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An Estimate of Detailed Depth Soundings in İzmit Bay before and after 17 August 1999 Earthquake

17 Ağustos 1999 Depremi öncesi ve sonrası İzmit Körfezi Hassas Derinlik Ölçümlerinin Değerlendirmesi

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Abstract

On the basis of detailed bathymetric data collected in March 1999 and January 2000 at two sites nearby the Hersek Delta, İzmit Bay, possible bathymetric changes caused by 17 August 1999 Kocaeli Earthquake were studied. Data acquisition systems, techniques and parameters were held same in all surveys. Obtained differences were estimated taking into account possible error sources for single-beam echosounders and depth reductions, along with the methodology for producing depth error budgets. The results reveal some bathymetric changes and some systematic variations in the depth difference, especially on the southern block of the right-lateral strike slip master fault.

Keywords: İzmit Bay, bathymetry, active faulting, echosounding

Introduction

İzmit Bay formed by three small tectonically active sub-basins and is settled down on a right-lateral strike-slip transform fault between two continental realms; Istanbul Block and Sakarya Plate (Figure 1a). The central and western sub-basins are separated by the Hersek Delta. Active tectonism affects the actual basin-fill deposits and plays an important role in the evolution of Hersek Delta (Sakınç and Bargu, 1989; Alpar, 1999).

At two different coastal sites near the Hersek Delta (Figure 1b), detailed bathymetric surveys were carried out in March 1999 for engineering purposes. In less than 5 months, on 17 August 1999, a devastating earthquake (Ms 7.4) occurred in this seismically active zone. Its source is located in the elastic-brittle layer of lithosphere (17 km) and caused right-lateral movement with an average offset of 4 m (Emre et al., 2000).

On the basis of high-resolution shallow reflection data, İzmit Bay constitutes negative flower structure controlled by a master fault (Alpar, 1999; Alpar and Yaltırak, 2000). The faults controlling its sub-basins represent releasing bends. Secondary small-scale faults oblique to the master fault with different angles are the products of the dextral shearing mechanism. They took up the deformation on themselves following the main shock, possibly causing bathymetric changes.

Some bathymetric changes, generally subsidence, were reported for the deeper parts of the easternmost sub-basin (Öztürk et al., 2000). However, these changes are questionable since the authors are completely unaware of error sources for depth measurement methodology and depth error budgets, and therefore, they compared 20-m isobath measured by Turkish Navy after the earthquake with that of surveyed about 30 years ago by the same institution conducted just for navigation purposes.

The major fault of the 17 August 1999 Earthquake did not give any surface rupture on the Hersek Delta, highly possibly due to its plasticity or westward shift of the delta together with the southern block (Alpar and Yaltırak, 2000). This proposal was later supported by the InSAR, Synthetic Aperture Radar interferograms (Wright et al., 2000), a new space geodetic technique which provides detailed information on surface deformation associated with seismic events. On the other hand, it is well known from previous marine seismic works carried out just north of the Hersek Delta that a fault with 40 m vertical offset (Ediger and Ergin, 1995) or two faults with smaller vertical offsets (Alpar and Güneysu, 1999) exist.

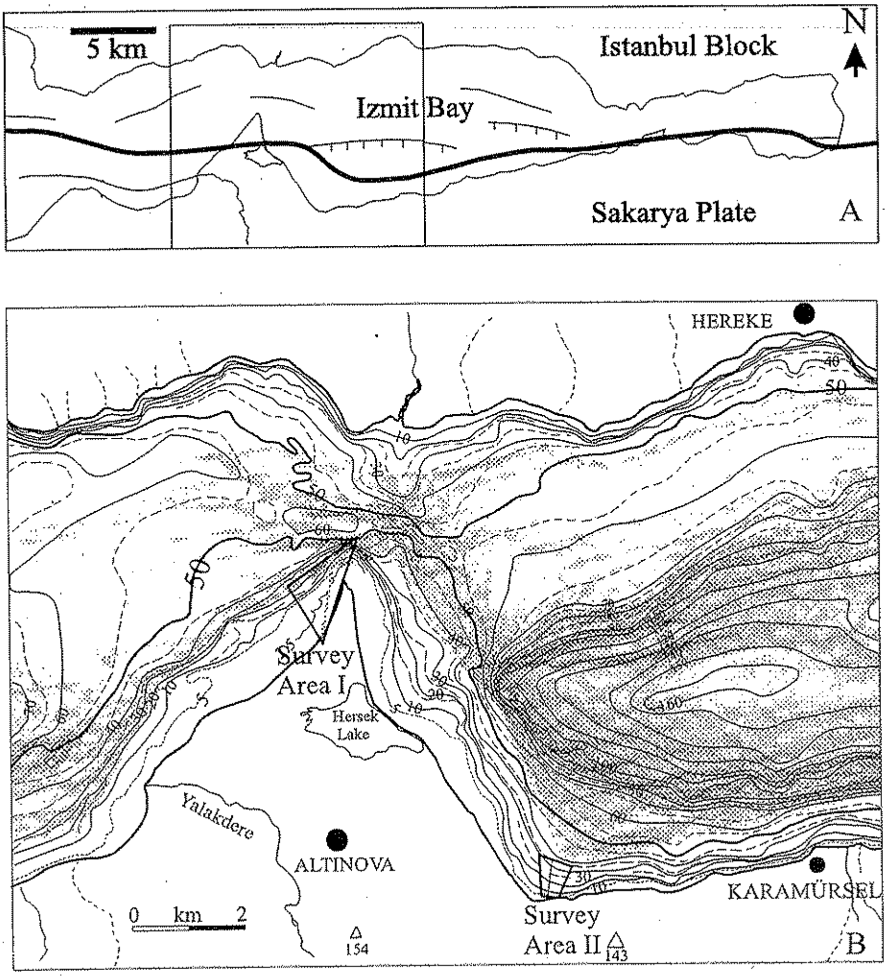

Figure 1. A) Tectonic setting of Izmit Bay (modified from Alpar and Yaltırak, 2000). B) Bathymetry of the Hersek Delta region, compiled from Alpar and Güneysu, (1999) and superimposed on multibeam data (courtesy DNHO). Triangles indicate survey areas for cases.

Following the 17 August 1999 earthquake, beyond the strike-slip the master fault (Figure 1a), secondary surface-breaking ruptures, subsidence, coastal landslides and sea water inundation were observed on land. Most prominent of surface-breaking ruptures is the 3.2-km-long Kavaklı Fault east of Gölcük. Its displacement is predominantly dip slip.

The north block of the faulting blocks has been downthrown 2 m on average, submerging into the sea (Altınok et al., 1999). Coastal landslides at Değirmendere, Halidere, Ulaşlı, Karamürsel and subsided areas along the shore from Kavaklı to Yeniköy were reported. In Karamürsel, coastal subsidence was in the order of 20 m along the 800 m coastline (Altınok et al., 2001).

All these observed coastal landslides, subsided areas, previous and new marine seismic reflection works may support that the earthquake highly possibly caused some bathymetric changes. Therefore, in order to check it out, bathymetric surveys were repeated in both survey areas in January 2000.

It is well known that depth error budgets are commonplace for single-beam echosounders. The error sources for single-beam echosounders, and depth reductions, along with the methodology for producing depth error budgets, have been well documented (Thomson, 1980; Carter, 1980, Alper and Bossler, 1985; Myres, 1990). The error sources for single-beam echosounders are the combination of various factors as shown below;

1. Errors due to water environment
    a. vertical and lateral variations of sound profiles
    b. sea level variations (waves, sea level changes, rounding of the readings of water level changes, pitch and roll errors)
    c. chart datum measurements
2. Instrumental errors
    a. echo travel time
    b. instrumental adjustments
    c. reading static draught (transducer depth)
    d. determination and rounding of sound velocity
    e. temporal variations in the research vessel's draught, settlement and squat variations and their estimation

3. Personal Errors

    a. blunders or gross errors
    b. regular or unsystematic erroneous readings
    c. false echoes.

Therefore, some corrections and reductions should be applied to depth measurements. There have been attempts in order to ensure that International Hydrographic Organisation (IHO) standards for depth measurement accuracy can be met (IHO, 1987).

The primary aim of this study is first to compare the bathymetric charts obtained before and after the earthquake and then to get understand if the changes are depend solely on morphological deformations taking into account inherited depth error budgets.

Material and Method

The bathymetric surveys examined cover two sites in the vicinity of Hersek Delta, İzmit Bay (Figure 1b). All surveys were conducted using Raytheon type 719 single-beam echosounder. IHO standards for depth measurement accuracy (IHO, 1987) were undertaken.

The variations of water level above the chart datum is a source of error. Since the survey area is rather small, local datum was used for reference level. The chart datum is same for all surveys. Therefore, the height of water level above the chart datum is only dependent on time. Relative vertical motion of the transducer with respect to its mean vertical coordinate (heave) is another source of sounding error. Since no heave sensor used, all measurements were strictly carried out when the sea state was calm, smooth or slightly throughout. On the other hand, the beamwidth of the echosounder is typically wide enough to absorb the positioning errors caused by pitch and roll. For the variations of the sea water velocity, daily bar checks (Ingham, 1974) were applied.

Dynamic draught is the instantaneous depth of the transducer below the mean water level and is made up of three components as shown in the following equation;

dynamic draught = static draught –settlement (load) – squat where static draught is the depth of transducer below the water level when the research vessel is rest, squat is the change in draught with changes in vessel speed and load is the change in draught over time, e.g. because of fuel consumption. Since the survey speed of the 8.5m-boat was held low, changes in load kept minimum and the static draught determined for each survey platform on a daily basis and added to all measurements as well, dynamic draught can be expected within the expected error limits.

Depth error budgets are seldom prepared, relying rather, on the positioning system accuracy specifications. In this study, positions were fixed using a total-station electronic position fixing system. Positions on the seabed (Hedge, 1985) were considered to have been fixed with an accuracy of ± 5 m.

Post Processing

Following the surveys, all soundings were first controlled by manual inspection for possible blunders or gross errors. Continuously measured water levels were subtracted from these measured depth to get charted depth.

This data was merged with navigation data and detailed bathymetric maps of the survey areas were prepared (Figure 2 and 3). For this purpose, a classical grid interpolation algorithm called as "krigging" was employed to generate graphical interpretations of the survey data such as depth contours or 3D surface models. This algorithm is essentially a least-squares depth interpolator which uses the variogram as a weighting function. The mathematics of this algorithm are outside the intend of this paper. The grid size is 5x5 metres for both cases.

The density of soundings is sufficient, in the order of 2500 and 1800 for survey areas I and II, respectively (Figures 2 and 3). In order to avoid spurious events, contours extrapolated outside the sounding points were not considered before making any subtraction prior to comparison of the results. In addition, non-overlapping marginal parts of the charts obtained before and after the earthquake surveys were not considered.

Results

Case I (Altınova) : The seabottom shallow than 5 m is made up of shells and sand of thick uppermost deposits of the present-day Hersek Delta. The upper part of the sedimentary layers is made up of shelly clay (0-4 m

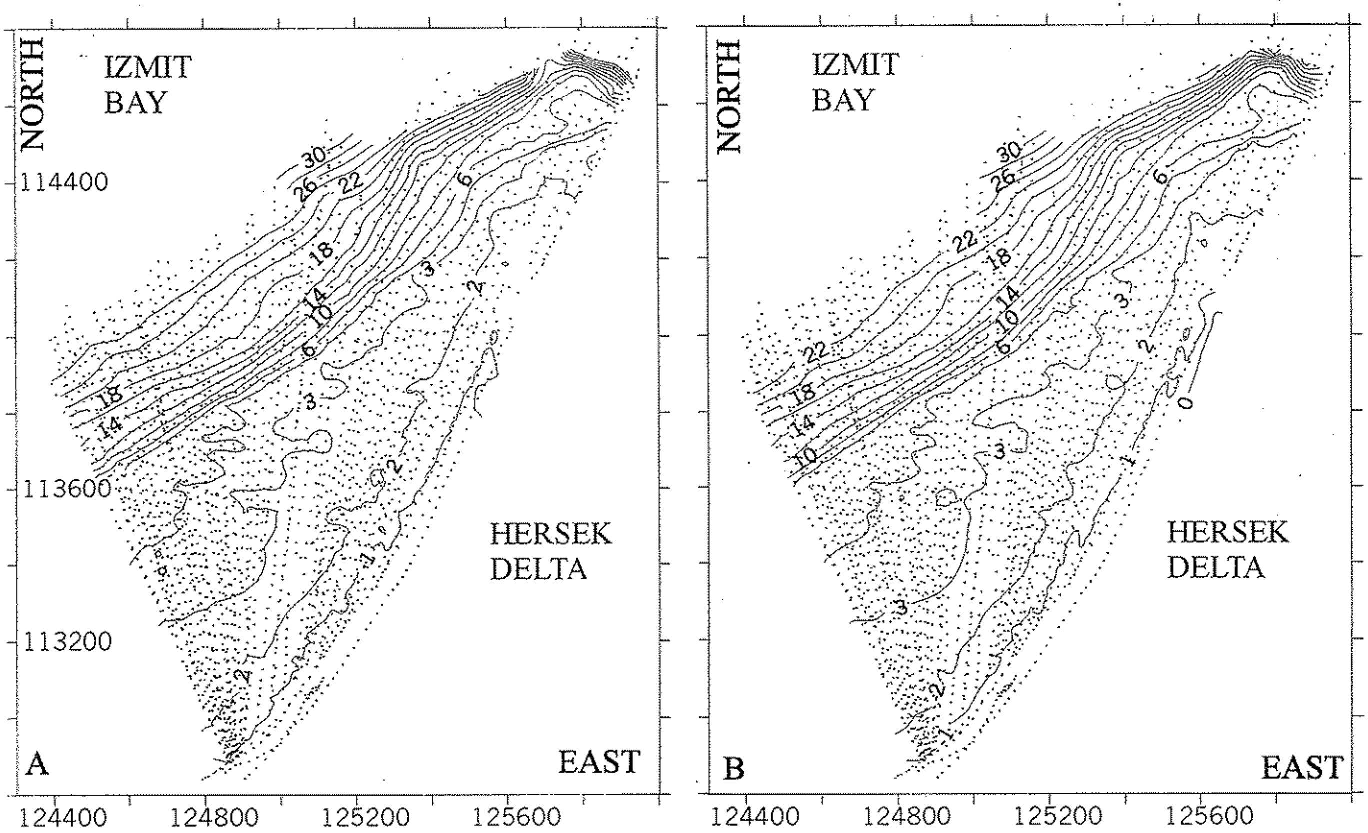

Figure 2. Detailed bathymetric maps of the Altınova study area (Case I) obtained from the surveys conducted A) before (March 1999) and B) after (January 2000) the 1999 Earthquake. Soundings (>2500) were plotted to see measurement density.

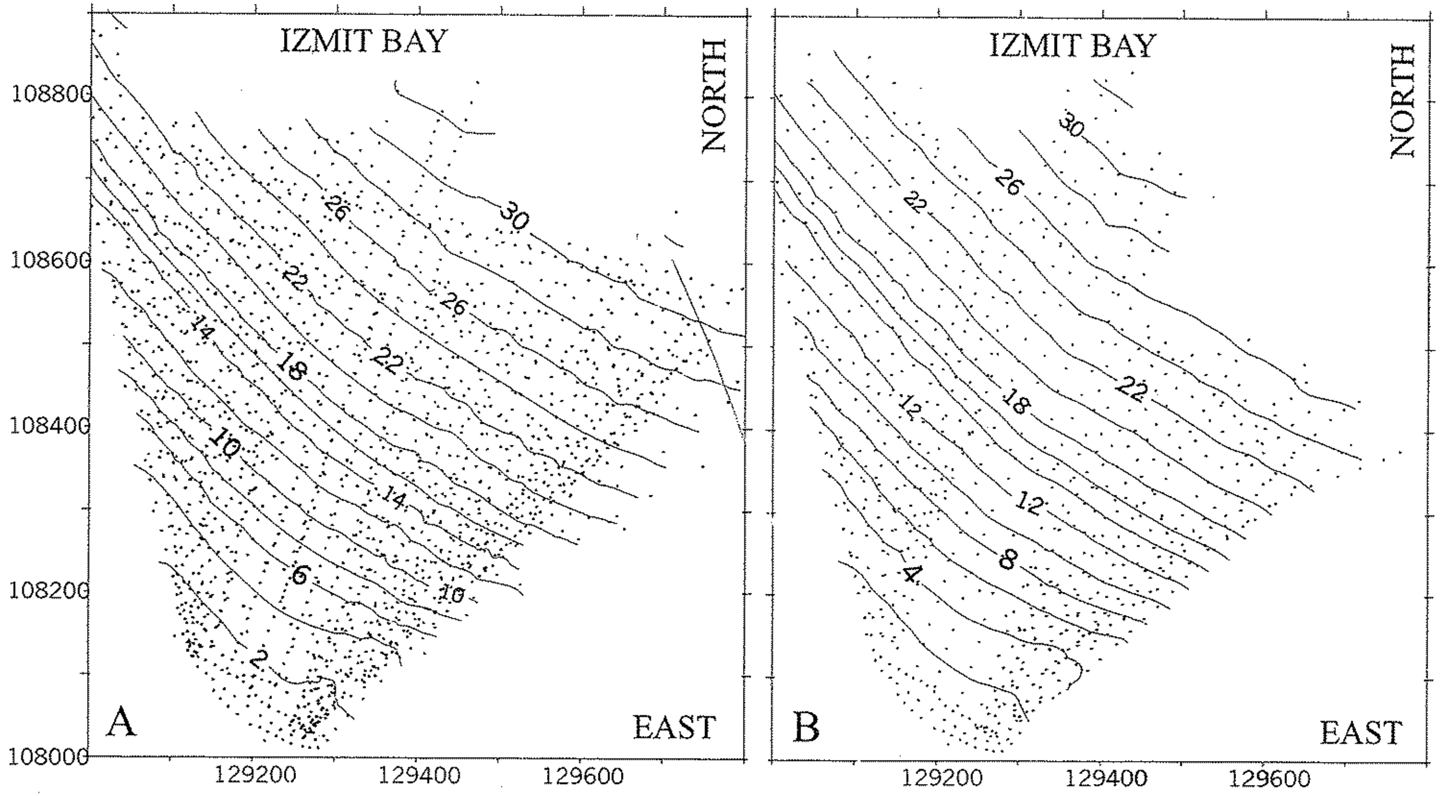

Figure 3. Detailed bathymetric maps of the Karamürsel study area (Case II) A) before (March 1999) and B) after (January 2000) the Kocaeli 1999 Earthquake. Depth soundings (>1800) were also plotted to see density of soundings.

water depth), loose sandy shells (4-12 m water depth) passing downward to denser shelly sands (12-22 m water depth) and sandy silty clay (deeper than 22 m). All these units unconformably overly a hard silty clay bedrock (early middle Pleistocene) (Alpar and Güneysu, 1999).

On the basis of comparison of the bathymetric charts obtained before and after the earthquake, the depth differences might be as high as 50-60 cm. On the central axis of the fan-shaped study area, differences are as high as -52 cm (deepening) and +10 cm (shallowing). Because sufficiently away from the main interest, i.e. central axis, the soundings may not be overlapped along the periphery of the study area. Therefore larger differences along the margins (Figure 4) should not be considered. Without considering marginal areas, a subsidence is a matter of fact especially along the 2.5-3 m depth contour (Figure 4).

If we neglect the depth measurements errors which could not be reduced, the differences between the surveys, at first sight, may be related with the 17 August 1999 Earthquake. The southwestern termination of the Yarımca-Hersek fault segment, which is oriented NEE-SWW in the central basin and cuts through the study area, may exhibit another explanation.

However, the composed effect of error sources is not a simple average of individual errors, but their integration. Therefore the total depth measurement error should be expected at least as high as the calculated differences between the cruises. Therefore, the differences could not be directly related to the tectonic or morphologic variations in the seafloor. Some systematic variations should be looked for in the depth difference. In this case, it is rather difficult to identify any important systematic variations in the calculated differences.

In any case, if the calculated differences are solely due to tectonic forces, the results may be explained by a possible subsidence. Another explanation is settlement or creeping of the loose surficial material (mainly sandy shells dominant at water depths 4 to 12 m) down to deeper areas.

Case II (Karamürsel) : A narrow (~250 m) band of sea floor with water depths less than 8 m consists of gravel, shally fine sand and silty sand. They pass downward to silty clay and sandy silty clay (10-25 m water depth). All these layers overly unconsolidated fossiliferous silty clay, sandy silty clay bands, clayey silty sand layers, rich sandy gravel levels and slightly-folded hard clay bedrock (early middle Pleistocene) (Alpar and Güneysu, 1999).

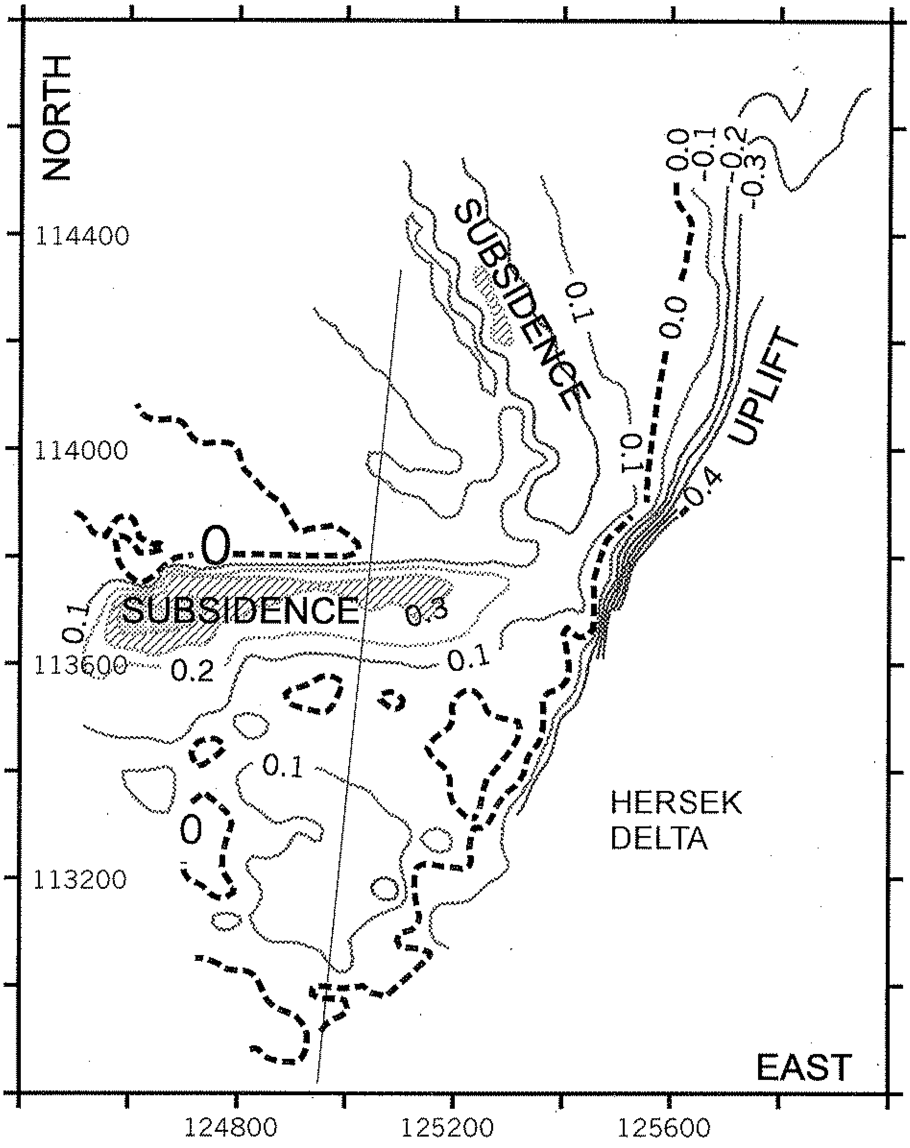

Figure 4. Bathymetric depth difference for the Altınova study area (Case I). Positive values stand for deepening.

Comparison of the bathymetric charts obtained before and after the earthquake indicates that depth differences (Figure 5) may vary in the study area. They may even be positive or negative, representing shoaling and deepening, respectively. On the central axis of the area, the differences are as high as -21 cm (deepening) and +65 cm (shallowing). Even these differences are partly within the measurement error limits, in this case, they are characterised much better by their distributive order and systematic. For example, deepening (20-40 cm) can be observed to the southwest of the NW-SE trending 7-9 m depth isobaths, while shoaling is a matter offshore part of this line. Therefore, if irreducible depth measurement errors are in negligible order, the differences between the cruises may be related to 17 August 1999 Earthquake.

The increment of the depth differences seaward rapidly may indicate a regional tilting. This tilting may be due to a regional tectonic uplift at the western side of the Hersek Delta, as a result of its westward shift on the soft sedimentary units, together with the southern block which moved westward during the earthquake. In addition, considering other dip-slip movements along İzmit Bay (e.g. Kavaklı and Kiler Point faults as given by Altınok et al., 1999) which occurred during the earthquake, about 30 cm of these upward variations on the seabottom may be related to tectonic events.

It is also known an important vertical subsidence occurred during the 17 August Earthquake in Ereğli Fishery Port, southeast of the survey area for Case II. Cracks were observed in the reinforced concrete wave wall which moved seawards about 10 cm. The 230-m-long breakwater suffered from settlements. The vertical displacement was measured as much as 1 m (Yüksel et al., 2001).

Conclusion

The most important of the depth error budgets in precise bathymetric surveys is water level changes. Therefore, sea level changes were precisely measured during both surveys before (March 1999) and after (January 2000) earthquake. In both cases, the range of these variations are in the order of 10 cm on daily basis and within 35 cm throughout the surveys. Since all sea level changes were observed carefully and corrected, considering the formula of

$$Stm = \pm(0.06+0.003d),$$

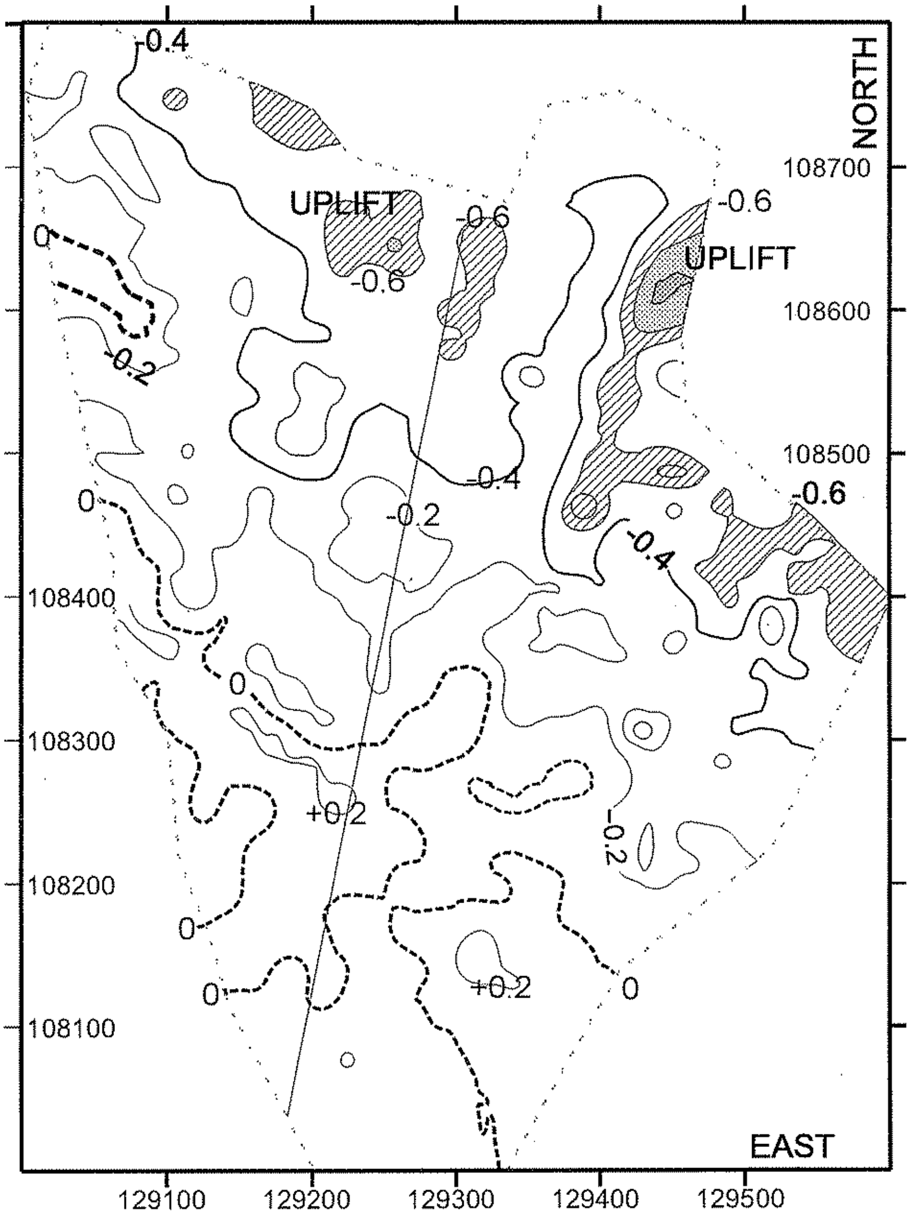

Figure 5. Bathymetric depth difference for the Karamürsel study area (Case II). Negative values stand for shallowing.

the maximum expected error in the water level corrections is in the order of ±6-15 cm, where d is the water depth in metres. The rounding error of tide gauge readings (Svr) can be added to these figures as ±2 cm.

Since bar checks were performed on the daily basis, depth error budgets coming from instrumental calibration, static draught measurements, sound velocity calibration may be assumed to be low enough. Total depth errors due to vertical and lateral variations of sound profiles (Sv), and rounding error of their readings (Svr) are in the order of ±0-12 cm, considering that each of them is in the order of 0.2% of the water depth, which is maximum 30 m in the survey areas.

The error in echo travel time (Sd) is in the order of ±10-19 cm, and the error due to pitch and roll (Sp) is in the order of ±0-9 cm, considering the formulas given below;

$Sd = \pm(0.10+0.003d)$,

$Sp = \pm 0.003d$.

In addition, other depth error budgets can be considered as ±10 cm for errors in reading transducer depth (Sdm) and heave (Sh), ±10 cm for errors due to temporal variations in the research vessel's draught, settlement & squat variations and their estimation, ±3 cm for transducer depth measurement, and ±3 cm for vertical datum measurement.

These estimations are within the standard error (±28 to 46 cm for maximum water depth of 30 m) given by the general formula of

$$S = 0.28 + 0.006d$$

and are in good agreement with the standard depth measurement error given by Alper ve Bossler (1985), which is between 0-30 cm for water depths less than 30 m.

If we consider all these depth error budgets, the depth differences obtained for Case I (Altınova) do not exceed those that could be attributed to the combined margins of the surveys and the methods of analysis, thus implying that the depth differences could not be easily related to tectonic deformations. However, if this is the case, in other words if a tectonic deformation is a matter, this may be explained either by a possible subsidence or by sliding of the surficial muds downwards.

On the other hand, allowing for the probable accuracy of the survey data and the method of the analysis, reasonably systematic depth differences may mainly depend on tectonic deformations for the Case II (Karamürsel). Other higher frequency measurement differences come from possible depth error budgets.

Geological Estimation

All these results obtained in this tectonically complex area (Figure 1a), may not be claimed as having direct geological meanings. However, fortunately, the surveyed areas are placed on two main realms; Case I on Istanbul Block and Case II on Sakarya Plate. In other words, the surveyed areas were separated by the master fault which opens the Karamürsel sub-basin and cuts through the Hersek Delta.

Beyond all of the deformations caused by secondary surface-breaking ruptures, subsidence, coastal landslides and sea water inundation, our results support the idea that the bathymetric differences, especially as observed in Case II, seem to be real. In the Case I, the depth changes could not be directly related to morphologic variations in the seafloor. On the other hand, there are some systematic variations in the depth difference for the Case II, and they can be related with possible tectonic or morphologic deformations. In other words, 17 August 1999 Earthquake caused bathymetric changes, especially on the Sakarya Plate which moved westward relative to Istanbul Block.

Özet

İzmit Körfezi, Hersek Deltası yakın kıyısındaki iki ayrı sahada 17 Ağustos 1999 depremi hemen öncesi ve sonrasında detaylı hassas batimetrik çalışmalar yapılmış, değerlendirilmiş ve aralarındaki farklar hesaplanmıştır. Olası derinlik ölçme hataları dikkate alınarak bu depremin belirtilen deniz alanlarında yarattığı muhtemel tektonik deformasyonlar araştırılmıştır. Elde edilen sonuçlar sağ yanal ana fayın güneyindeki blokta daha önemli ve sistematik olmak üzere bir takım derinlik değişimlerini göstermektedir.

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