

# Acoustical imaging of the nearshore seafloor depositions and deformations, a key study for Western Istanbul, Türkiye

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## Abstract

To protect the sustainability of the benefits from seas and near coastal areas, which have under the effect of the very complex hydrodynamic conditions and intensive human activities, without disrupting the balance of nature, it is necessary to image the status of the seafloor features. Therefore, this study presents the deformations, depositional conditions, underwater constructions, and the other non-natural impacts on the seafloor of the nearshore area at western Istanbul (between Küçükçekmece and Büyükçekmece lagoons) where it intensely used by the citizens. The results of the study may provide some guidance for understanding the impacts and risk factors of uses that are or will be conducted in coastal and/or near-coastal areas. Construction planning for civil coastal structures and areas should be done in great harmony with nature, minimizing negative environmental impacts. Although sediment distribution in the area is generally quite complex, the current state of the region, wave action, hydrodynamic conditions, the amount of material transported from the land, and bathymetry are important influencing factors. The seafloor has been damaged primarily by anchor deformation and associated bottom scanning, as well as disturbing trawl tracks. The seafloor was observed as partially shallowing near the constructions (such as natural gas pipelines, fishermen's shelter, and port piles) of coastal areas and associated with sand deposits. Therefore, scanning the seafloor using side-scan sonar may provide valuable frequency data to prevent future disruptions.

**Key words:** port activities, sediment classifications, side scan sonar, sub bottom profiler, coastal protection

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## 1 Introduction

Acoustic seafloor characterization, which enables to map the wider areas faster, has been a very useful tool for the imaging the seafloor features and provides important data for marine geology studies, hydrography, marine engineering, and environmental sciences etc. The advantages of high-resolution seafloor imaging with large swath widths compared to conventional seafloor sampling methods (such as grab, core sampling, Bull et al., 1998) are saving time from the survey and minimizing the costs. However, especially for the sediment distribution mapping studies, the different reflections from the seafloor should be identified with the conventional methods or previous studies, if enabled.

The side scan sonar (SSS) system, which provides high-resolution imaging of the seafloor with nearly photographic quality and great swath range, is one of the effective acoustic methods. It is beneficial for detecting geological structures (such as outcrops, faults) that cause acoustic differentiate on the seafloor and also very useful in the sediment (sand, clay, gravel, mud, etc.) classification of the seafloor according to backscattering strength (Richardson et al., 2001; Briggs et al., 2001; Goff et al., 2004; Ferri and Flood, 2006; Buscombe, 2017). Finer sediments that have high porosity, low density and sound velocity can be determined by the low backscatter intensity. In contrast, coarser sediments that have lower porosity cause increases in both density and ve-

locity and therefore are more likely to result in higher backscatter intensity. There are important caveats to consider with respect to grain size effects on backscatter intensity including, the possible presence of near-surface gas in muddy sediments that can result in increased backscatter intensity (Borgeld et al., 1999, Fonseca et al., 2002). Similarly, fine-grained surface sediments underlain by subsurface layers of coarser sediment can exhibit high acoustic backscatter intensity because of subsurface changes in impedance contrast. The presence of subsurface inhomogeneity induced by bioturbation can also result in high backscatter intensity in fine-grained sediments (Urgeles et al., 2002). Seabed surface roughness is an important variable to consider with respect to high-frequency acoustic backscatter intensity and has been investigated by several researchers (Stewart et al., 1994; Briggs et al., 2001; Richardson et al., 2001). The effects of roughness on backscatter intensity vary depending on the type, magnitude, and orientation of roughness as well as the frequency of the acoustic signal. In addition, using SSS is very useful in detecting wrecks, ruins, and deformations on the seafloor (Barnhardt et al., 1998; Grindlay, 2009; Collier and Brown, 2005; Dumanoğlu, 2014).

Sediment transport, deposition and erosion mechanisms are particularly effective in wave shoaling, breaking and surf zones. The usage of the coastal and near shore areas caused changes on these hydrodynamic affects. Throughout history, civilizations

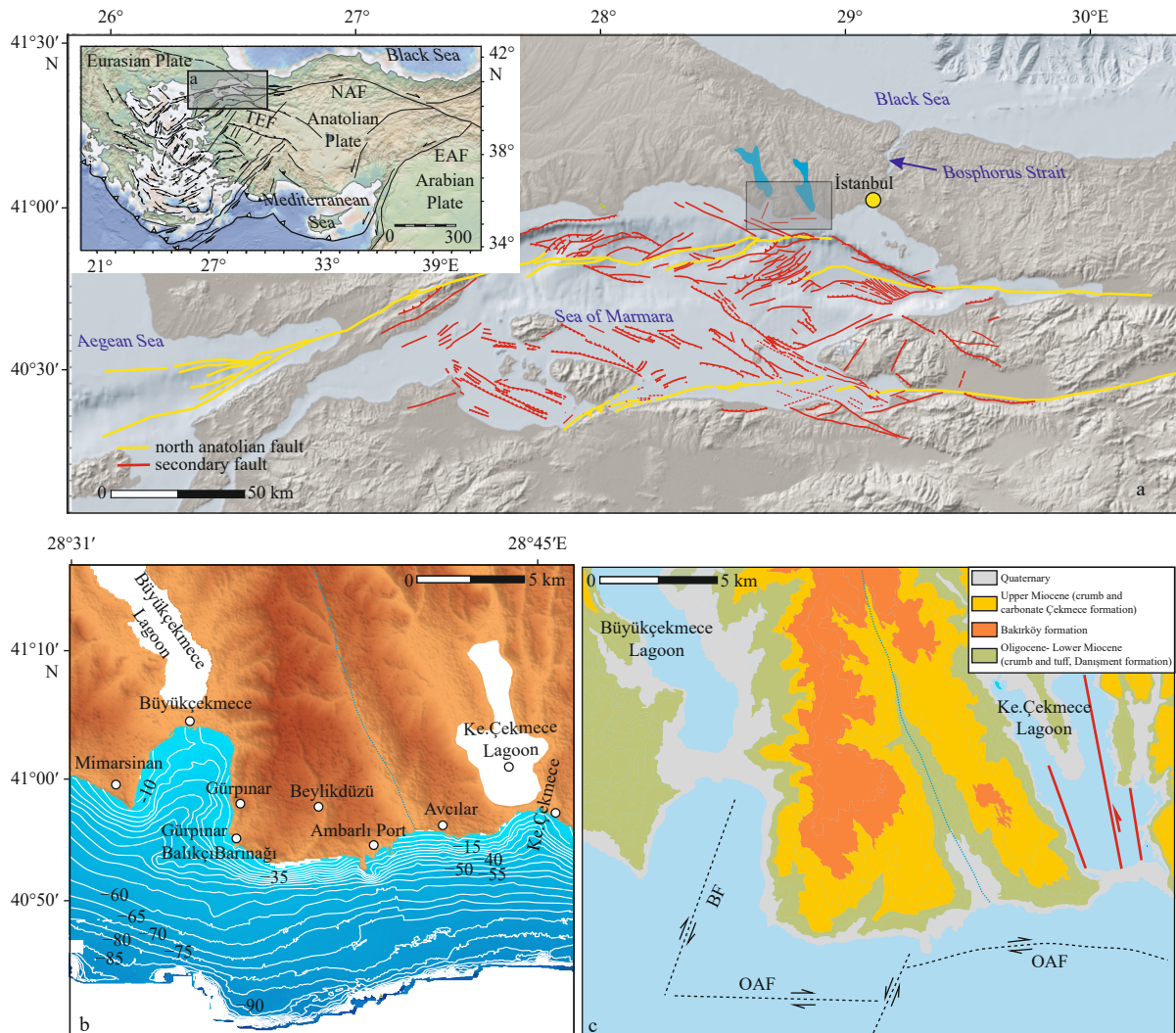
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have generally preferred to settle close to coasts because the sea is an important source of food, energy useful for transportation, and other marine economic fields. It has been an important and intensively used area in the world for a long time since it plays an important role in the social economy (Arthur, 1996; Auer, 1997; Chen, 1998; Cicin-Sain and Knecht, 1998; Gayr and Klee, 1999). On one hand, the deltas formed by the deposition of the terrigenous materials carried by the rivers in the coastal areas and the productivity of these soils were the biggest factors for the settlements in these regions. On the other hand, the mooring effects of large and/or small boats, ships, etc. that play a role in maritime trade, mostly cause deformations and abrasions on the seafloor. In addition to the deformation and abrasion on the seafloor and near the coastal areas sourced to the construction of the coastal engineering structures such as fishing port area, marinas, and breakwaters, can cause formation of morphological structures such as sand bars, barrier islands and/or disappearance or sudden appearance of beach areas. These are the main problems about the usages of the coastal areas because shallowing of the sea caused problems on ship traffic, changes of the beach areas are the directly related with the coastal management and tourism; the seafloor deformations or formation of the sandbars, barrier islands provided significant changes on the habitat. There-

fore, understanding, revealing the occurrence, and offering scientific solutions to these problems are becoming more and more important.

To protect the sustainability of the benefits from our seas and near coasts, which have very complex hydrodynamic conditions without disrupt the balance of nature, it is necessary to approach the problem scientifically by considering the environmental effects. Therefore, the construction planning of coastal civil structures and zones should be done coherently with nature and be eco-friendly, and so the minimum environmental impact should be taken into consideration.

The main purpose of this study is to define the seafloor features in the nearshore marine areas that are currently in intensive use, determine the anthropogenic impacts and reveal the effects on the seafloor. Thus, this study will be an important reference for understanding the effects and risk factors of the usages that made or planned to be made in coastal and/or near coastal areas. For this purpose, coastal marine areas at western Istanbul (between Küçükçekmece-Büyükçekmece lagoons, Fig. 1) was chosen as a study area because of its high level of settlement which has been used extensively as social life and trade center from past to recent. Furthermore, pressure of terrestrial input, ship traffic, marine engineering structures, and port activities



**Fig. 1.** Location (a), bathymetry (b), regional geology maps (c) of the study area (modified from Alp et al. (2018)). NAF: north Anatolian Fault, EAF: east Anatolian, TEF: Tharace Eskişehir Fault, BF: Büyükçekmece Fault, OAF: Offshore Avcılar Fault.

also lead to the selection of this study area.

## 2 General definition study area

The coastal area between the Küçükçekmece–Büyükçekmece lagoons of Istanbul has a length of about 20 km and has attracted the attention of humankind in tourism activities, industry, maritime trade, fishing, etc. for centuries. These lagoons are ancient estuaries and connected to the Sea of Marmara through narrow canals in the region (Salar et al., 2021). Their connection with the sea was cut by the sand bar, which were formed by currents and wave systems and lagoon conditions created in the early 20th century with man-made reinforcement barriers. An ancient port was reported (Öniz et al., 2014) between these lagoons which had been settled between these lagoons during BC 4th to AC 10th centuries. In addition, the ancient city of Bathonea was reported in the Küçükçekmece Lagoon (Aydingül, 2013). Ambarlı harbor, west Marine Marina, Gürpınar fishing port, associated breakwater structures and pipelines at the recent constructions placed on the seafloor and the coast.

The shelf of the study area is generally low sloped, it suddenly deepens from the shelf break with a high slope and is compatible with the general morphology of the Sea of Marmara (Gazioğlu et al., 2002). The widest shelf which covers approximately 15 km is among the Büyükçekmece Bay and offshore extensions of the river outputs from the coast can be seen in Fig. 1. Subhorizontal sea bottom morphology has irregular bathymetric features and narrow canyons around the lagoons of Büyükçekmece and Küçükçekmece. Due to the valley structure in Büyükçekmece Bay, the submarine morphology is unique to the northern Marmara Shelf (Ergintav et al., 2011; Nasif et al., 2019). The valley's formation had been controlled by an inactive fault and it is the major evidence that shows the ancient stream coming from Büyükçekmece Lagoon (Vardar et al., 2018). The region offshores the gulf of Büyükçekmece bay has a complex morphology if compared to the region offshore the lagoon of Küçükçekmece. Rock outcrops identified in seismic datasets (Alp et al., 2018) indicate tectonic compression and high erosion. The depth of the outcrops is at 85 m and are presented as wave-cut terraces (Alp et al., 2018). The outcrops on the edge of the Büyükçekmece valley are also associated with the decreasing on the sea level and are at the same levels as the old deltas around the Büyükçekmece valley (Vardar et al., 2018).

## 3 Material and methods

The acoustic reflection dataset was acquired with the DeepVision DE3468D Dual CHIRP Digital 340/680 kHz SSS system in 2017. To provide high quality dataset by considering the features of seafloor morphology, the 340 kHz frequency and 128 000 baud-rate operation settings were utilized. Wavelength is about 4 mm, theoretically minimum along-track resolution is of about 1.5 cm (calculated assuming a horizontal beam width 0.9°) and swath-range is 150 m (total 300 m). The 6 m long zodiac boat was used, and the boat speed was fixed as an average of 2–2.5 knots. In the study area, SSS data were collected in accordance with the coastal morphology as permitted by ship traffic (Fig. 3).

The following basic data processes were applied to the SSS data. Pre-processing, the conversion of the recording format to the program format. Main processing, this process covers radiometric (calibration), mosaic processes. Post-processing, it provides to increase the quality by eliminating noises.

The seafloor sediment identification was made according to Barnhardt et al. (1998), the definitions of the main units' reflection

**Table 1.** Acoustic returns and the outcrop features of the seafloor formations

Map unit	Acoustic reflection intensity	Outcrops features
Mud (M)	weak	smooth flat
Sandy Mud (SM)	weak	smooth flat
Muddy Sand (MS)	medium	smooth flat
Sand (S)	medium	smooth flat
Gravel (G)	strong	low relieve often covered with ripples or boulders
Rock (R)	strong	high relief, fractures common

are given in Table 1.

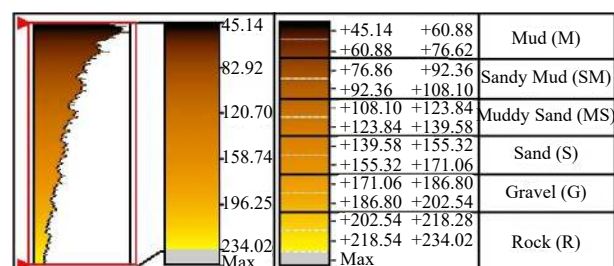
Also, the intensity values obtained by the acoustic signals produced by the side-scan sonar reflecting from the seabed and returning to the receiver vary according to the sediment unit. These value ranges are in different colors and each range shows a different sediment unit (Fig. 2). These unit ranges were obtained from the SonarWiz program (Pratomo et al., 2018). These reflections and amplitude values were determined from the collected acoustic data. Afterwards, the boundaries where they overlapped and correlated with previous studies were mapped.

Depending on the reflection intensities (weak to strong), the color scale ranges from very dark brown to light brown. The intensity of reflection and the darkness of the color are inversely proportional, and the seafloor formation with the weakest reflection density and the darkest color is “Mud (M)”. Depending on the decrease in the reflection density and the gradual lightening of the color, the sediment sequence continues as “Sandy Mud (SM), muddy Sand (MS), Sand (S), and Gravel (G)”. The seafloor formation with the strongest reflection intensity and the lightest color (light brown) is “Rock (R)” (Table 1, Fig. 2).

The sediment distribution maps of the study area, which were previously presented in Oktay (1998), Olgun (2001), Alpar et al. (2014), were used for the ground trawling of acoustic data. Those maps were acquired from the conventional sediment sampling methods, and the gaps between sampling locations were filled by the computer interpolations. According to the correlation of two data sets (acoustic and sediment sampling), the borders of the different sediment formations can be mapped more accurately.

The bathymetry map of the study area given in Fig. 1b was obtained from high-resolution seismic data, which were previously published by Nasif et al. (2019), Vardar et al. (2018), Alp et al. (2018). This map can be able to show only the main morphological structures such as valley in Büyükçekmece Bay according to the coarse resolution due to wide spaces between seismic profiles.

A sub bottom profiler (SBP) acoustic dataset to supplement the SSS dataset and identify deformations in the study area was also used. The SBP provides continuous high-resolution seismic images of the upper sedimentary layer from the seafloor to an av-



**Fig. 2.** Acoustic returns of the seafloor formations.

erage depth of 30 m and is widely used as one of the main methods in high resolution seafloor surveys (Nasif et al., 2019). The SBP used in this study was obtained using the BATHY 2010P engineering seismic system, which generates CHIRP signals in the 275–675 kHz band range. Position information was recorded simultaneously with the Magellan Proflex 500 scientific GPS on the header of the data via the seismic system. The tolerance of the system, which receives the position information from 20 satellites simultaneously, is  $\pm 1$  m. The obtained data with odc extension were converted to SEG-Y format in the system's own program, filtering and amplitude gain were applied to the data using the kogeo seismic toolkit (v. 2.7). Time (ms)-depth (m) conversions were made using 1 500 m/s for seawater and near-surface sediments (Aksu et al., 2016).

#### 4 Results and analysis

Approximately 250 km of side-scan sonar data and three seismic profiles were collected in the study area (Fig. 3). The reflection intensity (Fig. 2), acoustic returns (Table 1), and spatial distributions of acoustic data at the southern shelf of Istanbul (between Küçükçekmece-Büyükçekmece lagoons) allowed mapping of natural formations, civil engineering structures, and the deformations and morphological formations from port activities.

##### 4.1 Seafloor classification

Gravel and mass transport deposition units are prevalent whole study area and determined at 0–2 m water depths. Sand reflections were generally recognized between 0–5 m in the water depths at near coastal areas of Büyükçekmece Bay, between Ambarlı harbor and Gürpınar fishing port, between Ambarlı harbor and Avclar fishing port and nearshore of the Küçükçekmece Lagoon. However, the sandy units were distributed between 5–18 m water depths in Küçükçekmece Lagoon, the rest of the shal-

lower areas were covered by benthic habitats possibly connected to sunlight up to a depth of 5 m.

Towards from Büyükçekmece bay to the Gürpınar fishing port, at 5–10 m water depths, the reflection of the sandy mud unit is dominant and covered approximately 0.5 km to 1 km spatial area from the shore. This formation is getting narrower from west to east in accordance with the sea-bottom morphology. The muddy sand unit reflection that extends to Küçükçekmece offshore, covers the area up to the 20 m water depth and sandy mud unit reflections are determined in the areas deeper than 20m. Sandy Mud formation was dominantly observed at the center Büyükçekmece bay, in an area of approximately 10 km<sup>2</sup>. Mud formation was observed predominantly in Büyükçekmece bay and Gürpınar-Küçükçekmece (after about 1 km). Terrestrial debris flows (Fig. 4) were also observed along the entire coast. A small sea-floor deformation is observed on the riverfront near Gürpınar/Büyükçekmece (Fig. 5). In the east of Gürpınar fishing port, it has observed a possibly active sandbank structure, which is 100 m long, 10 m wide with a height of 0.5 m.

##### 4.2 Non-natural traces on seafloor

Artificial coastal structures constructed by humans and related acoustic impact reflections on the seafloor are given in Figs 6–8. The study area is highly used for ship transportation and fishing because of westmarine marina, Ambarlı Port, fishing ports; therefore, ship traffic is highly intense and related sea-floor deformations are observed in the acoustic data. Especially offshore and nearby seafloor areas of Ambarlı Port are suffered from anchor damages that can be clearly observed as a linear line deformation. The anchor deformations observed generally show an area of about 5 km<sup>2</sup> in front of the Ambarlı Port and in an area of 2 km<sup>2</sup> in front of Küçükçekmece Lagoon (between 250–1 000 m water depths). There are also random anchor deformations de-

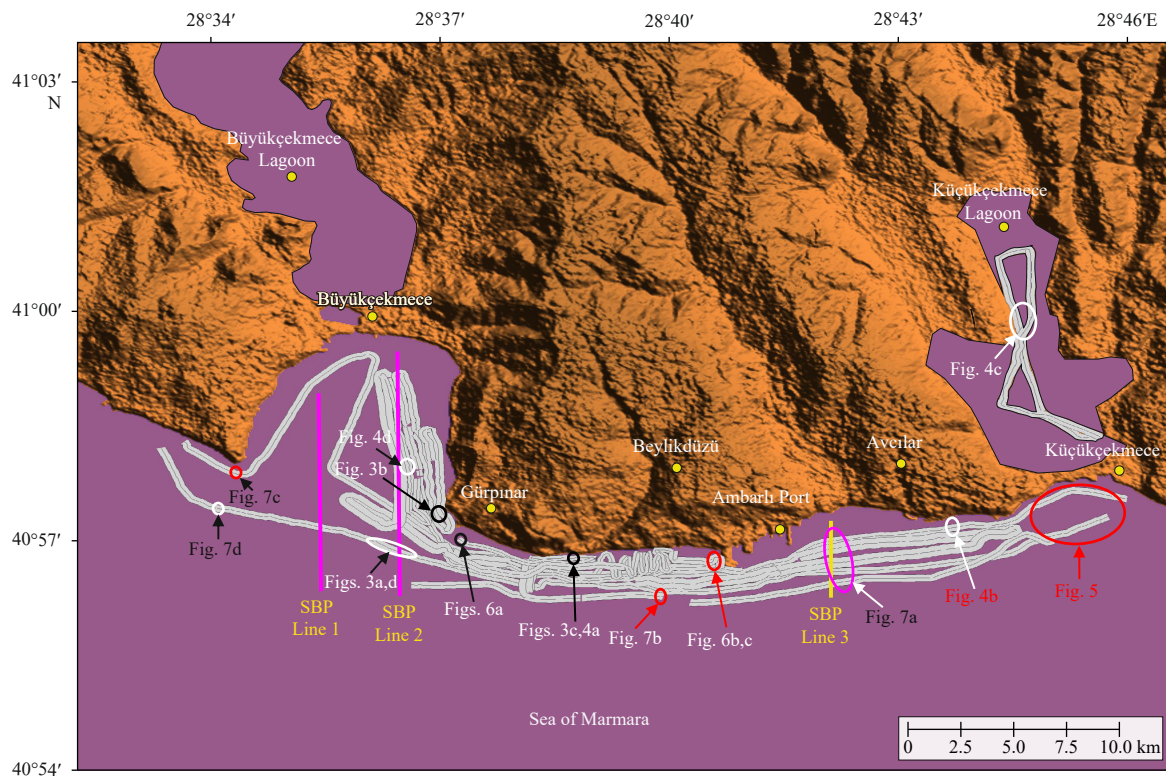
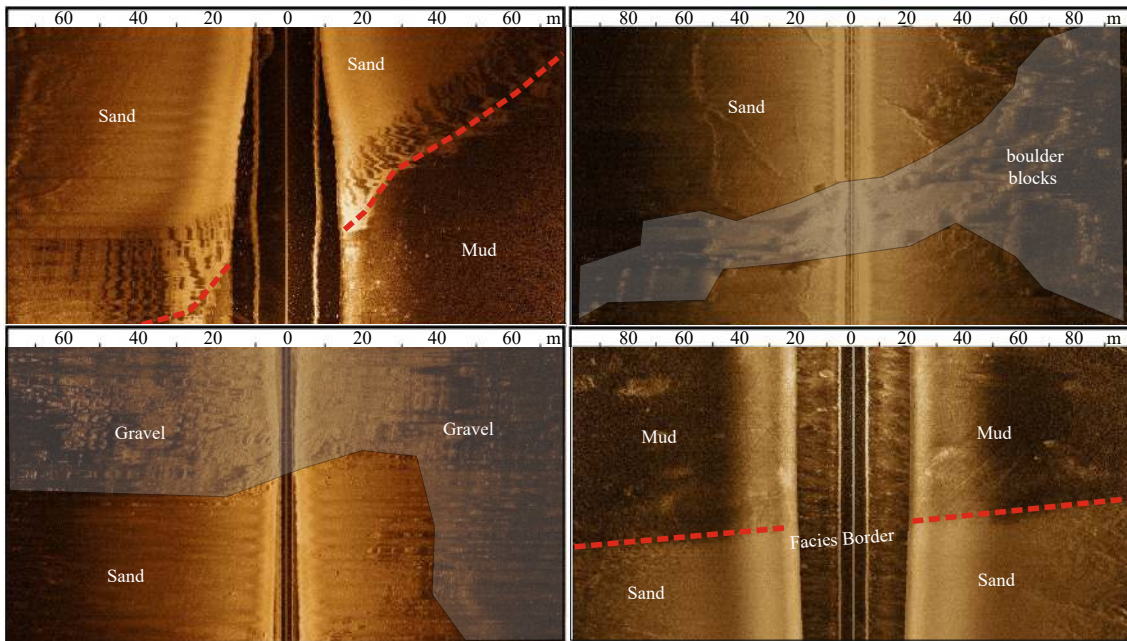
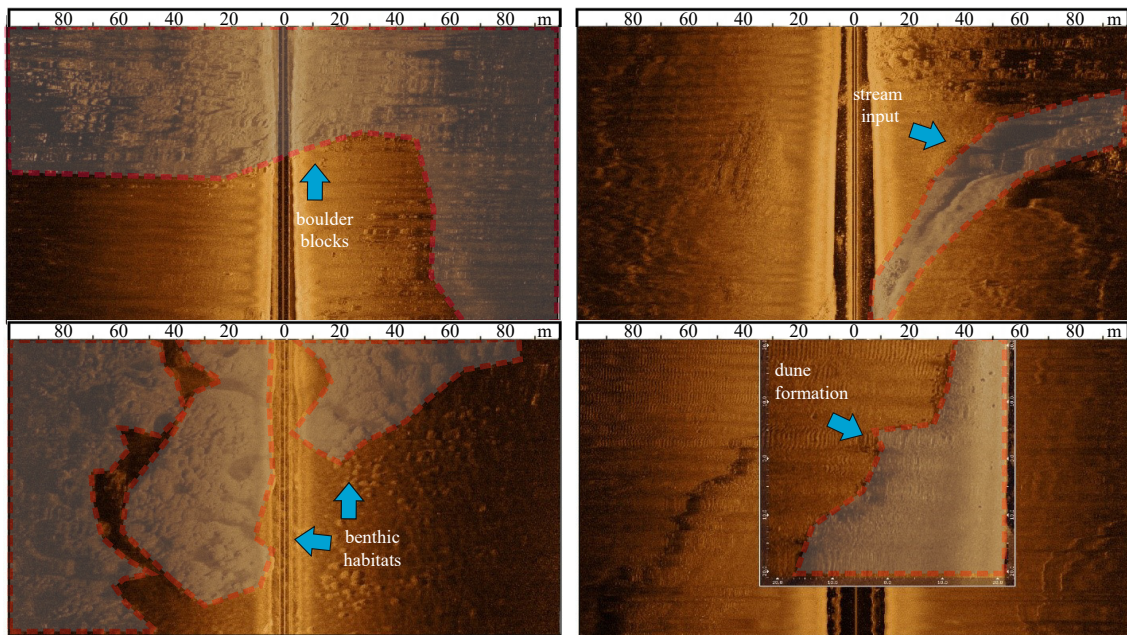


Fig. 3. The location map of the acoustic data (side scan sonar, and sub bottom profiler), and the mosaic map.



**Fig. 4.** Side scan sonar (SSS) ecograms showing the difference acoustic reflections.



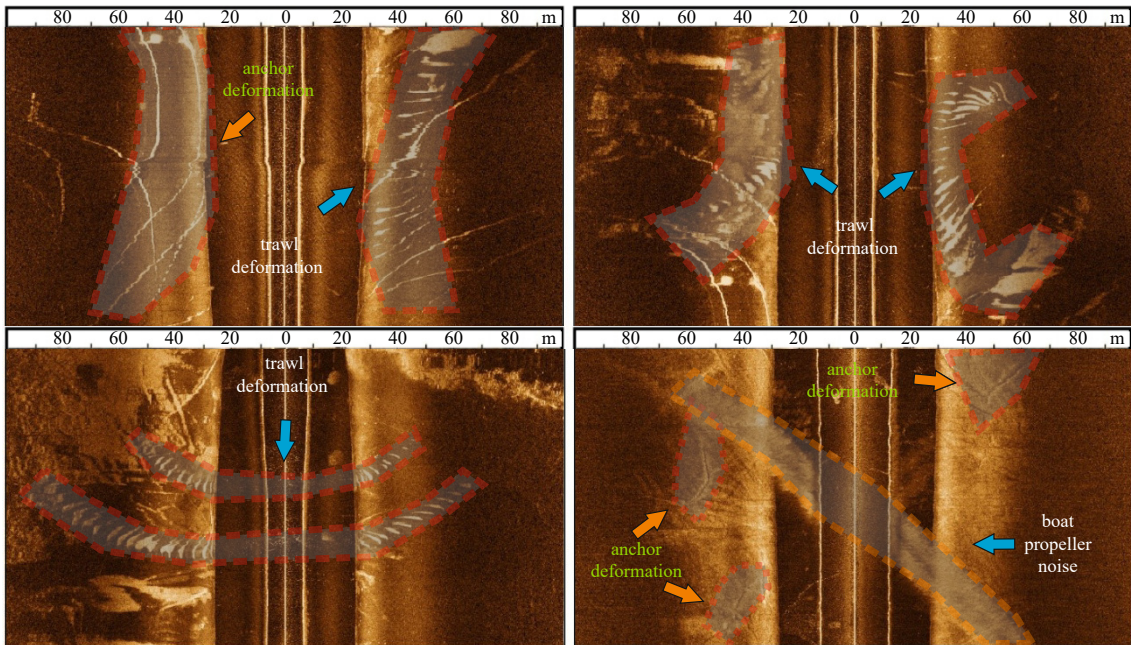
**Fig. 5.** Morphological structures formed on the seafloor.

terminated in Avclar, Gürpınar and Büyükçekmece bays (Fig. 6). In addition, the same directional deformation reflections, which consist of two parallel deformation planes and with parallel cuts in themselves, were encountered. These structures seem to consist of the impact of two elements at certain intervals on the seafloor. Due to this formation mechanism of the reflection, the possibility of trawling fishing in this area has been revealed.

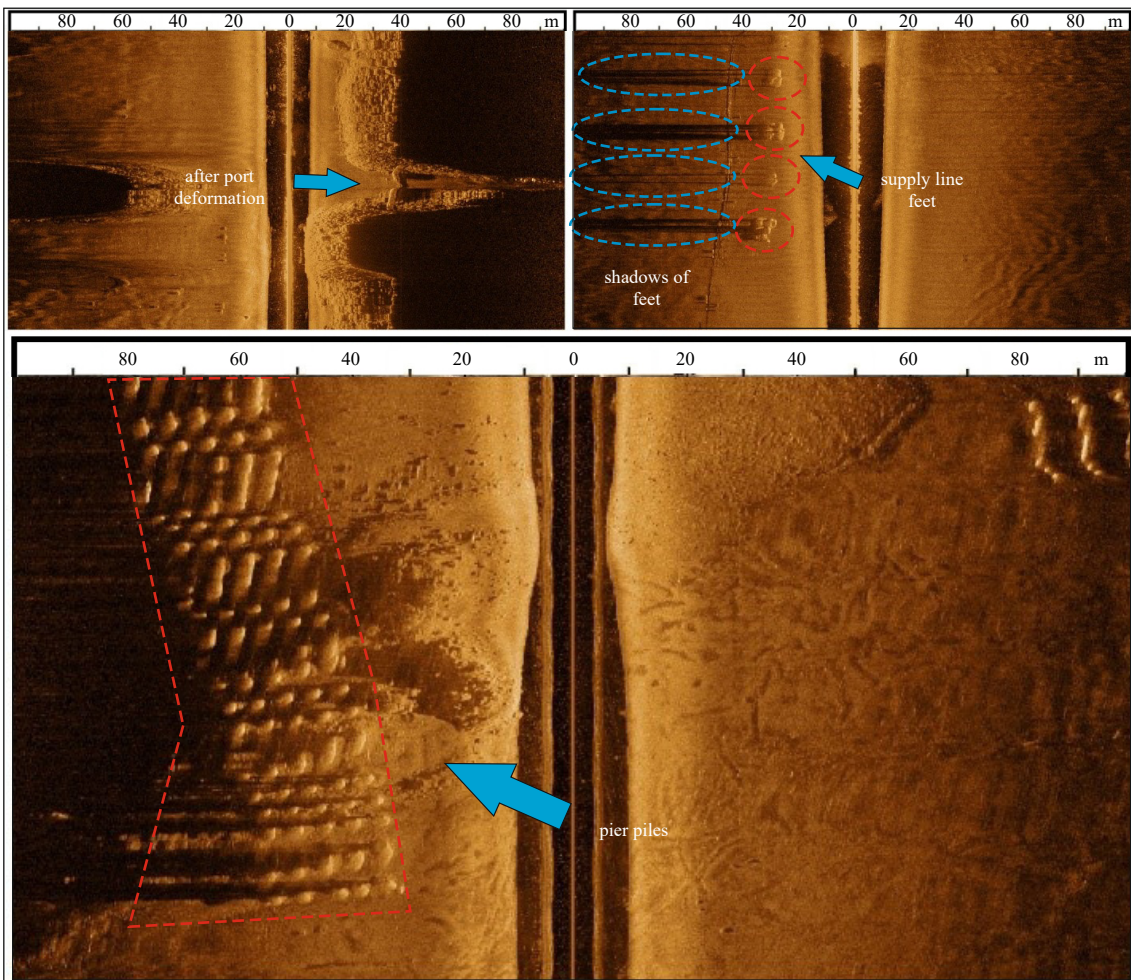
In places, the sedimentary units such as muds are randomly deformed as cut shortly or fluctuated from the sediment type. This reflection feature is generally observed at the near the ports and approximations at 0–5 m water depths and considered as the source of the pitch effect on the water loop and related distribution effect on the mobilization of the seafloor sediments. Seafloor interactions with engineering structures constructed in nearby

coastal areas (such as port feet, pipelines, fuel platforms) and deformation effects such as scraping the bottom while these structures were made, in addition, the submarine morphological elements (Fig. 7) were determined that can be formed and evolved due to the change of the hydrographic system. Traces of the engineering structures, effects of the ships and fishermen, deformations of the wastewater discharge, pipeline passages (natural gas, water, etc.), rubbles, etc., and shipwrecks are also strongly affecting the study area (Fig. 8) 30 m long and 7 m wide, reflection interpreted as a wreck is determined at the west of the Gürpınar.

In the seismic data obtained in the study area, formations of sediment types, outcrops, reefs, paleoshorelines, etc. on the seafloor were displayed according to reflection types (Fig. 9). Paleoshorelines are determined according to the reflection types



**Fig. 6.** Deformations caused by fishing and the boats on the seafloor (anchor and trawl web tracks).



**Fig. 7.** Port and supply line feet view.

and sediment truncations on the seismic profiles that indicate the sea level still stands. These levels are indicated as wave-cut

terraces at [Alp et al. \(2018\)](#). These areas are in the S-N direction in Büyükçekmece bay ([Fig. 9](#)) and Avclar offshore.

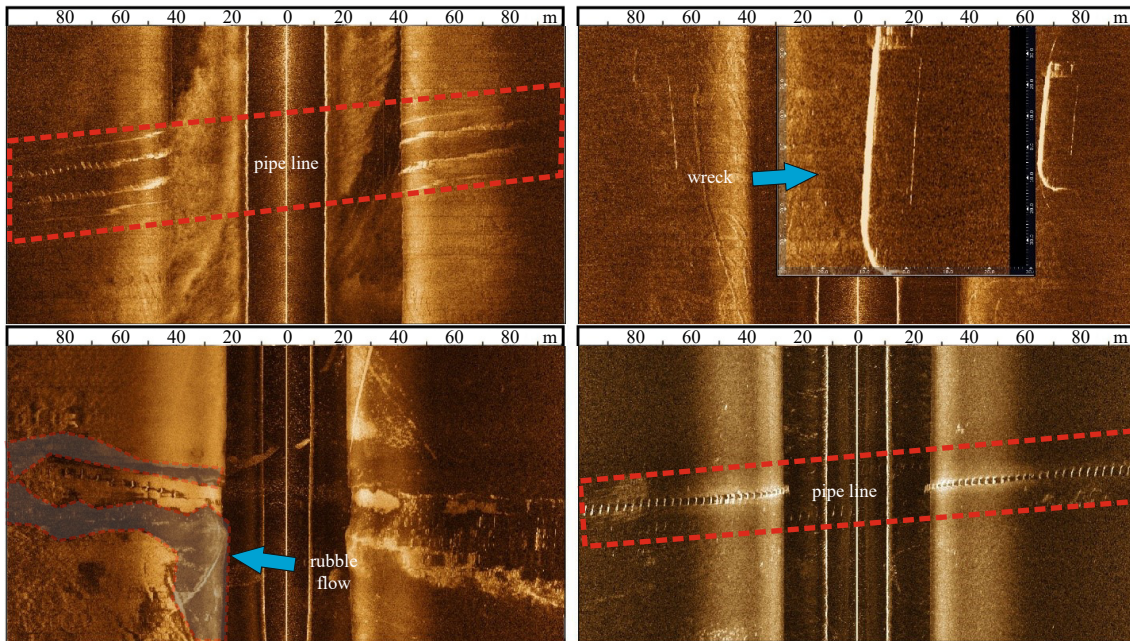


Fig. 8. Pipelines, wreck, and rubble flow images.

## 5 Discussion

The deformations and the different reflections of the sediments can be clearly identified from the SSS and SBP data (Figs 4–9). However, it is hard to say the sediment type according to only the reflections. Even if the reflection types are similar (Barnhardt et al., 1998), the reflection intensity values are different from other studies (Grindlay, 2009; Collier and Brown, 2005). It is clear that the grounding of the reflections should be done with sampling methods or maybe video captures. So, correlations with the sediment distribution maps previously given (Oktaç, 1998; Olgun, 2001; Alpar et al., 2014) were made in this study.

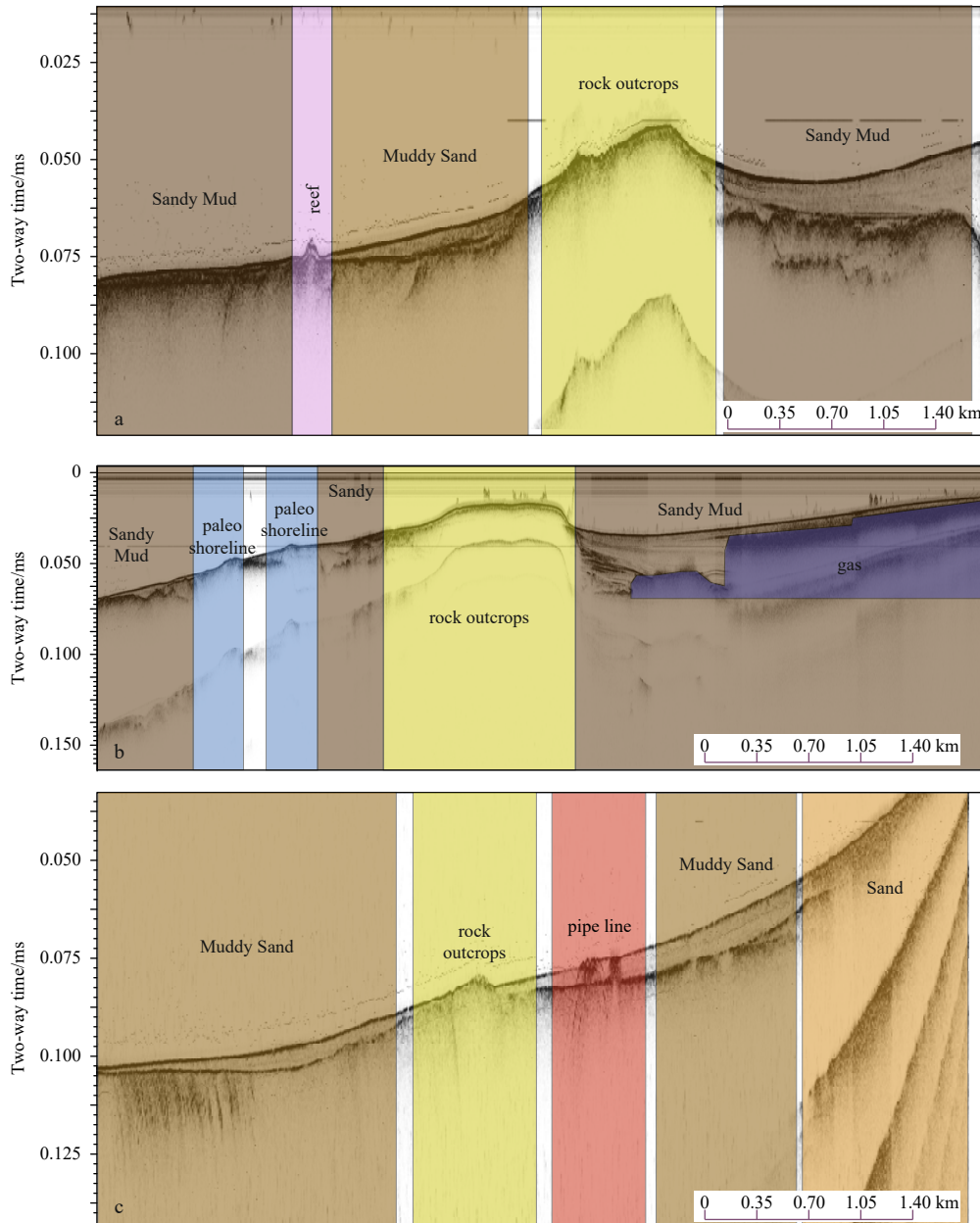
It is observed that “Mud (M), Sand (S), sandy Mud (sM), muddy Sand (mS), Sandy Silt, Silty Sand” unit groups are dominant in the region. There are also debris flows from terrestrial inputs along the coastline. SM type represent the most dominant sediment group in the region. This group is generally distributed in low slope deepening control and in areas deeper than 25 m in accordance with shelf morphology. It is also widely recognized in the Büyükçekmece valley. Sea-bottom topography, regional flow system and possible detrital intense input are main control effects of the sediment distribution. Relatively parallel sediment type distributions (Fig. 10) indicate that the longshore currents are dominant in the study area and play an important role in sediment distributions. This finding is relatively different from the mean sea level circulations given in Chiggiato et al. (2012).

Also, climate changes, waves and seafloor morphologies play decisive roles with current on sediment transportation, deposition, and erosion of the sediments with in general. According to local conditions, waves and streams erode the rocks in the coastal areas and cause coastal progression or sediment accumulation. Sediment reaches a dynamic balance in terms of mobilization. This process is due to thousands of years of influence from external factors such as wind, waves and currents and sources such as streams that feed them and eventually lead to material loss from them. When the balance occurs between these factors, both a stable shoreline and a stable sea bottom profile will emerge; no significant erosion (coastal regression) or accumulation (coastal progression) is encountered.

The presence sediments of the Büyükçekmece bay have different characteristics at the interior and nearshore. It can also be possible with these sediments originating from the coastal landslide, the tectonic movements the region has experienced from time to time and the longshore current system in the region (Yaltırak, 2002; Derman, 2004). The wide part of the seafloor between Büyükçekmece and Küçükçekmece lagoons are covered with the mud-dominant (M) sediments (Altınok et al., 2009). This may represent more stable and stagnant conditions for the longshore current system. This deposition character is also against Chiggiato et al. (2012). That shows the general surface circulation of the Sea of Marmara is not controlling the sediment distributions of the study area, which probably has unique deep circulations (Özgan, 2020).

The dominant material deposits that can be associated with landslide debris are prominently observed close to the shore in the Gürpınar region. The bottom current regime of the region prevents material accumulation between Büyükçekmece and Küçükçekmece, and the bottom flows of the Bosphorus limit the sediment transportation to the region due to the location of the bathymetric threshold at the front of Yeşilköy-Bakırköy. Dark and wide reflections are interpreted as topographical sea continuity of the coastal morphology. The sediment transport from Küçükçekmece Lagoon to the marine can be observed. The Küçükçekmece Lagoon floor consists of sediments with high cohesive and adsorption capacities (Algan, 1987), except for the southern part, which consists of a sandy bottom material. It is explained that the base material consists of coarse-grained sediments in the connection areas of the Küçükçekmece Lagoon compared to other regions, and the coarse-grained material is transported from the shore to the lagoon by the currents and winds entering the connection channel (Algan, 1987).

Port activities have heavily damaged the seafloor of the study area. These damages can be observed as: anchor deformation and associated floor dredging, destructive traces of the trawl fishing net, engineering structures built on the near shore and seafloor (such as natural gas pipelines, fishing ports, marinas, and harbor piles) and associated shallowing according to the sedi-



**Fig. 9.** Seafloor natural structures and formation types by seismic method (SBP Line 1) (a); paleo shoreline, gas, and formation types (SBP Line 2) (b); formation types, rock exposure and pipeline view (SBP Line 3) (c).

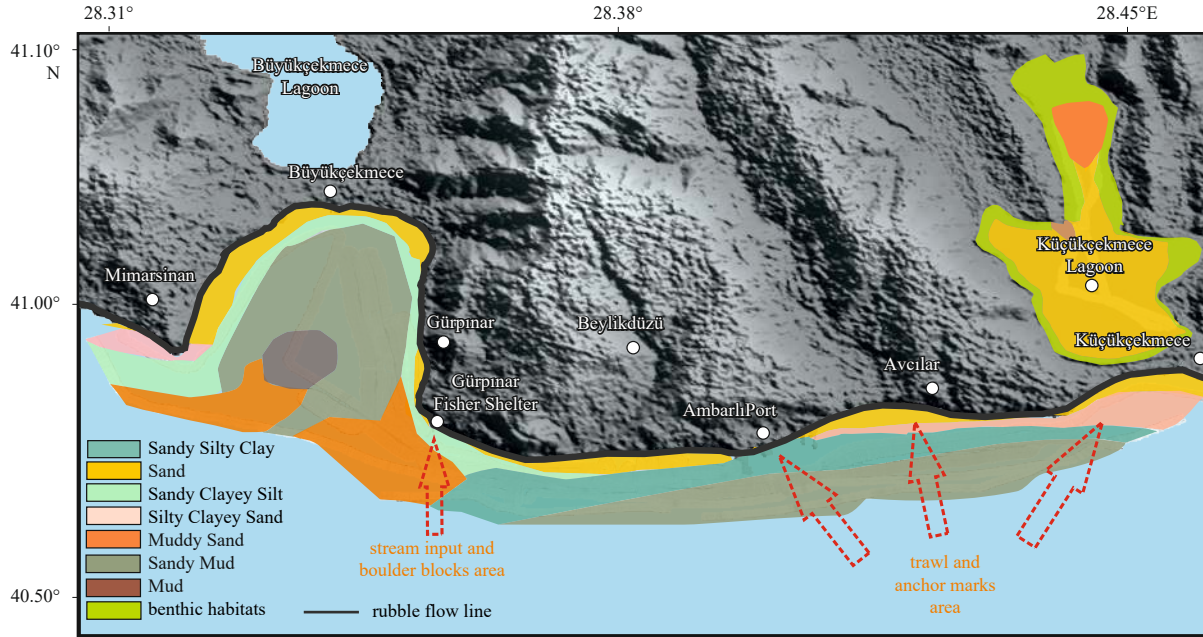
mentary deposition. The constructions affect marine species, which pose a serious danger to the seas. The most important factors that disrupt the balance of the coastal profile is the uncontrolled material drainage from the coasts and shores of the coast and the materials that feed the shore, such as dams and unconscious structuring. Erosion or shallowness, carvings or spurs from sea structures such as harbors, shelters, coastal walls and breakwaters are the best-known examples. Depending on all these, sediment transport changes along the coast and perpendicular to the coast and erosion and/or accumulation occur on the coasts. In this context, [Sari et al. \(2013, 2014\)](#) draws attention to the presence of anthropogenic pollutants in the study area and indirectly supports the findings of human origin in the region.

## 6 Conclusions

This study mainly focuses on presenting the acoustic identification of the sea-floor sediment classification of the nearshore

zone and the deformations caused by engineering structures and human-sourced impacts between Küçükçekmece–Büyükçekmece lagoons. Human-induced deformations and/or depositional conditions according to the intensive usage of the study area are presented in this study.

The distribution of the sediment reflections is highly heterogeneous in the study area, waves, hydrodynamic conditions, the amount of material carried from the land, and the variable bathymetry are the important factors on the accumulation and deposition of the sedimentary units. Structures built on the shore, in particular, affect the carrier properties of current systems and cause the formation of dune structures in their vicinity. These dunes are considered to be still active and will therefore become shallower in the near future, creating a barrier to marine traffic. This event reveals the importance of conducting detailed hydrographic and oceanographic research before these structures are built. It shows that the construction of such structures should be



**Fig. 10.** Seafloor sediment distributions and deformation map.

avoided, especially in areas where foreshore currents are dominant. In addition, erosion systems are active in those areas, likely preventing these dunes from being stored where they would normally be transported. As a result, a previously existing beach area may have vanished. Although this idea cannot be proven since there is no map showing the recent past in the region, it reveals how important the mapping of marine areas is. In this respect, this study will be an important reference and source of discussion for future studies.

Comparing the conventional methods, the study area can be imaged with wider swath, however, still gaps on the reflection map. Therefore, the sediment distribution map previously given in (Oktay, 1998, Alpar et al., 2014) was modified by overlying with SSS data and the re-draw manually. Thus, the weaknesses of the two methods were avoided, and maps that were more accurate could be obtained.

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