Sea-floor sediments and bedforms around Turkey, revealed by side-scan sonar imagery

Side-scan sonar
Sediment distribution
Bedforms
Northeastern Mediterranean
Bosphorus

Sonar à balayage latéral
Répartition du sédiment
Formes de dépôt
Méditerranée nord-orientale
Bosphore

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ABSTRACT

The use of side-scan sonar imagery to construct facies and bedform maps of an area of sea floor has been known for some considerable time. Such maps reveal the type of sediments and bottom morphology, allowing sedimentologists to infer the sedimentation processes.
Side-scan sonar imageries presented here were collected by an EG&G Mark 1B Side Scan Sonar System from the Mersin Bay, Akkuyu Bay, Anamur Bay, Teknecik Bay and the Strait of Bosphorus.
The distribution of the sea-floor sediments in the bays was found to be closely related to local sediment supply, waves and current dynamics, as well as the topography of the sea floor. The presence of bedforms such as sand dunes and sand patches indicates bedload transport of sediment. Relict features, such as gravel patches, beachrock outcrops and sinkholes, were believed to have been formed during lowstand of the sea level.
In the strait, gravelly sediments cover a great part of the sea floor. Sandy sediments are mainly concentrated in the channels on both sides of the sill. Occurrences of rocky surfaces and gravel patches indicate strong current activities.

RÉSUMÉ

Cartographie des sédiments et des formes de dépôt déterminée par sonar à balayage latéral à proximité de la Turquie.

L'imagerie par sonar à balayage latéral révèle la nature des sédiments, la rugosité du fond et permet d'en déduire les phénomènes de sédimentation. Un système sonar EG&G Mark 1B a été utilisé à proximité de la Turquie dans les golfes de Mersin, Akkuyu, Anamur, Teknecik et dans le détroit du Bosphore.
La répartition des sédiments y est corrélée à l'apport local en sédiment, aux vagues et aux courants, ainsi qu'à la topographie du fond. La présence de formes de dépôt telles que dunes ou bancs de sables indique le transport du sédiment sur le fond. Plusieurs formes observées ont probablement été créées lorsque le niveau de la mer était bas : galets, affleurements rocheux et dépresssions. Les graviers tapissent une grande partie du détroit. Les sables se trouvent principalement dans les chenaux, de chaque côté du seuil. Les surfaces rocheuses et les bancs de galets traduisent l'action intense des courants.

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INTRODUCTION

During the past two decades, high resolution acoustic systems (Sieck and Self, 1977), which include depth sounder, side-scan sonar, and subbottom profilers (tuned transducers, electromechanical and sparker), have been extensively used in marine geophysical explorations. Depth sounder and subbottom profilers are designed to provide data from beneath each transducer or transducer array. In contrast, the side-scan sonar system provides data from several tens or hundreds of metres on both sides of the ship's course, generating sonar images of the sea floor which are similar to satellite photographs, both in scale and content.

The great potential of the side-scan sonar system has been proven in the various disciplines of marine science (*e.g.* Belderson *et al.*, 1972). More particularly, the application of the system is wide-ranging in marine sedimentology (Stefanon, 1985), marine biology (Newton and Stefanon, 1975), hydrography (Bryant, 1975; Thorpe *et al.*, 1985), and underwater archaeology, as well as engineering surveys (McQuillin and Ardus, 1977).

The present study, focusing especially on the sedimentological application of the side-scan sonar system, explains the sediment distribution and bedforms of the bays of Mersin (Karaduvar and Pozcu), Akkuyu, Anamur, and Teknecik, as well as the Strait of Bosphorus (Fig. 1). Although, in the context of shelf dynamics, the Bosphorus seems to lie outside the northeastern Mediterranean framework, we thought it proper to include it in the present paper, since little is known about the sediment distribution and bedforms in this meandering strait (Okyar, 1987; Alavi *et al.*, 1989*a*; Ergin *et al.*, 1991).

The interpretation of side-scan sonar imageries is supported by grain size data previously published elsewhere (DAMOC, 1971; IMS-METU, 1979, 1985*a*, 1986*a*; Bodur, 1987; Ediger, 1987; Bodur and Ergin, 1988*a*, 1988*b*, 1992; Ediger and Ergin, 1990; Ergin *et al.*, 1991).

The technical and operational characteristics of the side-scan sonar system are beyond the scope of the present paper.

MATERIALS AND METHODS

Data used in this investigation were collected during various cruises of the IMS-METU (Institute of Marine Sciences) aboard the R.V. *Bilim*, R.V. *Lamas*, and R.V. *Erdemli*, in 1984-1986.

Approximately 180 km of side-scan sonar profiles (Figs. 2*a*, 4*a*, 6*a*, 8*a*, 10*a*, 12*a*), along a total of 65 tracklines, were collected, using an EG&G Mark 1B Dual Channel Side Scan Sonar system. The scanning range of the system was adjusted to 50 m, 100 m and 200 m scales (per channel), depending on operational needs. In addition, Atlas Deso-10 and Raytheon depth recorders were simultaneously used along the side-scan sonar profiles. Position fixes were achieved by using the Decca/Del Norte Trisponder navigation system. The positional accuracy of this system is ± 3 m.

The side-scan data are interpreted and mapped using the methods outlined by Muddie *et al.* (1970), Flemming (1976), and Hobbs (1986). The classification of bedforms is based on terminologies proposed by Berne *et al.* (1993). To simplify the descriptions, we refer in this paper to sand dunes ("small dunes" of Berne *et al.*, 1993) for bedforms with spacing less than 20 m and heights less than 0.8 m.

GEOLOGICAL SETTING

Mersin, Akkuyu, Anamur and Teknecik Bays

The areas surveyed in the northeastern Mediterranean Sea, the Mersin Bay, Akkuyu Bay, Anamur Bay, and Teknecik Bay are located in the Cilicia Basin (Fig. 1). Lying between the Taurus Mountains of Turkey to the north and the Kyrenian Mountains of Cyprus to the south, this basin inferred to be extensional or strike-slip controlled (Mulder, 1973; Sengör *et al.*, 1985), and is characterized by deltaic shallow marine-to-continental Plio-Quaternary sediments which overlie the evaporite series of Upper Miocene age and are about 2-3 km thick (Mulder, 1973).

The Cilicia Basin, one of the Neogene basins in the eastern Mediterranean, has received the bulk of its sedimentary load from the rivers on the Turkish coast (Ergin *et al.*, 1988). Four major rivers (Ceyhan, Seyhan, Tarsus and Göksu) and several ephemeral rivers drain into the basin. The annual supply of sedimentary material by the major rivers amounts to approximately 4.31×10^6 m^3 yr^{-1} (Aksu *et al.*, 1992). The ephemeral rivers, which flow for 3-4 months of the year, have a far greater erosional impact on their banks and beds (DSI, 1978). The drainage areas and discharge rates of these rivers are shown in Table 1.

Table 1

Drainage areas and rates of water discharges of the major and ephemeral rivers debouching into the Cilicia Basin, (n.a. = no available data).

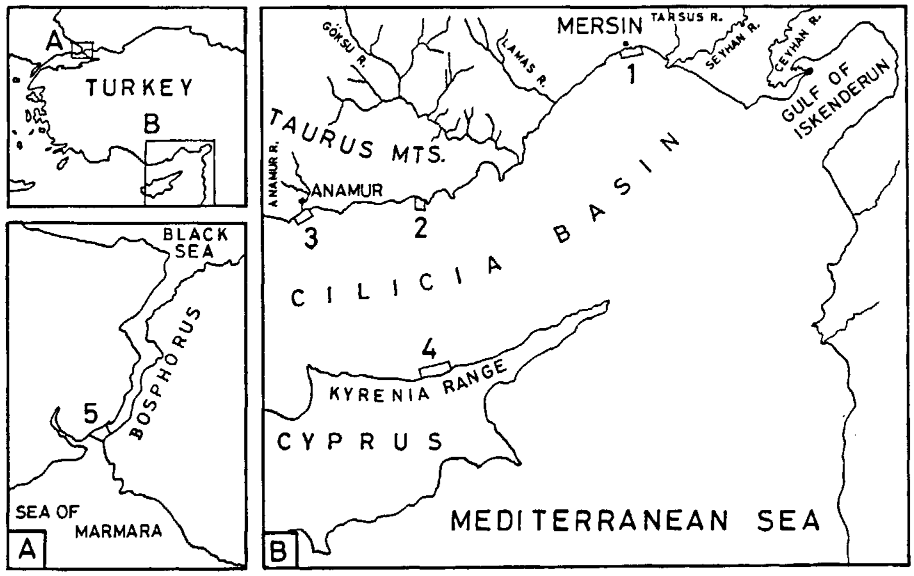
Rivers	Drainage area (km^2)	Flow rates (m^3/sec)	
		Min.	Max.
Ceyhan	20466	3	1510
Seyhan	13846	44	1957
Tarsus	1416	1	1222
Göksu	10065	25	1550
Deliçay	305	0	330
Lamas	1055	2	62
Anamur	313	2	478
Sultançay	n.a.	n.a.	n.a.

Strait of Bosphorus

The area studied between the Üsküdar and Besiktas coasts is situated in the southern part of the Strait of Bosphorus (Fig. 1), a 31 km long meandering strait between the Black

Figure 1

Location maps of the surveyed areas in the Strait of Bosphorus (A), and the northeastern Mediterranean Sea (B). 1- Mersin Bay; 2- Akkuyu Bay; 3- Anamur Bay; 4- Teknecik Bay; 5- Strait of Bosphorus.



Sea and the Marmara Sea. Its width varies between 0.7 and 3.5 km, with an average value of 1.3 km. Depths range between 30 and 100 m, with an average value of 35 m.

Geologically, the Strait of Bosphorus, as a former river valley, reached its present position in the Early Pleistocene (English, 1904; Penck, 1919; Pînar, 1948: *in* Pînar-Erdem and Ilhan, 1977). The ancestral valley may have been initially formed as a segmented and linked series of grabens of Late Miocene to Pliocene origin (*e.g.* Brinkman, 1976) between parallel sets of faults in the Paleozoic-Mesozoic basement (Eroskay and Kale, 1986). Detailed seismic surveys in the southern part of the Strait of Bosphorus have shown the Quaternary sedimentary sequence overlying the Paleozoic basement to be about 40 m thick (Okyar, 1987; Alavi *et al.*, 1989*a*).

HYDROGRAPHIC SETTING

A cyclonic circulation pattern characterizes the surface current system in the eastern Mediterranean Sea (Nielsen, 1912; Schott, 1915; Wüst, 1961; Lacombe and Tchernia, 1972; *in* Ünlüata, 1986). The westward current along the southern Turkish coast, called the Asia Minor Current, flows between Turkey and Cyprus in a meandering fashion (Ünlüata, 1986). The representative flow speed of the westward surface current is of the order of 10 cm s^{-1} (Ünlüata, 1986). It is to be noted that the magnitude of the westerly flow is significantly reduced in the nearshore areas west of the Göksu River delta (Ünlüata *et al.*, 1983). This reduction in current velocity is attributed to topographic steering by the bathymetry of the shelf and to the rugged topography of the coast between the Göksu delta and Cape Anamur (Ünlüata *et al.*, 1983). On the other hand, several anticyclonic and cyclonic circulation systems exist at relatively shallow water depths, mainly due to local wind and to the coastal irregularities (Collins and Banner, 1979). Generally, southwesterly wind regimes prevail throughout the year along the southern coast of Turkey (Mediterranean Pilot, 1976), northerly wind regimes being largely confined to the winter months (Özsoy, 1981). Gales from the NE or SW are most frequent during winter. Swells associated with southwesterly winds occur off the coast of Cyprus and Turkey (Mediterranean Pilot, 1976). These weather conditions play an important role in the formation of waves and currents which control the sedimentation processes in the nearshore areas.

In the Mersin Bay, current measurements at one station at a depth of about 5 m above the sea floor (total depth 10 m) revealed that the maximum current velocities ranged from 40 to 57 cm s^{-1} in all directions during the months of October and November 1985 (IMS-METU, 1986*b*). However, the mean flow direction during this measurement was found to be eastward (approximately 50 cm s^{-1}) (IMS-METU, 1986*b*).

Current measurements carried out in the Akkuyu Bay have shown the flow direction some 25 m above the sea floor (total depth 50 m) to be southwestward and the current speed to range from 2 to 4 cm s^{-1} in the months of December 1983-January 1984 (IMS-METU, 1984*b*).

At Teknecik, during the same period, flow direction was found to be eastward; the current speed was measured as ranging from 4 to 35 cm s^{-1} at about 25 m above the sea floor (total depth 40 m) (IMS-METU, 1984*b*).

No measurements of currents were carried out for the Anamur Bay. However, the Asia Minor Current prevails in this bay (Ünlüata *et al.*, 1983). Additionally, the presence of longshore currents from SW to NE and downward submarine canyon currents have been postulated by Ediger (1987).

In the Strait of Bosphorus, a two-layer current system comprises Black Sea water of about 17.5 salinity flowing south at the surface and Mediterranean water at about 38.5 salinity flowing north along the bottom (Gunnerson and Özturgut, 1974). The current system is driven by the free surface elevation at the northern entrance and the salinity differences between the Marmara and the Black Seas (Latif *et al.*, 1990; Oguz *et al.*, 1990). The upper and lower layer currents are separated by a level of no motion located, on the average, at 25 m depth in the south and 25-40 m depths at the northern entrance of the strait (Özsoy *et al.*, 1986). According to Özsoy *et al.* (1986), currents in both layers increase towards the southern section of the Bosphorus. During the hydrographic surveys in the Strait of Bosphorus, blocking events in both layers were reported (Özsoy *et al.*, 1986; Oguz *et al.*, 1990; Latif *et al.*, 1990; Besiktepe *et al.*, 1994). The lower layer blocking typically occurs during the spring and summer months, when the net freshwater influx into the Black Sea increases. The upper layer blocking events occur in the autumn and winter months, when the surface flow reverses under the influence of strong southerly and southwesterly winds.

Current measurements at two stations in the northern survey area in the Strait of Bosphorus over a period of one month have shown that the average velocity at 5 m above the sea floor is nearly 50 cm s^{-1} in the European side channel and 80 cm s^{-1} in the Anatolian side channel (IMS-METU, 1985*c*). The main direction of flow was found to be towards the north as expected.

RESULTS AND DISCUSSIONS

Mersin Bay

Two areas, off the coasts of Karaduvar and Pozcu, extending from east to west in the Mersin Bay, were studied.

Karaduvar

The sea floor of the Karaduvar slopes gently seaward, with an average gradient of 0.2° (Fig. 2*A*). The isobath contours of Karaduvar generally run in a E-W direction. However, some deviations, especially in a SE-NW direction, from the general trend of the isobath contours are observed (Fig. 2*A*). Side-scan sonar imageries show that these are due to sand dunes (Fig. 3).

Based on the interpretation of side-scan sonar data and previous samplings (Bodur, 1987), the sediments overlying the sea floor of Karaduvar are composed of muddy sand, sand and shelly gravel materials (Fig. 2*B*). Muddy sand covers a great part of the sea floor. Sand, accounting for an average of 58% of all samples, is usually found at depths greater than 4 m, shelly gravel being mainly confined to the nearshore areas. The prevalence of these coarse-grained materials suggests high energy setting due to wave and current activities.

However, the most prominent characteristic of this area is the presence of numerous gravel patches and sand dunes on the sea floor (Figs. 2*B*, 3). The former were previously interpreted by Bodur and Ergin (1988*a*) as gravel waves. However, the creation of such features requires a current speed of more than 150 cm s^{-1} (Belderson *et al.*, 1972), whereas according to the current data of IMS-METU (1986*b*), the maximum measured near-bed current velocity within this area is about 57 cm s^{-1}. This renders the interpretation by Bodur and Ergin (1988*a*) less convincing. Additionally, these patches of gravel were considered to be deltaic deposits of the ancestral Seyhan and Ceyhan rivers dating from the last glacial period and not covered by finer post-glacial deposits (IMS-METU, 1986*a*). It has also been explained that at the time of post glacial, the growth of a complex delta of the Deliçay, Tarsus and Seyhan rivers took place in a west-southwest direction, parallel to the main current of the northeastern Mediterranean waters (Okyar, 1991; Ergin *et al.*, 1992). At that time, the current velocity in this area may have been so high that the fine-grained materials were winnowed out of the sediments supplied from the rivers, with the result that only gravel was deposited.

The sand dunes, with a height of 50 to 80 cm and wave length of 5 to 10 m, often show bifurcation as well as

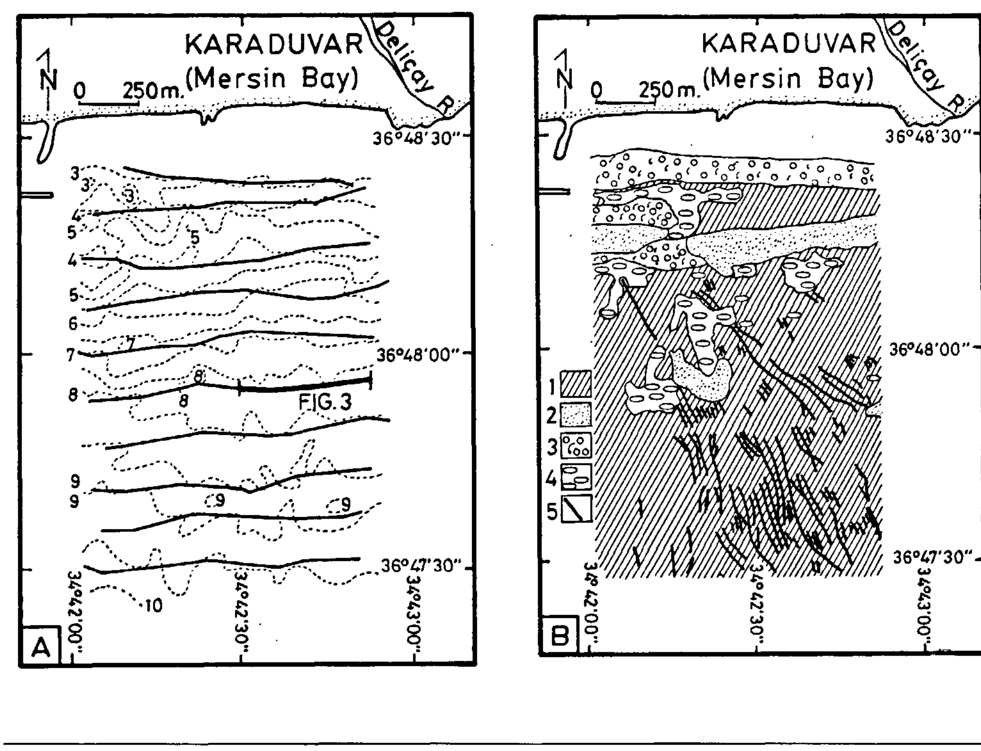


Figure 2

(A) Bathymetry (contour interval 0.5 m) and side-scan sonar lines of the surveyed area off Karaduvar in Mersin Bay. Heavy line indicates location of side-scan sonar imagery in Figure 3.
(B) Distribution of sedimentary facies and bedforms on the sea floor off Karaduvar based on the analysis of side-scan sonar imageries. 1- muddy sand; 2- sand; 3- shelly gravel; 4- gravel patches; 5- sand dunes.

a general SE-NW trend (Fig. 3). These sand dunes are nearly asymmetric in cross-section, with lee slopes as a rule facing the southwest. These bedforms have been reported from tidally influenced environments (*e.g.* Stride, 1963; Dingle, 1965; McCave, 1971; Harris and Collins, 1985) where tidal currents are strong. In the Cilicia Basin, the tidal currents are weak, and thus these bedforms are though to be formed by a combination of storm-induced currents and wave effects (M.A. Latif, pers. comm., 1996).

Pozcu

The sea floor of the Pozcu (Fig. 4*A*) slopes gently seaward with an average gradient of 0.31°. However, this gentle slope is disrupted by two E-W (shore-parallel) trending shoals (Fig. 4*A*). The first lies about 700-800 m from the shore at a depth of 7-8 m, with its crest 5 m below sea level (Fig. 4*A*). The second shoal is less prominent and lies about 1550 m from the shore at a depth of 11.5-12.5 m, with its crest 10 m below sea level (Fig. 4*A*). These shoals are interpreted as beachrock outcrops (IMS-METU, 1986*a*; Bodur and Ergin, 1992), most probably formed during stillstand of sea level at some time in the late Holocene (*i.e.* 7000-5000 yr BP) when the level was 5-10 m lower than at present (Curray, 1965). Beachrock has also been reported by Alexanderson (1972) for many localities in the eastern Mediterranean.

The sediments covering the sea floor of Pozcu are mainly composed of muddy sand (Fig. 4*B*). Some gravelly sand materials are restricted to the northeast of the nearshore area (Fig. 4*B*). Additionally, scattered occurrences of sand with sand patches are also found on the muddy sandy ground (Fig. 4*B*). The two gravelly shelly beachrock outcrops in the form of narrow belts which have been observed lie parallel to the shore (Figs. 4*B*, 5). Unlike the sea floor of the

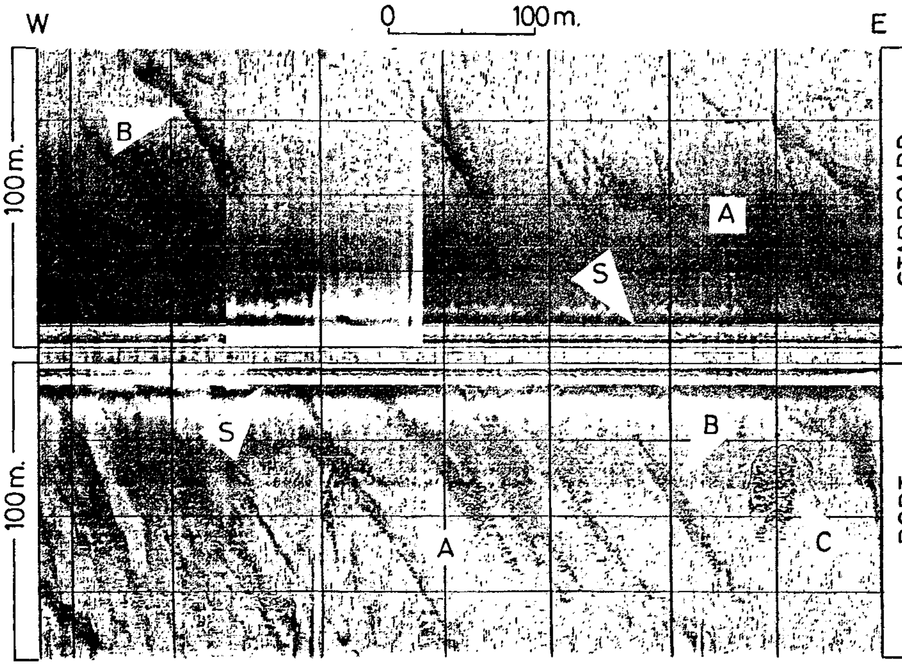


Figure 3

Side-scan sonar imagery of a muddy sandy (A) sea floor off Karaduvar. Note the sand dunes (B) trending in a NW-SE direction which are approximately normal to current direction. Note also the isolated gravel patches (C). S- sea floor. Dark tone of starboard channel is due to high gain setting. For location see Figure 2A.

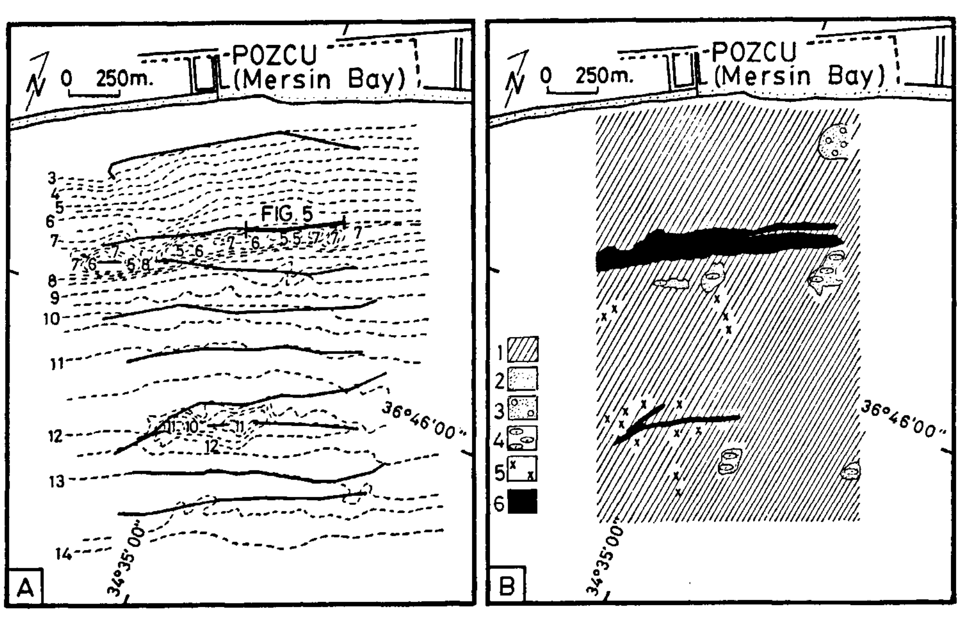


Figure 4

(A) Bathymetry (contour interval 0.5 m) and side-scan sonar lines of the surveyed area off Pozcu in Mersin Bay. Heavy line indicates location of side-scan sonar imagery in Figure 5. (B) Distribution of sedimentary facies and bedforms on the sea floor off Pozcu based on the analysis of side-scan sonar imageries. 1- muddy sand; 2- sand; 3- gravelly sand; 4- sand patches; 5- rock fragments; 6- gravelly shelly beachrock outcrops.

Karaduvar, the sea floor of the Pozcu area is characterized by the absence of sand dunes. This is attributed to the particular hydrodynamic energy conditions in the studied areas, Pozcu being subjected to fewer waves and currents than the Karaduvar area. Two topographic highs in this area (Fig. 4*A*), and the obstruction caused by the structure of the Mersin Harbour (not shown in the Figures) appear to play a significant role in reducing the intensity of the waves and currents.

Akkuyu Bay

In general, the sea bottom of Akkuyu Bay (Fig. 6*A*) appears to be even and gently sloping towards the south, with an average gradient of 1.5°.

Immediately adjacent to the coast, a ribbon-like area 25-100 m wide, consisting of bare rock, extends seawards from the land (Fig. 6*B*). Beyond the bare rock, lies a wide area (500 m to 1000 m wide) covered with sand. Sand, accounting for an average of 85% of all samples, seems to be deposited in nearshore areas (IMS-METU, 1979). According to grain size data, the lesser amounts of mud within the sand fraction in nearshore samples indicate washing/winnowing activities in these areas (IMS-METU, 1979). Extensive sand dunes are present in this sandy area (Figs. 6*B*, 7). Sometimes bifurcating, they show a general NE-SW trend and are estimated to be spaced at 8-10 m and about 0.8 m high. As stated in the previous section, the flow in this bay was found to be in a southwestward direction at a depth of about 25 m above the sea floor (total depth 50 m). The sand dunes observed were located at water depths less than 25 m. Their trend reflects a transverse flow. Therefore, they are believed to be formed by the winter currents which sweep the coast from NW to SE in this area (IMS-METU, 1984*B*). This assumption also indicates that the southwestward current generated in deep water does not affect the nearshore areas. Further south of the dune-covered sandy surface, a slight "depression" area, 100 m-300 m wide, extends as a belt, generally from NW to SE. This area presents a "rough" texture on the sonograph, suggesting a gravelly sand outcrop (Fig. 6*B*). An area (ribbon-like and 200 m-

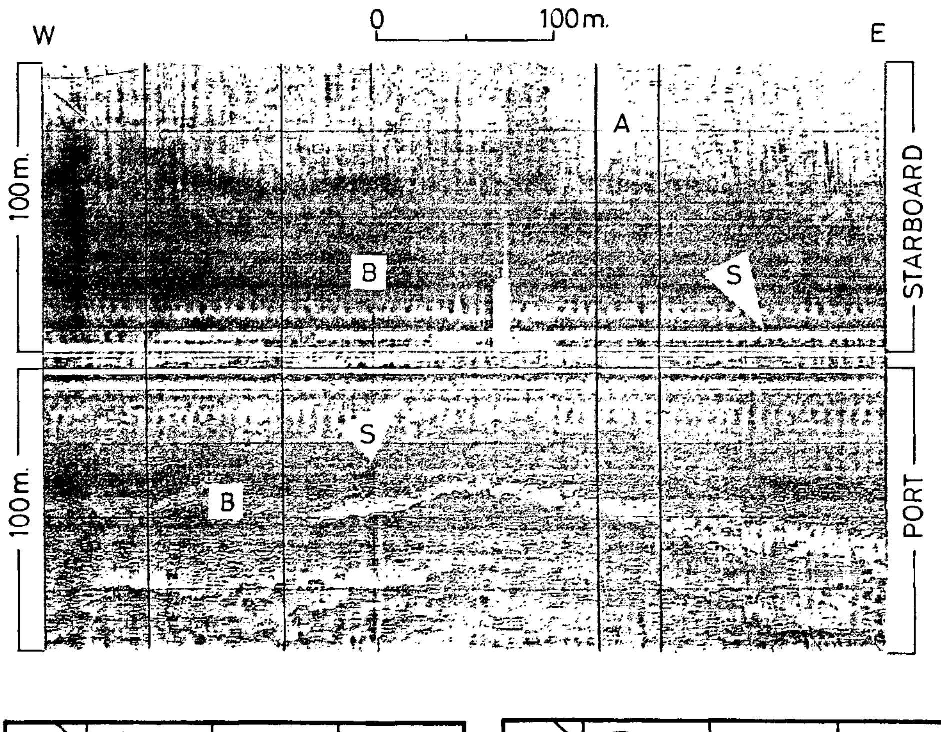


Figure 5

Side-scan sonar imagery showing the gravelly shelly beachrock outcrop (B) off Pozcu. A- muddy sand; S- sea floor. Dark tone of starboard channel is due to high gain setting. For location see Figure *4a.*

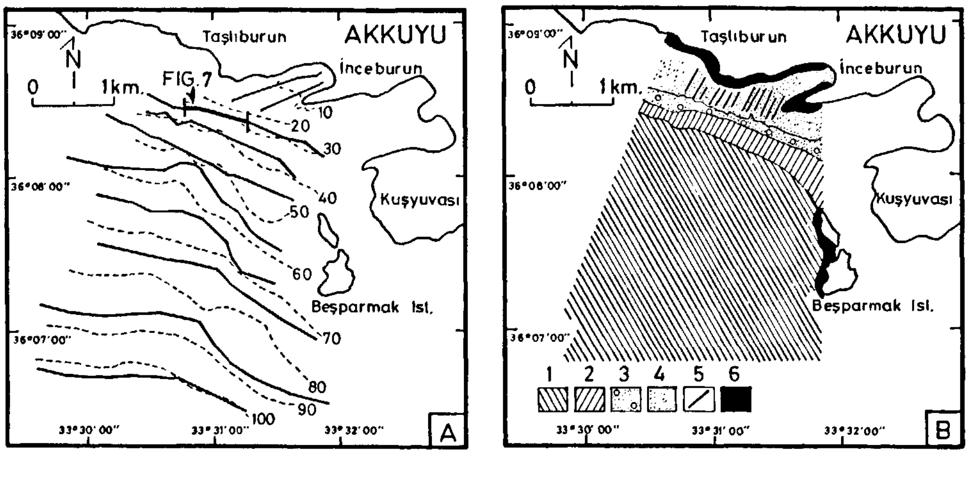


Figure 6

(A) Bathymetry (contour interval 10 m) and side-scan sonar lines of the surveyed area off Akkuyu Bay. Heavy line indicates location of side-scan sonar imagery in Figure 7.
(B) Distribution of sedimentary facies and bedforms on the sea floor off Akkuyu Bay based on the analysis of side-scan sonar imageries. 1- sandy mud or mud; 2- muddy sand; 3- gravelly sand; 4- sand; 5- sand dunes; 6- rock.

500 m in width) further to the south is interpreted as muddy sand, extending approximately between the 30 m and 40 m depth contours. Further south, the surface consists of sandy mud to mud (Fig. 6*B*). Core samples obtained from this locations contain mud deposits up to 40 cm thick (IMS-METU, 1979). This reflect rather stable depositional conditions compared with sandy areas (IMS-METU, 1979).

Anamur Bay

Two physiographical areas are recognized in the Anamur Bay (Fig. 8*A*): a gently sloping area extending from the shore line to the depth contours of about 50 m (in the southwest) and 100 m (in the northeast); and the steep sloping walls of the upper reaches of the canyon (referred to as a slope by Ediger, 1987). The gently sloping area tends to broaden towards both the SW (about 2 km) and NE (about 4 km), its gradient decreases from 3° to 1° in the southwest and northeast directions, respectively (Ediger, 1987). In contrast with the gently seaward sloping area, the gradients of the slope proper increase to 10° and 14° down to the canyon and valleys. Most parts of the continental slope are extensively dissected by minor submarine canyons/valleys (Ediger *et al.*, 1993). These submarine canyon and valleys are in line with the major thrust fault system on the adjacent land (Ediger *et al.*, 1993).

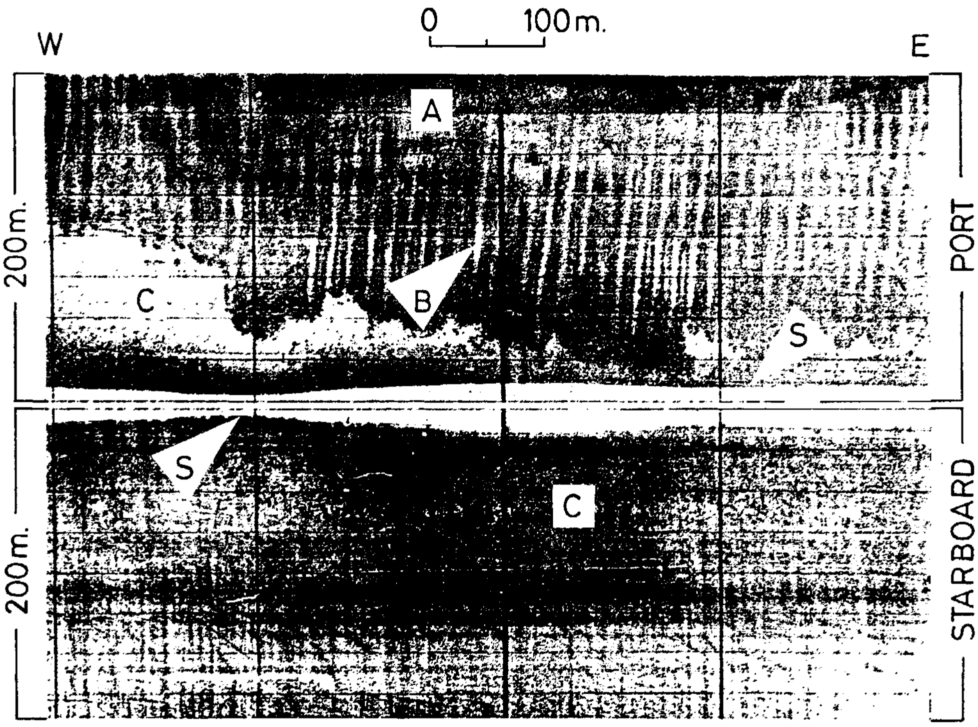


Figure 7

Side-scan sonar imagery showing the sand (A) and gravelly sand (C) materials on the sea floor off Akkuyu Bay. Note the sand dunes (B) on port channel. S- sea floor. For location see Figure *6a.*

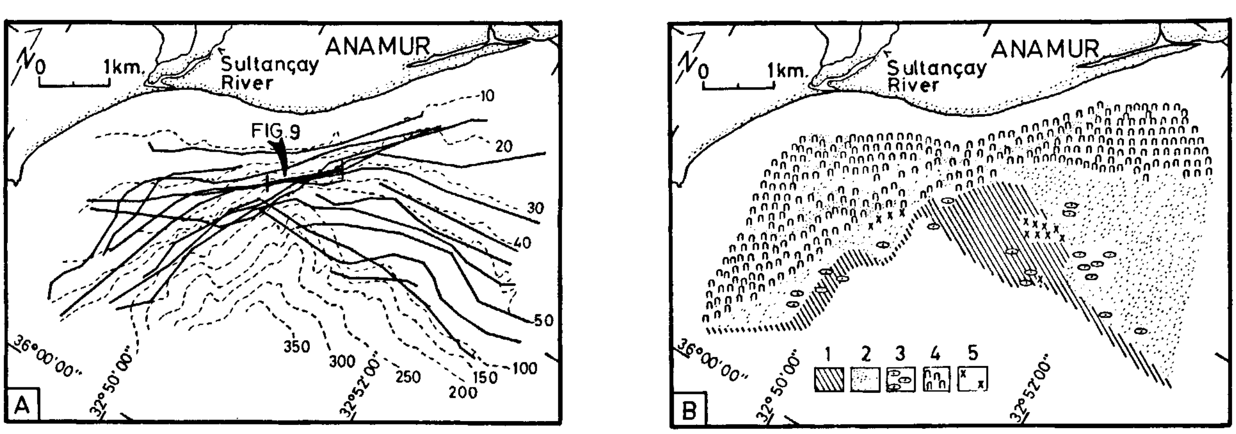


Figure 8

(A) Bathymetry (contour interval 10 m between 10 and 50 m; and 50 m between 50 and 350 m) and side-scan sonar lines of the surveyed area off Anamur Bay. Heavy line indicates location of side-scan sonar imagery in Figure 9.
(B) Distribution of sedimentary facies and bedforms on the sea floor off Anamur Bay based on the analysis of side-scan sonar imageries. 1- mud; 2- sand; 3- sand patches; 4- sea grasses; 5- rock fragments.

The large parts of the shelf between the depths of 10 and 40 m are covered by patches of sea grass (Fig. 8*B*). The sea-grass patches show different shapes, ranging from curved to linear (Figs. 8*B*, 9). Most of the surface sediment samples from this zone contain Posidonia oceanica (Ediger, 1987). The same type of reflection patterns have been reported in the northern Adriatic Sea and represents the phytobenthos growth (Newton and Stefanon, 1975; 1982). These plants often grow over sandy bottoms in clear waters away from sources of fresh water input and create favourable ecological conditions for carbonate production (Alavi *et al.*, 1989*b*). Below the sea grasses, a sandy bottom is observed (Fig. 8*B*). Sand patches and rock particles are present on both sandy and muddy bottoms (Fig. 8*B*). All deeper parts and walls of the canyon are covered with a thin layer of mud-dominated sediments (Fig. 8*B*).

The distribution of the sediments and rock particles is principally controlled by the prevailing system of longshore currents (from SW to NE) in shallow waters, and slumping or sliding processes on the canyon walls (Ediger, 1987).

Teknecik Bay

In general, the sea floor (Fig. 10*A*) is very irregular and rocky, with several major seamounts and canyons (IMS-METU, 1984*a*). According to high- resolution seismic reflection data, the sea floor itself is rocky (IMS-METU, 1984*a*).

Based on the average slope gradient, the shelf was divided into two regions: (1) the inner shelf shoreward of the shelf break (in approximately 50 m of water), with a gentle slope averaging 2°-3°; and (2) the upper slope extending from a depth of 50 m to the limit of the surveyed area, with a relatively steep slope reaching 5°-6° or even locally 10°.

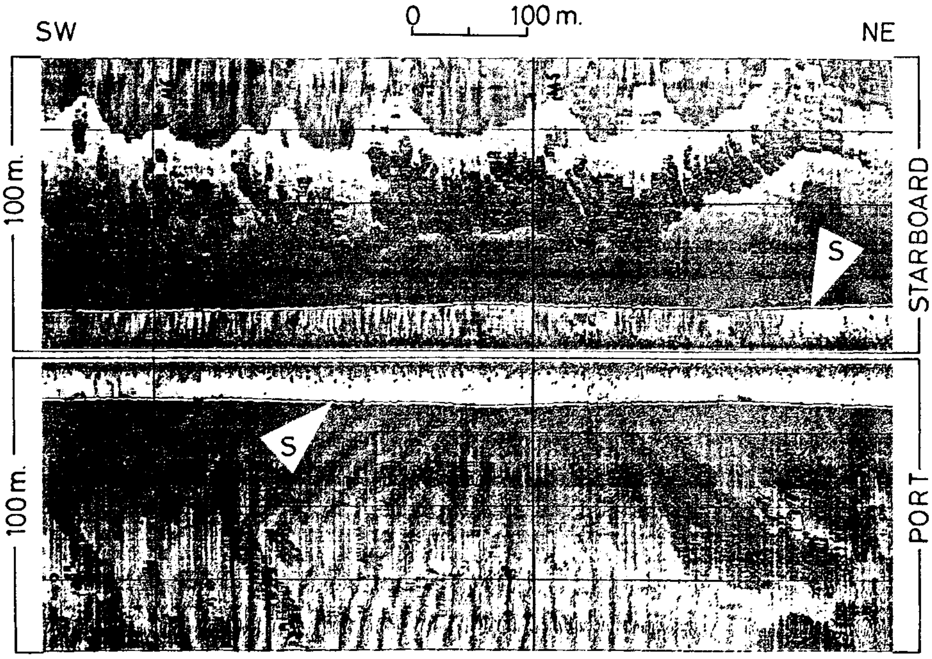


Figure 9

Side-scan sonar imagery showing the sea grasses (dark tones) on the sandy bottom (light tones) off Anamur Bay. S- sea floor. For location see Figure 8a.

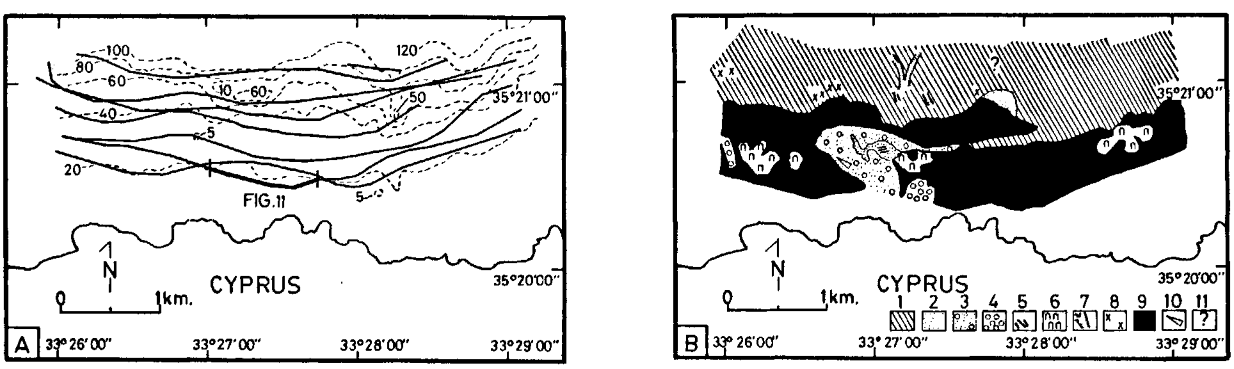


Figure 10

(A) Bathymetry (contour interval 20 m) and side-scan sonar lines of the surveyed area off Teknecik Bay in Cyprus. Heavy line indicates location of side-scan sonar imagery in Figure 11.
(B) Distribution of sedimentary facies and bedforms on the sea floor off Teknecik Bay based on the analysis of side-scan sonar imageries. 1- sandy mud; 2- sand; 3- gravelly sand; 4- gravel; 5- sand dunes; 6- seaweed on rock surface; 7- channel; 8- rock boulder; 9- irregular rocky surface; 10- possible shipwreck; 11- unidentified objects.

Side-scan sonar survey indicates that the sea floor area within the inner shelf region of Teknecik is rocky, irregular and partly seaweed covered (Fig. 10*B*). There are numerous sinkholes (Fig. 11) or collapse structure features (circular or ellipsoidal depressions 50 m to 100 m in diameter on average), with seemingly sharp edges (IMS-METU, 1984*b*). This rocky area is interpreted as marine calcarenite limestone (Girne formation) by Norman and Atabey (1988). According to these authors, sinkholes in the marine calcarenite Girne formation were probably formed during subaerial exposure to weathering 18 000-20 000 yr BP, when the sea level was at its minimum, during the Würm glacial stage. This irregular rock surface is separated into two segments (eastern and western) by a relatively smooth area which is interpreted as gravelly sand (Fig. 10*B*). A small patch of sandy ground with sand dunes can also be seen in this area (Fig. 10*B*).

Further north beyond the irregular rocky surface, the upper slope region consists predominantly of sandy mud (Fig. 10B). However, this is possibly a thin layer, because at several localities basement rock protrudes through the surface, sometimes forming small hills, often appearing as "boulders" (IMS-METU, 1984*b*). Numerous channels appear to underline the thin cover of sandy mud. Channel widths are 50-100 m, visible lengths are about 500 m or more. The sand area, which forms half-moon shape, is possibly part of an old beach when the sea level was lower than its present level. Scattered on the sandy mud surface are numerous unidentified objects, usually rectangular in shape and sometimes clustered together. These are possibly sunken man-made structures (IMS-METU, 1984*b*).

Strait of Bosphorus

The bottom topography between Üsküdar and Besiktas (Fig. 12*A*) is characterized by the presence of two channels close to the banks of the strait separated by an elongated sill along the thalweg (IMS-METU, 1985*b*; Okyar, 1987; Alavi *et al.*, 1989*a*). The crestal part of the sill is defined by the 30 m isobath (Fig. 12*A*). The channels gently deepen towards the north. The coastal slopes of the channels are much steeper (4°-13°) than those on the flanks of the sill (1.3°-2°).

The sea floor just off the coast of Kabatas on the European side is covered by sandy gravel (Fig. 12B). Gravelly sand materials extend just beyond the sandy gravel. On the slope of the central bank, coarse materials (sandy gravel) are dominant. On the central part of the bank, shelly sandy gravel and some gravel patches are common (Figs. 12B, 13). The deepest parts of the channels on both sides are covered by shelly sand materials. Towards the Asian side from the Üsküdar side channel, shelly sandy gravel materials are dominant on the sea floor. Shelly sand materials predominate just off the coast of Üsküdar. Sand dunes tend to occur at the southwestern tip of the central rise and their trends agree with the general direction of the bottom currents (*i.e.* northward). Observed sand dunes suggest that the minimum bottom current may be about 50 cm s^{-1} (*cf.* Belderson *et al.*, 1972), in agreement with available current measurements (IMS-METU, 1985*c*). Patches of sand on sandy gravel and shelly sandy gravel floors are common in the areas of slower current (less than 50 cm s^{-1}, *cf.* Belderson *et al.*, 1972). They are aligned with their long axes either more or less parallel or transverse to the current direction. In addition, rocky surfaces and occurrences of large blocks around the Üsküdar headland indicate strong current activities there. Similarly, gravel patches on some parts of the central rise suggest that strong currents sweep over it.

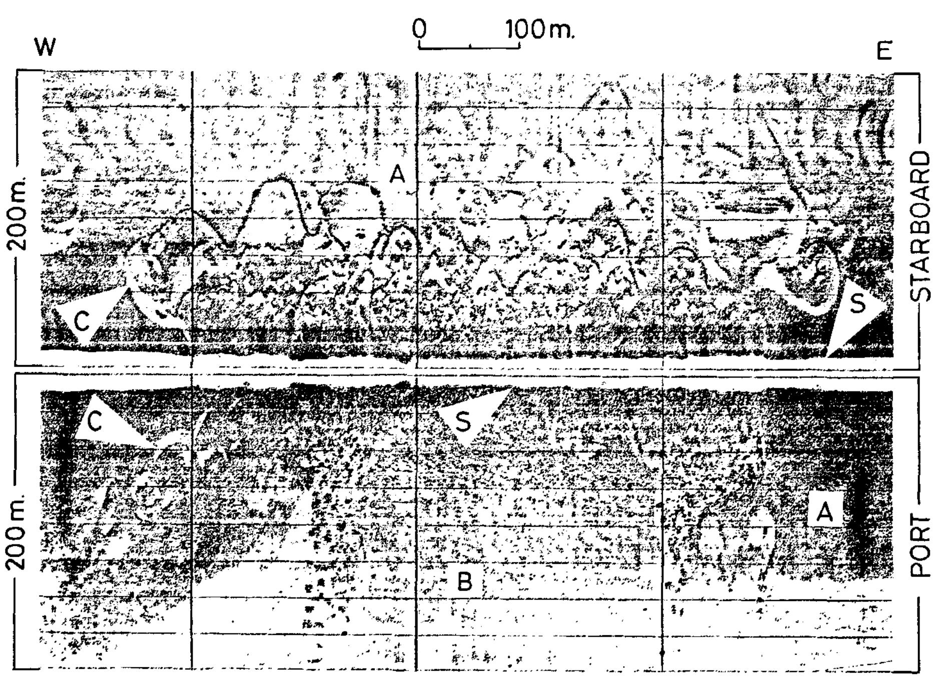


Figure 11

Side-scan sonar imagery showing the irregular rocky surface (A) and sinkholes (C) on the sea floor off Teknecik Bay. B- gravel materials; S- sea floor. For location see Figure *10A.*

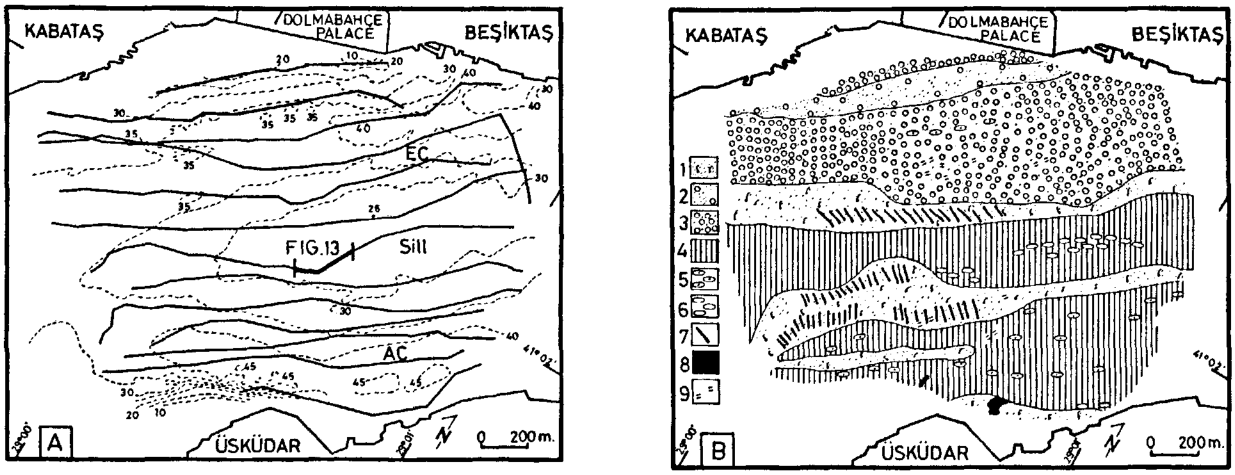


Figure 12

(A) Bathymetry (contour interval 10 m) and side-scan sonar lines of the surveyed area in the Strait of Bosphorus. EC- European side channel; AC- Anatolian side channel. Heavy line indicates location of side-scan sonar imagery in Figure 13.
(B) Distribution of sedimentary facies and bedforms on the sea floor of the Strait of Bosphorus based on the analysis of side-scan sonar imageries. 1- shelly sand; 2- gravelly sand; 3- sandy gravel; 4- shelly sandy gravel; 5- sand patches; 6- gravel patches; 7- sand dunes; 8- rocky surface; 9- anchor tracing.

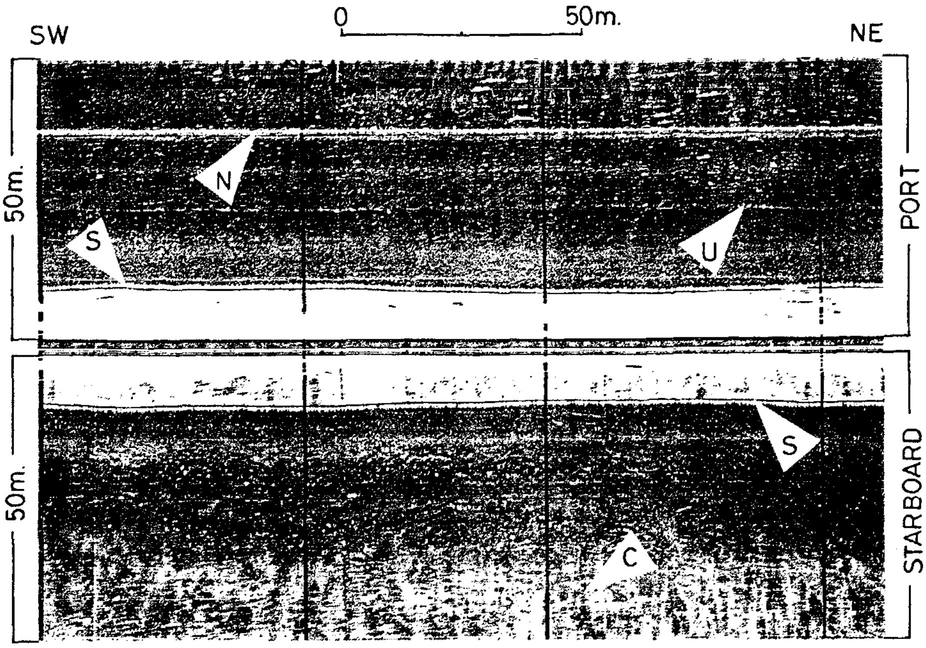


Figure 13

Side-scan sonar imagery showing the gravel patches (C) on the shelly sandy gravel floor of the Strait of Bosphorus. N- deformed helix trace; U- sea-surface echo; S- sea floor. For location see Figure *12a.*

CONCLUSIONS

Facies mapping of the sea floor around Turkey using side-scan sonar profiles constitutes an efficient method for describing sedimentary provinces. The most important result of the present study is to correlate the distribution of sea-floor sediments and bedforms in relation with (1) sea level changes and (2) physical regimes.

Three distinct associations relating to sea-level changes identified in the studied areas comprise: (a) numerous sinkholes in the marine calcerinite limestone off the Teknecik Bay; (b) gravel patches on the seafloor of Karaduvar in Mersin Bay; and (c) two beachrock outcrops off the coast of Pozcu in Mersin Bay. Of these, the sinkholes were formed during the last glacial (Würm) maximum when most parts of the Mediterranean shelf were exposed and subaerially eroded. No karst features of a comparable age are known to exist in the Mediterranean Sea. Gravel patches considered to be relict deposits of Seyhan and Ceyhan rivers were also deposited during the last glacial period when the sediment supplies from the rivers and the delta progradation increased due to more pluvial conditions (cf. Aksu *et al.*, 1992; Danobeitia *et al.*, 1990). Beachrock outcrops, which appear at about 5 to 10 m depths correlated with the stillstand period of last glacial transgression (*i.e.* 7000-5000 yr BP). Beachrock occurrences have been reported from many localities in near-coastal areas of the Mediterranean, *e.g.* from Morocco, Spain, Italy, Greece and Cyprus (Alexanderson, 1972). In South Corsica, Nesteroff (1984) obtained four sea-level data points from the beachrock formations. These are located at 1, 3, 4 and 15 metres below the present sea-level and are dated about 1200, 2450, 2450 and 6640 yr BP, respectively. These indicate that similar conditions must have prevailed in most parts of the Mediterranean during the post-glacial time.

The distribution of sea-floor sediments and bedforms around Turkey are also controlled by changing physical regimes according to environmental differences. In the surveyed bays, coarse-grained sediments (sand and gravel) generally occur in nearshore areas, *i.e.* in areas subjected to strong hydrodynamic activity. Fine-grained sediments (mud) mainly occur in offshore areas. In areas near river mouths where there is an abundant supply of fine- grained sediments, mud also occurs. The occurrences of sand dunes and sand patches in the bays indicate mobility of the sea-floor materials as a consequence of waves and currents. From these findings, we can conclude that the sediment distributions and bedforms in the bays are mainly controlled by the local sediment supply, water depths, waves and currents. This result is also consistent with the shelf dynamics and sediment distribution of the Mediterranean Sea (Emelyanov, 1972). In the Strait of Bosphorus, the sediment distribution and bedforms are mainly controlled by the prevailing bottom current regimes, as in the case of the Strait of Gibraltar (Kelling and Stanley, 1972). Gravelly sediments, gravel patches and rock outcrops occur in areas of strong bottom currents. In contrast, sandy sediments, sand patches and sand dunes are found in the areas of relatively weak bottom currents.

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