in the Sea of Marmara, while there is not any large earthquake occurred on land on the Kocaeli Peninsula. Small scale earthquakes located on this platform have become much more interesting to researchers after two 4.2 Ms events occurred along the Tuzla-Pendik coastal area after the disastrous 17 August 1999 earthquake. Some NE-SW trending lineaments on the Kocaeli Peninsula are evident from digital elevation models and satellite images. The valleys along these lineaments show low resistivity and shear wave velocities, implying buried discontinuities. Seismic studies showed that the associated discontinuities observed in the acoustic disturbance at sea may be some of the faults on which the modern Sea of Marmara evolved. In present, the old faults in the Palaeozoic basement may be reactivated by the earthquakes occurring along the North Anatolian fault zone, causing damage to the settlements along the alluvial valleys extending inland.

Keywords: Sea of Marmara, tectonic setting, fault, seismic reflection, earthquake, underwater failures

Introduction

The basement of the Çataica-Kocaeli Peneplain is made up of Palaezoic units (İstanbul group). Younger Quaternary sediments are placed on top of the basement. This terrestrial layer has different lithologies and contain Palaeozic pebbles of all age. Alluvial deposits form relatively thin veneer over this sequence.

Lower Carboniferous isostatic and tectonic movements in the region were followed by Hersinian and Alpine episodes which caused N-S and E-W oriented folding and faulting (Ketin, 1983). The present morphology of the İstanbul and Kocaeli peninsulas indicates that the dominant factor is likely to be neotectonic which can be divided into two periods; the early neotectonic period (Early Miocene-early Pliocene) when the Thrace-Eskişehir fault was dominant, and the late neotectonic period (late Pliocene to present) when the right-lateral North Anatolian fault is dominant (Yaltırak, 2002). It is generally accepted that the NE-SW trending sinistral faults on the Kocaeli and Armutlu peninsulas are the most interesting structures caused by this ductile shear deformation system. The Kocaeli platform has been eroded on a large scale in the late Pliocene resulting in the formation of the Çatalca-Kocaeli Peneplain; a former plateau which has been lowered by erosion.

Morphologic Lineaments

It is during the Pliocene that the shore area between Darıca and Tuzla have been covered by alluvial sediments, due to the erosion of a wide coastal plain behind it. Therefore, it is fairly difficult to observe the morphological evidences of the tectonic features to the east of Tuzla. In addition, shore erosion and barrier beach development due to existing heavier and larger grained sediments caused the connection of the small islands offshore Tuzla to the land; forming small capes projecting into the sea and marking a notable change in coastal direction. Contrary, there are no depositional morphologic features along the coastal area to the west of Tuzla cape; but a few 4-5 m high cliffs take place in that area. Small-scale bays and inlets developed by storm wave action and storm surge at weak areas where the faults meet with sea. The topographic elevation of the plateaux between the hills increases landward (Oktay and Eren, 1994; Güneysu, 2001).

The lineaments observed on land are evident on digital elevation model (Figure 1). They are oblique to shore in general; N-S trending to the north of the study area and NE-SW trending to the places close to the coast. The lineament F2 extends northward along a large valley to the east of Pendik. The lineament F3 starts from the valley to the west of Tuzla. Hot water springs at İçmeler locality take place on F3. The lineament F4 starts from the coasts of Tuzla and extends northward with some hot water springs. Finally, the lineament F5 is situated along the valley between the towns Tuzla and Gebze. There are hydrothermal alterations along F5 on which the settlements (Şifa and Mimar Sinan quarters) have been severely affected from the 17 August 1999 earthquake disaster. All these lineaments form the branches of the Ömerli dam lake to the north (Figure 1). Similar lineaments to the east of the study area, east part of İzmit Bay, were considered as active faults (Şaroğlu et al., 1992).

In this study seaward continuation of these lineaments observed in the Tuzla District will be investigated by seismic reflection method.

Material and Method

Electrical resistivity and shear wave velocity changes along the lineaments, on which small and medium scale seismic activity occurs, were investigated at the first attempt. Electrical penetration is 30 m. Compressional (Vp) and shear (Vs) wave velocities were calculated from the seismic refraction application using 12-channel array with a layout of 24 m (Baş, 2001). On the basis of good correlations between the geophysical data and the lineaments, their continuation at sea were investigated by using high-resolution seismic reflection method (Figure 2). Two different data sets were used; TN-DHNO analogous sections acquired with 100-J Uniboom and IU-IMSM digital sections acquired with 1.25-kJ sparker. The record lengths are 100 and 250 ms (two-way travel time), respectively.

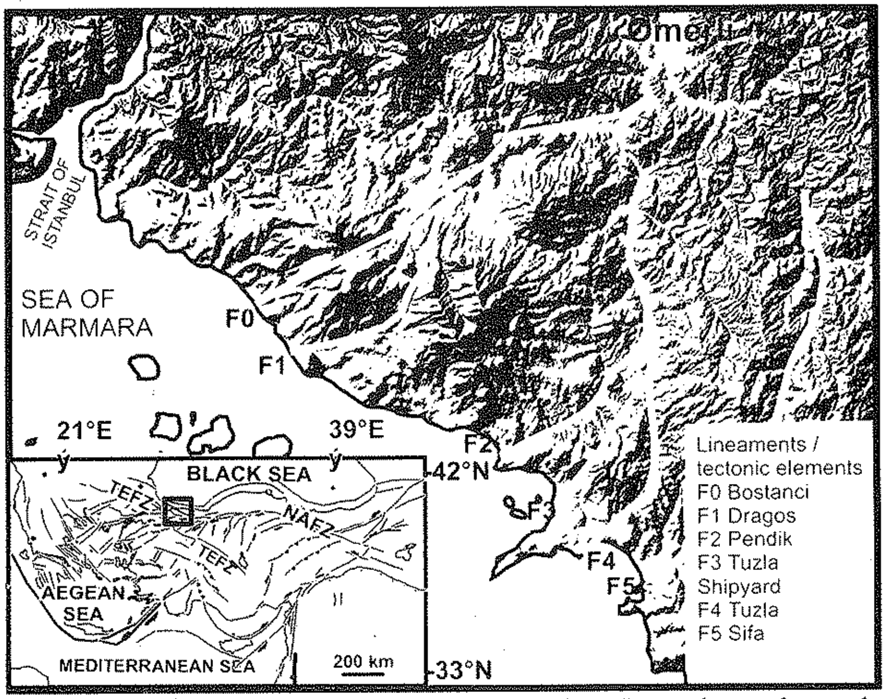

Figure 1. The lineaments on the topographic data. Inset shows the study area (modified from Yaltırak et al., 2000).

Results

It is known more than two hundred important (V<Io<IX) earthquakes that hit the Marmara region (Ambraseys and Finkel, 1991). Modern seismological studies indicate some small magnitude events on the Kocaeli platform (Figure 3). The distribution of the epicentres of these earthquakes are concordant with the lineaments we defined. The earthquakes occurred between 28 April and 2 June on the land (see Figure 3a given by Taymaz et al., 2001) are on the lineaments F4 and F5. Following these events, 07 July 2000 and 16 January 2001 earthquakes occurred; they were called Tuzla and Kartal earthquakes. The fault plane solutions of these Ms 4.2 earthquakes show strike-slip mechanism (Figure 3). The macroseismic epicentre of the Tuzla earthquake is located on the seaward extension of the F2 lineament, while that of the Kartal earthquake is on the F1. On the other hand, the Pendik fault (the dashed line in Figure 3), which is first proposed by Alpar (1999)

from high-resolution sparker data, takes place at the extension of the lineament F3.

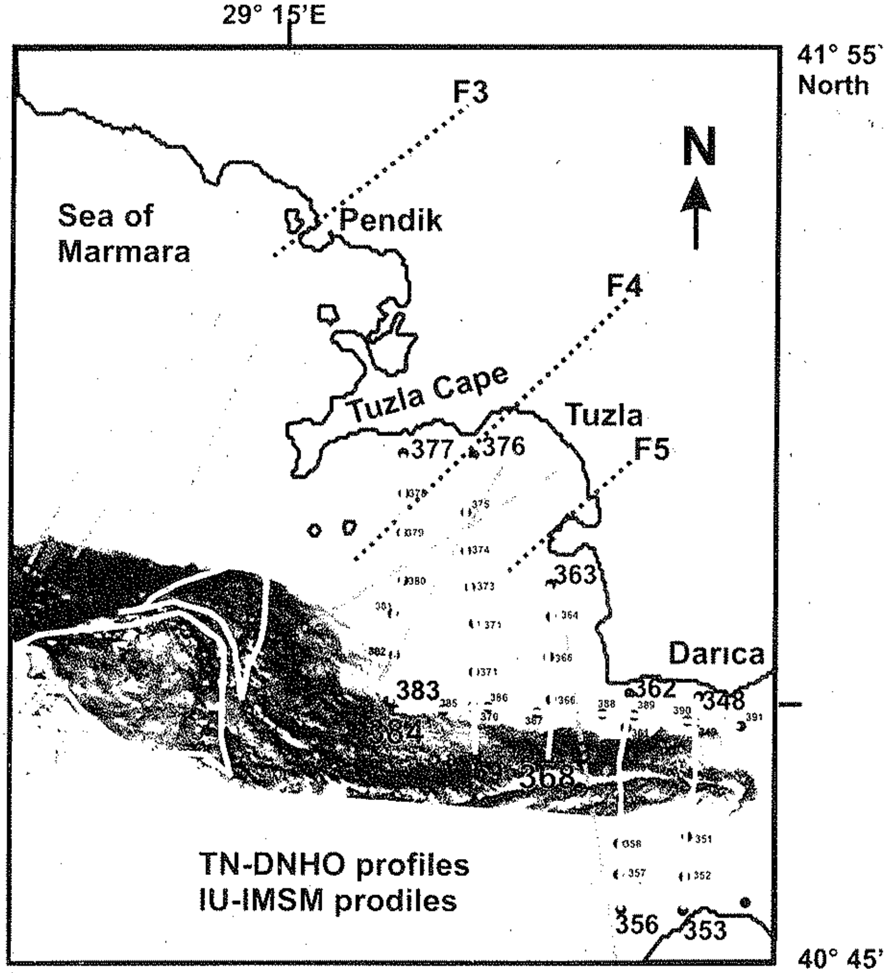

Figure 2. Seismic reflection lines. Multibeam bathymetry shows the Tuzla underwater landslide with its distinguished headscarp.

The electrical resistivity depends on the decomposition of the rocks (Baş, 2001). As an example, the resistivity values are about 50 ohm.m at the shallow parts of the Palaeozoic units (Aydos sandstones and Kartal shales) while they become much higher (250-450 ohm.m) with depth. They are 50-60 ohm.m on debris flows at the slopes and 20-40 ohm.m on aluvial deposits. The aluvial deposits located at the junctions of the capes with land and around the lakes at Tuzla are much thicker and cause lower resistivities. The resistivity of the Neogene units on the lineament F5 is as low as 5 ohm.m. Electrical results show that the thickness of the alluvial deposits along the lineaments may show changes. Resistivity changes are concordant with formation boundaries as well. To make a correlation with lithology; high resistivity represents stable and resistant areas, medium resistivity shows stable but relatively changing basements and most conductive results represent unstable, weak and faulty areas.

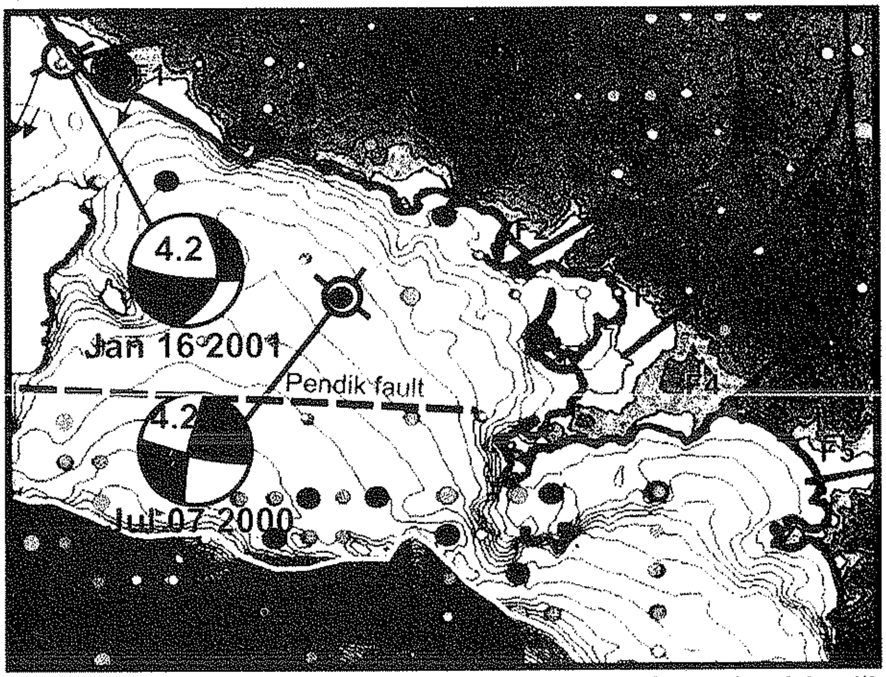

Figure 3. Earthquake activity. Fault plane solutions of Kartal and Pendik earthquakes (data from ftp://ftp.koeri.boun.edu.tr/pub/seismo/catalog/). The dashed line is the Pendik fault (Alpar, 1999) and takes place at the extension of the lineament F3.

The shear wave velocity (Vs) for the topmost 2-4 m of earth is between 300 and 1100 m/s (Baş, 2001). Tuzla, Baltalimanı and Dolayoba formations have the highest Vs; 900-1100 m/s. Decomposition near the earth surface causes Vs to decrease; 400-700 m/s for the widely distributed Aydos formation (Palaeozoic) and 300-400 m/s for alluvial blanket deposits along the coastal area and inside the valleys. Some liquefactions have been experienced for such areas during the last 17 August 1999 earthquake.

Structural elements existing along the lineaments observed on land may continue at least on the northern shelf of the Sea of Marmara. Recent multibeam bathymetric data covers the continental shelf, slope and the basin. On the 3-km-wide steep (~17° slopes) continental slope, fine grain sediments are transported from shelf down to the basin by turbidity currents. In addition, a big underwater fan covers an area of 8 km^2 offshore Tuzla Cape (Figure 2). It originates at about -700 m, terminating at about -1140 m water depth. This large submarine landslide is associated with a particular scar directly up gradient. Its amphitheatre-shaped steep upslope region (headscarp) is integrated with the shelf edge (Yalçıner et al., 2002). This rotational landslide is controlled by the Adalar fault. However, it is not always easy to determine whether a mass movement is a slump, debris flow, rock fall, etc. based solely on surficial morphology. Steep bottom slope, scarp areas and slumps can be recognised on the seismic reflection data on which we are looking for the extension of the NE-SW trending F4 and F5 lineaments.

F4 Lineament

Two different sedimentary sequence units are evident in the seismic sections (Figure 4) recorded in the Tuzla Bay. They are an acoustic turbulence at the bottom (Palaeozoic units) and covering Plio-Quaternary sediments. A strongly reflective subbotom reflector (i.e. enhanced reflector) occurs at various subbottom depths down to <200 m at the shelf edge (Figure 5) giving low-frequency chaotic reflections. These depths of occurrence are correlated to those of upper boundary of the Palaeozoic sequence 5-100 ms TWT below the seafloor depending on its locality on the shelf. The enhanced reflector indicates a marked contrast in acoustic impedance and represents an erosional truncation surface. The thickness of the upper Pliocene and Quaternary-sequence increases offshore and thick deltaic sediments (sandstones), which carry some fingerprints of coastal onlap and regression, constitute the upper portion of the succession close the shelf edge.

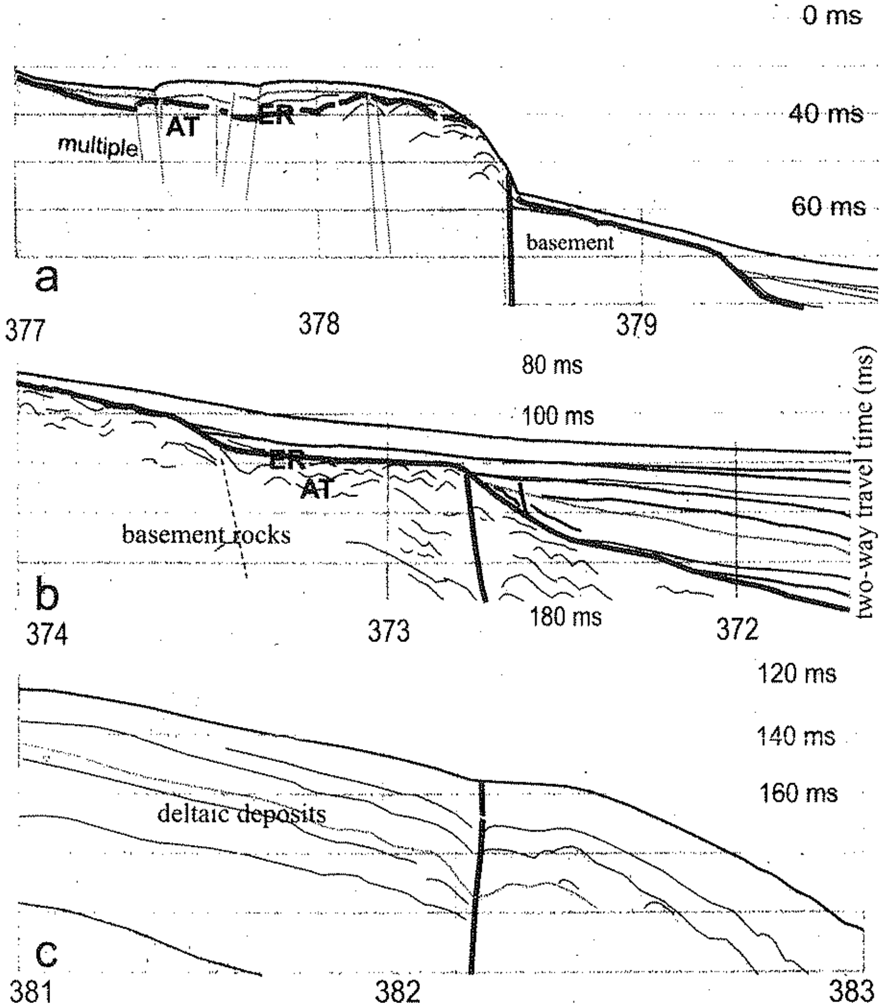

Figure 4. Examples from high resolution seismic reflection profiles. See Figure 2 for locations. Depths are two-way travel time in ms. Fix intervals are about 750 m. An enhanced reflector (ER) with underlying acoustic turbidity (AT) is evident for the sections a) 377-380 and b) 371.5-374. Deltaic deposits are thick on the seismic line c) 381-383.

Hypothetic continuation of the lineament F4 intersects with the seismic line 377-380. The most striking structural feature on this section is a sudden slope change of seabottom at 35 m water depth around the shot point 378.5 (Figure 4a). At this locality a fault in the acoustic basement also cut through the upper sequence which is thin. Adjacent sections were also considered if this fault may represent another tectonic or morphologic elements in the Bay, instead of the extension of lineament F4. However, there is not any similar fault, geomorphic feature or any abrupt seafloor changes (between 372.8 and 376 shots) on the seismic line 376-369 just placed to the east (Figure 5). The upper sequence disappears at the shot 374.5 and the Palaeozoic basement outcrops northward. No faults were observed within the widely folded layers of the basement. The overall picture indicates that the fault at the shot 378.5 and smaller scale faults located to the north of this one, all affected the basement and upper sequence (Figure 4a), could not be observed on the seismic section 376-369. This appearance may support that the fault at 378.5 can be correlated with the lineament F4 (Figure 5).

F5 Lineament

Hypothetic extension of the lineament F5 intersects with two seismic lines. Approximate cross points correspond to the shots 372.8 and 382.1 on the eastern (374-372) and western (381-383) lines, respectively (Figure 4b,c). One can evidently see a sudden slope change of the basement rock between the shots 372.7-372.8 on the eastern line (Figure 4b). That point is 90 m below the modern sea level and can be considered as the coastline when Tuzla Bay was a shallow marine environment, with its southern extension on the northern Marmara shelf exhibiting lacustrine conditions. The basement at this point is represented by high frequency, discontinuous and chaotically folded reflections. Seismic reflection can not be traced horizontally between the shots 372.7-372.8, possibly due to extensive deformation of the sequences, where one can propose and draw a fault cutting through the basement rocks at this locality. If not considering a small local fault located 80-90 m deep around the shot point 372.6, there is not any important effect of this old fault to the overlying Plio-Quaternary formations.

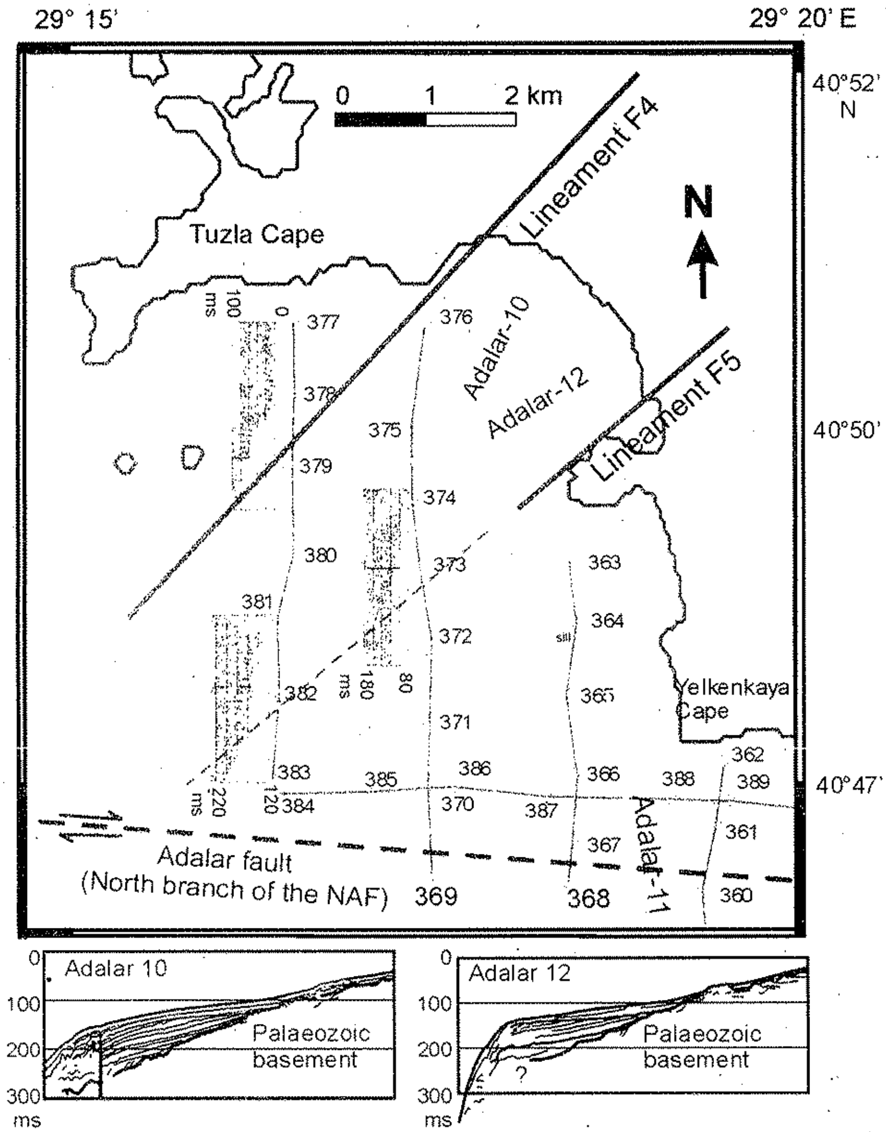

Figure 5. Line drawing interpretation of the seismic sections Adalar 10 and 12. The lineaments F4 and F5 are superimposed to make a direct correlation.

On the western seismic line, the acoustic basement which is cut through by older faults is unfortunately below the record length (Figure 4c).However, some structural deformations observed around the shot point 382.2 in the deltaic deposits may show the existence of a deeper fault (Figure 4c). Similar deformations were defined on the seismic section Adalar-10 (Figure 5). The deltaic sequences widely observed below the water depth of –60 m were deposited on the basis of sea level changes in the Sea of Marmara and also the transported material from the valleys along the proposed faults in this study. Even the thick deltaic deposits located on the SW end of the seismic section Adalar-12 prevent us to follow the extension of the lineament F4 in the basement, there are some deformations in the deltaic deposits (Figure 5).

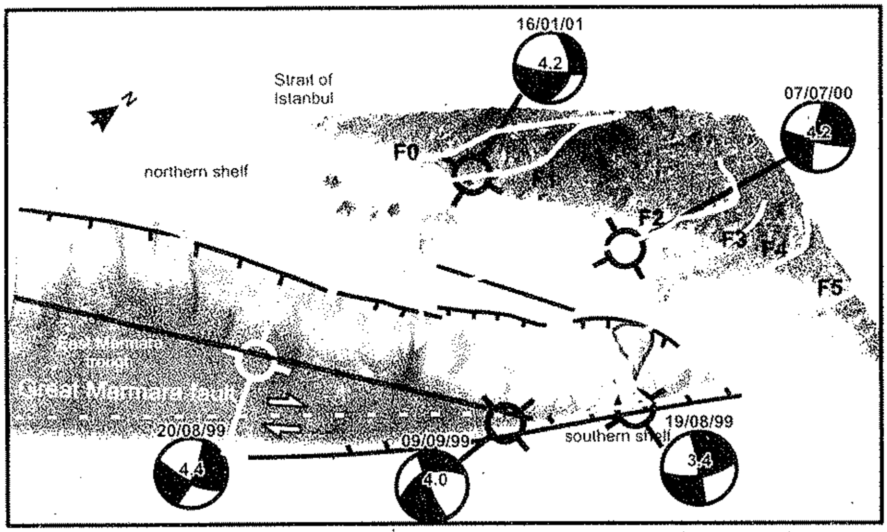

Figure 6. Representation of the proposed structural elements in a 3D digital image of the region.

Conclusions

Similar to those at the east part of İzmit Bay, some lineaments on the massive units of the Kocaeli plateau in the Tuzla District were observed in a morphological manner (Figure 1). They form the branches of the Ömerli dam lake located to the north and considered as structural elements. The geometries of these elements are in good agreement with the distribution of low shear wave velocity and low resistivity zones on land. Lowest resistivity and the distribution of the earthquake epicentres (Figure 3) are also in accord with these lineaments. The Kartal and Pendik earthquakes occurred after the 17 August 1999 disaster and showing strike slip fault plane solutions (Figure 3) imply that these lineaments might be important faults (not small scale) that are active or can be reactivated. It is believed that the damage observed on the lineaments F4 and F5 after the 17 August 1999 earthquake is not only due to poor basement conditions (low seismic velocity) but also due to tectonic conditions.

Some associated faults at the offshore extend of the lineaments F4 (Tuzla fault ?) and F5 (Şifa fault ?) were detected in the Palaeozoic basement on the reflection sections. It is believed that these faults are extending southward until they meet the northern branch of the North Anatolian fault zone (or the Adalar fault) (Figure 6). They may be reactivated depending on the seismic activities on this branch of the North Anatolian fault. The medium scale earthquakes occurred within the following 2 successive years after the 17 August 1999 event have shown the very same kinematic mechanism.

It is believed that the old faults in the Palaeozoic basement of the Kocaeli platform are not seismogenic faults, but they should have been reactivated during the recent evolution of the Sea of Marmara under the influence of the Thrace-Eskişehir fault initially and the North Anatolian fault afterwards. The Thrace-Eskişehir fault cut through the basement in the beginning. The compression caused by block rotations is taken by the escapement of the associated blocks along the existed faults. Later, the North Anatolian fault controlled the well-known geologic evolution of this basin by cutting thorough it.

The position of the recent earthquakes and their fault plane solutions indicate that the NE-SW trending faults, we suggest on the basis of the lineaments observed and the geophysical data on land and offshore, have been reactivated in the past and will be reactivated in future, depending on the large earthquakes along the northern branch of the North Anatolian fault zone. Even it is believed that their magnitudes could hardly exceed 5.5 Ms, these interesting observations deserve further geophysical studies to pinpoint such estimates.

Özet

Tarihsel ve aletsel dönemde İstanbul'u etkileyen Marmara Denizi merkezli birçok deprem olmasına karşılık Kocaeli platformu kara alanları üzerinde büyük bir deprem oluştuğu bilinmemektedir. Ancak bu platformlar üzerinde küçük büyüklüklü depremlerin varlığı ve Kocaeli 1999 depreminden sonra Kartal ve Pendik sahillerinde oluşan depremler dikkat çekicidir. Kocaeli platformu üzerindeki yükselti verileri ve uydu görüntüleri KD-GB yönünde uzanan birçok morfolojik çizgisellikler göstermektedir. Bu çizgisellikler boyunca uzanan vadilerde özdirenç değerleri ve kesme dalgası hızları düşük değerler vermekte ve süreksizlikler göstermektedir. Bu süreksizliklerin deniz içindeki devamı sismik yansıma yöntemiyle araştırılmıştır. Bu süreksizlikler Paleozoik temel içinde var olan faylardan bazılarıdır. Marmara Denizi de bu temel üzerinde gelişmiştir. Bu temel ilk kez, D-B yönlü sıkışmaya bağlı olarak, sol yanal Trakya-Eskişehir fayı tarafından kesilmiştir. Dönme hareketinden dolayı oluşan sıkışma, blokların mevcut faylar üzerinde kaçması ile karşılanmıştır. Daha sonra, Kuzey Anadolu fay kuşağı, oluşan yapıları keserek, Marmara Denizi'nin oluşumunu sağlamıştır. Günümüzde ise, Paleozoik temel içindeki eski faylar Kuzey Anadolu fay kuşağı üzerinde oluşan depremler nedeniyle zaman zaman yeniden harekete geçebilmekte ve üzerlerinde yer alan vadiler boyunca kurulmuş yerleşimlerde yapısal hasara neden olabilmektedirler.

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