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Holocene sedimentation patterns and bedforms in the wave-current-dominated nearshore waters of eastern Mersin Bay (eastern Mediterranean)

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ABSTRACT

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The distribution and bedforms of Holocene sediments in relatively high energy, wave-dominated nearshore waters of the eastern Mersin Bay (eastern Mediterranean) were investigated by high resolution seismic profiles, sidescan sonar records and surface sediment samples. High-resolution seismic reflection profiles show that the sedimentary column consists of two main sequences separated by a mid-reflector (R), showing irregular and erosional surface features, which is interpreted as the Late Pleistocene/Holocene boundary. The upper sequence which is seen as parallel to slightly divergent reflection configurations in a sheet-like to wedge-shaped geometry, approximates to Holocene deposits reaching up to 10 m in thickness about 2 km seaward of the shoreline, with a slight tendency to increase offshore. Seismic data indicate that the unconformity between the late glacial subaerial surface and the overlying post-glacial transgressive deposits occurs at depths of 1–10 m below the seafloor. Holocene sedimentation rates are estimated to be 10–100 cm per 1000 yr. Typical ridge–furrow systems cutting into beachrocks are apparently products of mechanical erosion at very shallow water depths. The lower seismic sequence underlying the reflector R may represent pre-Holocene deposits and is characterized by complex stratified reflection patterns, commonly showing hummocky to mounded and chaotic cut-and-fill facies. Sidescan sonar records indicate prominent features of these nearshore areas such as gravel waves between sand patches and beachrocks: The former are thought to have been produced as a result of the interaction of waves and currents on the sediment surface with an apparently westerly migration direction for sand, whereas the latter were formed during the lowstand of sea level in the Late Holocene. Muddy sand is the dominant sediment type in the nearshore waters of Mersin Bay (in depths less than 15 m) with local sand and gravel patches and beachrock outcrops.

Introduction

The study area is located off a narrow coastal plain between the Mezitli River mouth to the west and the Deliçay River mouth to the east and extends seaward onto the nearshore areas of inner shelf to depths less than 15 m (Fig. 1). In the north, the high relief of the Taurus Mountains forms the coastal hinterland. Three areas, off the coasts of Pozcu, Mersin Harbor and Karaduvar, measuring about 2 km^2 each, were examined. Compared with the wide deltaic plain east of the study area, the topography of the western coasts is characterized by more pronounced high relief (Fig. 2), forming several fan-delta systems.

The morphology of the inner shelf of Mersin Bay has been strongly influenced by fluctuations of sea level during the Quaternary (e.g. Evans, 1971; Erol, 1981). Outbuilding has been caused primarily by extension of the coastal plain across the continental shelf, including the deposition of fan-delta sequences on the shelf (Ergin et al., 1992a). The adjacent onshore geology underlying the alluvial coastal deposits of the Plio-Quaternary

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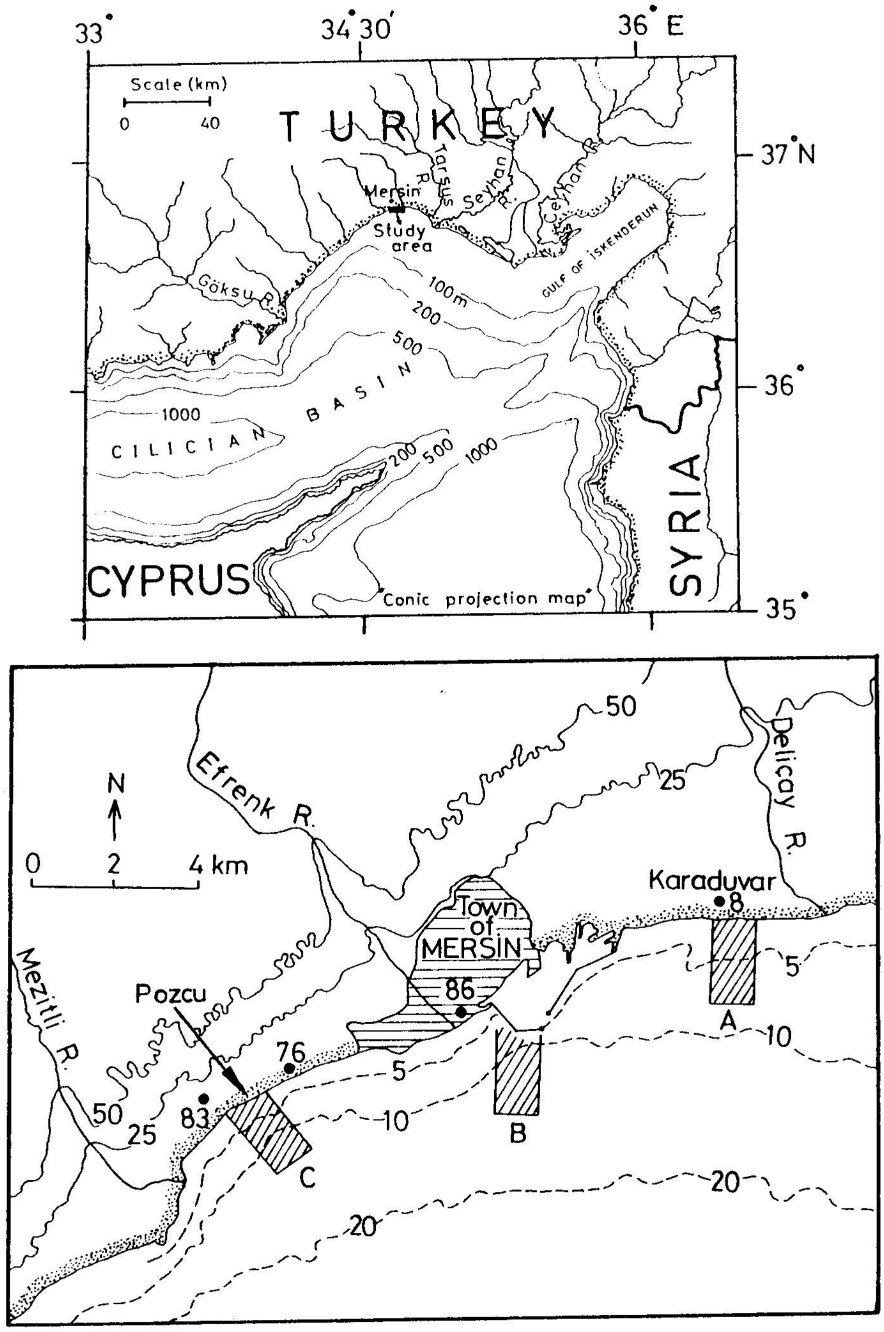


Fig. 1. Location map of the studied areas in the Mersin Bay; off the coasts of Pozcu (*C*), the town of Mersin (*B*, off Mersin Harbor) and Karaduvar (*A*). Depths and elevations are in metres.

is dominated by Late Tertiary (mostly Neogene) sedimentary rocks, mainly limestones, marls and sandstones (Figs. 2 and 3). These rocks infill the southern margin of the Neogene Adana Basin (Yalçin and Görür, 1983) which extends seaward underneath the Mediterranean in a southward direction to form the basement rocks of the near coastal areas. The northern and northeastern part of Adana Basin is now buried under the Tarsus–Seyhan–Ceyhan coastal plain ("Çukurova Plain").

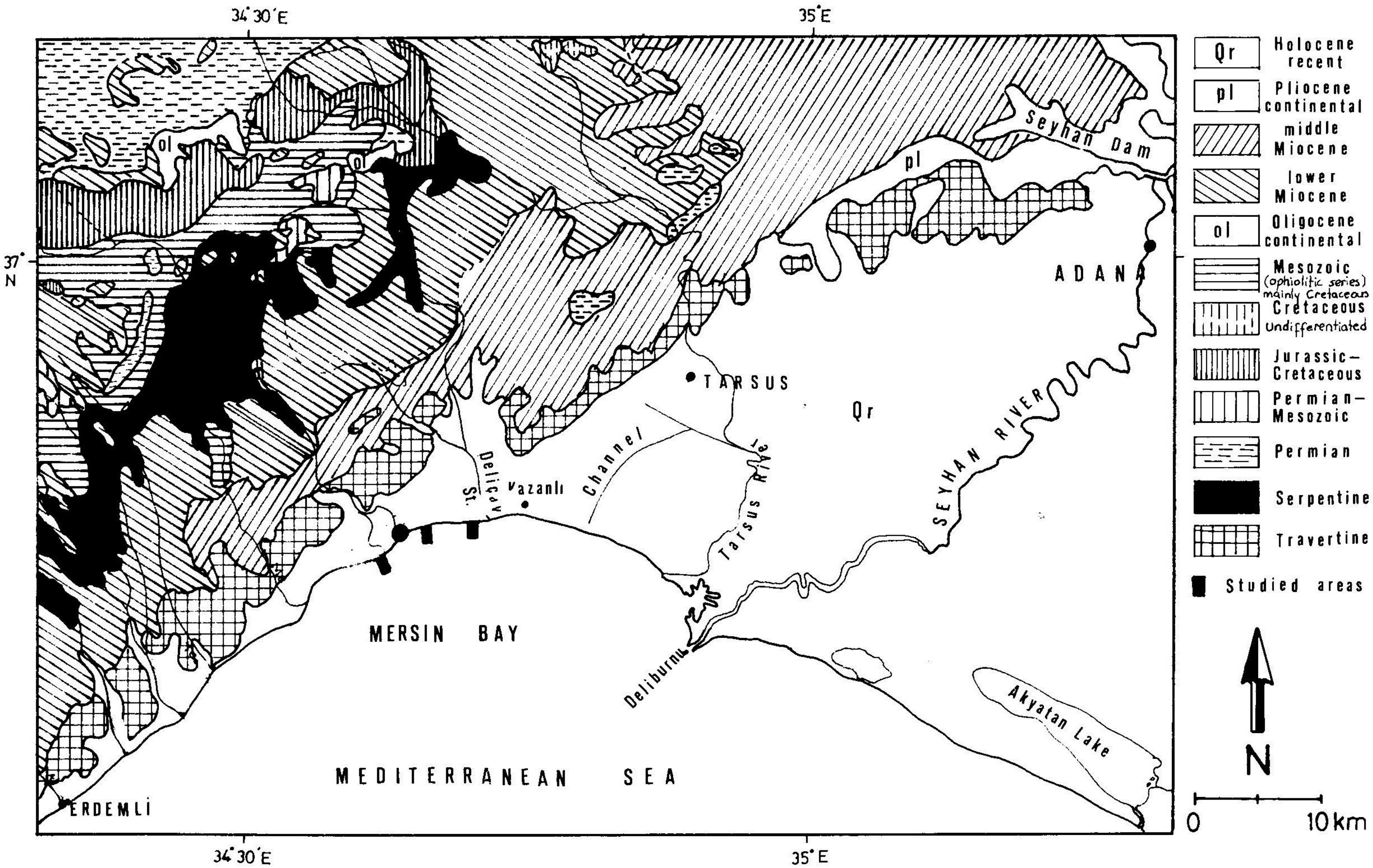


Fig. 2. Geological map showing Mersin Bay and its surroundings (after Ternek, 1962).

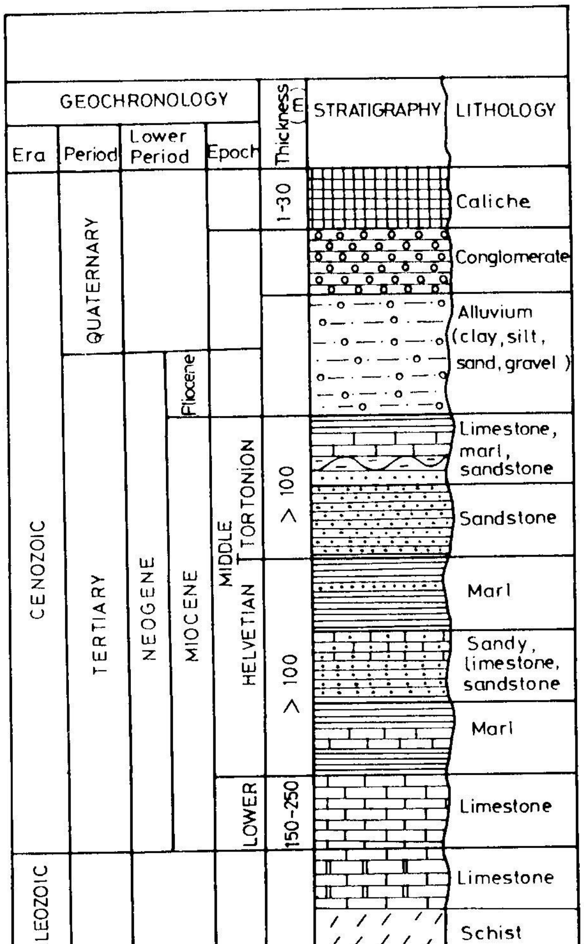


Fig. 3. Typical lithostratigraphic log for the coastal geology near the studied areas (after DSI, 1978 and pers. communication).

Oceanic circulation in Mersin Bay is characterized by the northwest–westward flow of the Asia Minor Current that is modified along the shallow waters of the coast by local winds and the configuration of the coast (Collins and Banner, 1978; Ovchinnikov, 1966; Ünlüata, 1986; Özsoy et al., 1987). The representative westward flow speed in the nearshore surface waters of Mersin Bay is of the order of 10 cm/s, although velocities from 3 to 60 cm/s were also measured at 5 m depths in nearly all directions during relatively stormy periods in November 1985 (IMS-METU, 1986). Tidal fluctuations are relatively small, within 20–50 cm/s (cf. Bal and Demirkol, 1987/88). Salinity measurements carried out in Mersin Bay generally show high values in offshore waters (37–39 ppt); low values (down to 26 ppt) are reported from nearshore waters at the surface due to seasonal peaks of inflow of river runoff into the bay (IMS-METU, 1986).

The ephemeral rivers [from west to the east: Mezitli, Efrenk (Müftüdere) and Deliçay], with drainage areas of the order of 300–400 km^2, are the largest fluvial sources of sediment to this area: The minimum and maximum annual water discharges of these rivers are 0–8, 0–110, and 0–330 m^3/s, respectively (compilation data from Ergin et al., 1992a). High suspended loads in nearshore surface waters with decreasing concentrations towards the open sea in Mersin Bay are also known from secchi disc readings and suspended matter analysis (IMS-METU, 1986).

The climate of the area is typically Mediterranean, with long dry summers and short, mild and rainy winters. The mean annual rainfall in vicinity of Mersin Bay is about 650 mm.

The texture, mineralogy and geochemistry of the surficial bottom sediments of nearshore Mersin Bay are well established (Mange-Rajeztky, 1983; Bodur and Ergin, 1988; Ergin et al., 1988; 1989). A study of the distribution of Holocene sediments on the inner and mid-shelf areas (5–100 m water depth) of Mersin Bay was carried out by Ergin et al. (1992a,b) who also used lithological data from numerous boreholes for lithostratigraphic reconstructions. Relatively little is known, however, about the regional shallow seismic characteristics and structures of sediments in the nearshore waters of Mersin Bay (Bodur and Ergin, 1989), particularly offshore between the Deliçay and Mezitli Rivers. This paper addresses the distribution pattern of the Late Quaternary sedimentary sequences and their surface structures in response to the various hydrographic conditions prevailing in the nearshore waters of Mersin Bay. This work is intended to be complementary to that presented by Ergin et al. (1992a). Discussion is limited to the sedimentological-geological framework of the upper 50 m of the sediment column.

Materials and methods

Fifty-six bottom sediment samples were collected off the coasts between the Deliçay and

Mezitli Rivers, nearshore Mersin Bay onboard the R.V. *Lamas* during 1985 (Fig. 4). A Dietz Lafonde grab sampler was used which takes samples representing about the top 10 cm of the seafloor. The textural parameters of sediment samples were determined using standard wet–dry sieving techniques for the sand (0.063–2 mm) and gravel (>2 mm) fractions and pipette methods for the mud fraction (<0.063 mm) as described by Folk (1974). The sediment types were classified using the nomenclature of Folk (1974).

Positioning was maintained using a Decca/Del Norte Trisponder navigation system. Water depths were measured with a Raytheon echosounder.

Single-channel high resolution seismic reflection profiles with shallow penetration were collected along 40 track lines (usually 1–2 km in length, both parallel and perpendicular to the coast) in the nearshore waters of Mersin Bay (3–15 m water depths; Figs. 5–7) in 1985 using an EG&G Uniboom sound source with a power output of 200 J. The incoming signal was filtered between 400 and 14,000 Hz. An assumed seismic velocity of 1700 m/s was used to derive the water depth and thickness of sediment above a regional unconformity. Seismic stratigraphic analysis methods outlined by Mitchum et al. (1977a,b), Mitchum and Vail (1977), Payton (1977), Vail et al. (1977), Sangree and Widmier (1979), Brown and Fisher (1980) and Bally (1983) and cited references therein were used to recognize the depositional sequences and unconformities on seismic profiles.

An EG&G Model 295-3 sidescan sonar system tuned to a frequency of 105 ± 10 kHz along 28 track lines parallel to the shore (Figs. 5–7) allowed the surficial features to be mapped.

Representative lithological logs from four boreholes drilled near the coast (from several private and government institutions) were also available (Fig. 8) for palaeogeographical reconstructions.

Results and discussion

Microtopography and surface sediments

In general, the depth profiles of the seafloor (Fig. 4) show a gentle slope with an offshore decrease in gradient towards the east. The slope

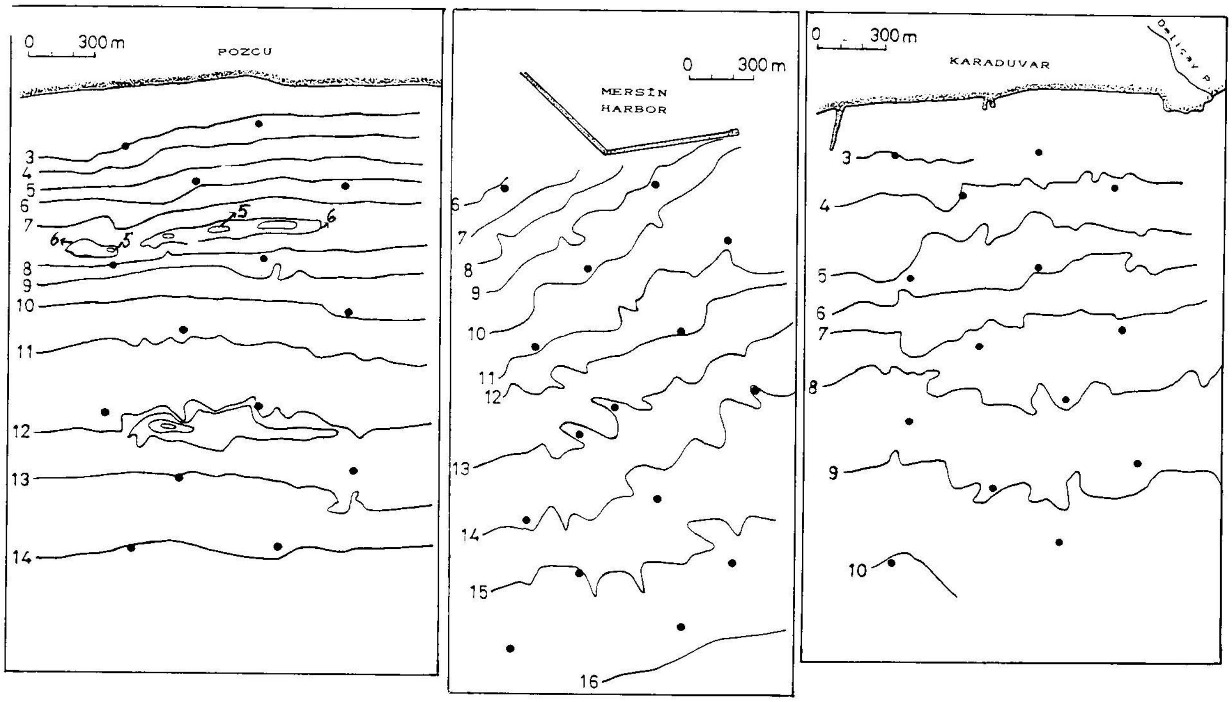


Fig. 4. Bathymetry of the studied areas in Mersin Bay together with locations of surface sediment samples.

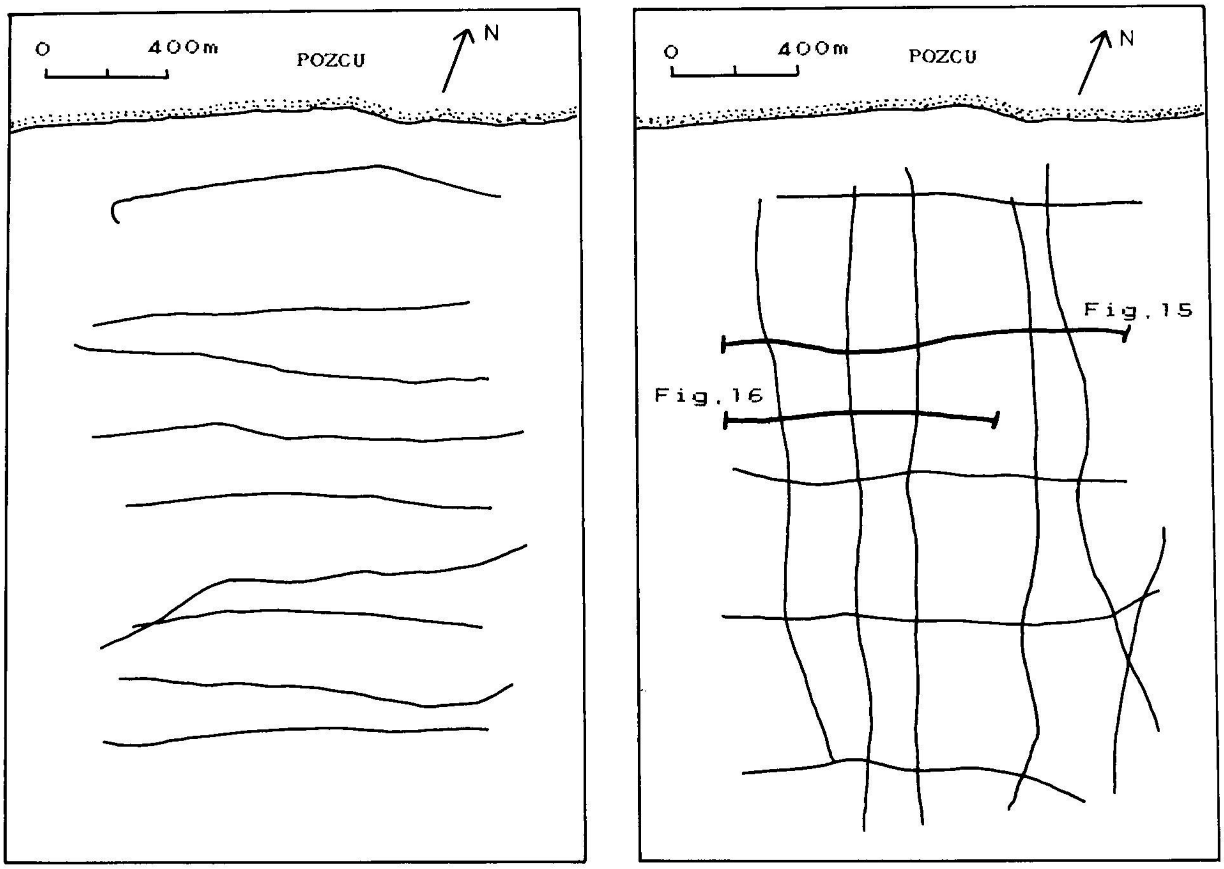


Fig. 5. Trackline map of seismic reflection profiles (right) and sidescan sonar surveys off the Pozcu coast.

ranges from 0.3° to 0.6° in the Pozcu area, whereas to the east it flattens to approximately 0.05°–0.3° in Karaduvar. Off Pozcu, a series of subcircular highs (5 to 6 m water depths) caused by the presence of gravelly-shelly beachrock outcrops runs nearly parallel to the shore between the 7 and 8 m isobaths. These beachrock patches were probably exposed at the surface under present day conditions after extensive reworking of the overlying sediments by waves and currents. The topography of the floor off Mersin and Karaduvar has a regular relief except for small discrete highs (Fig. 4).

Complete grain size descriptions are detailed in IMS-METU (1986) and Bodur and Ergin (1988). Analyses show that most of the samples contain less than 2% gravel. Sand and mud (mainly silt) are thus the dominant sediment types (Fig. 9). Exceptions do occur, however, off the Pozcu coasts between about 7 and 8 m water depth where large beachrock fragments are commonly found. Mud also dominates off Mersin Harbor (Fig. 9).

Off the Karaduvar coasts, sand is the dominant component of the samples and is secondary to silt in abundance in surface sediments. Approximately 75% of all samples contain greater than 50% silt. No sample consisted of more than 15% clay, and 75% of all samples contained less than 6% gravel. In contrast to the offshore Pozcu and Mersin Harbor areas, the area off the Karaduvar coasts, between 7 and 10 m water depths, is marked by the occurrence of gravel, which appears to be an important constituent of the sediments (Fig. 9).

The combination of the grain size results (IMS-METU, 1986; Fig. 9) and sidescan sonar records (Figs. 10–13) show muddy sand to be the dominant

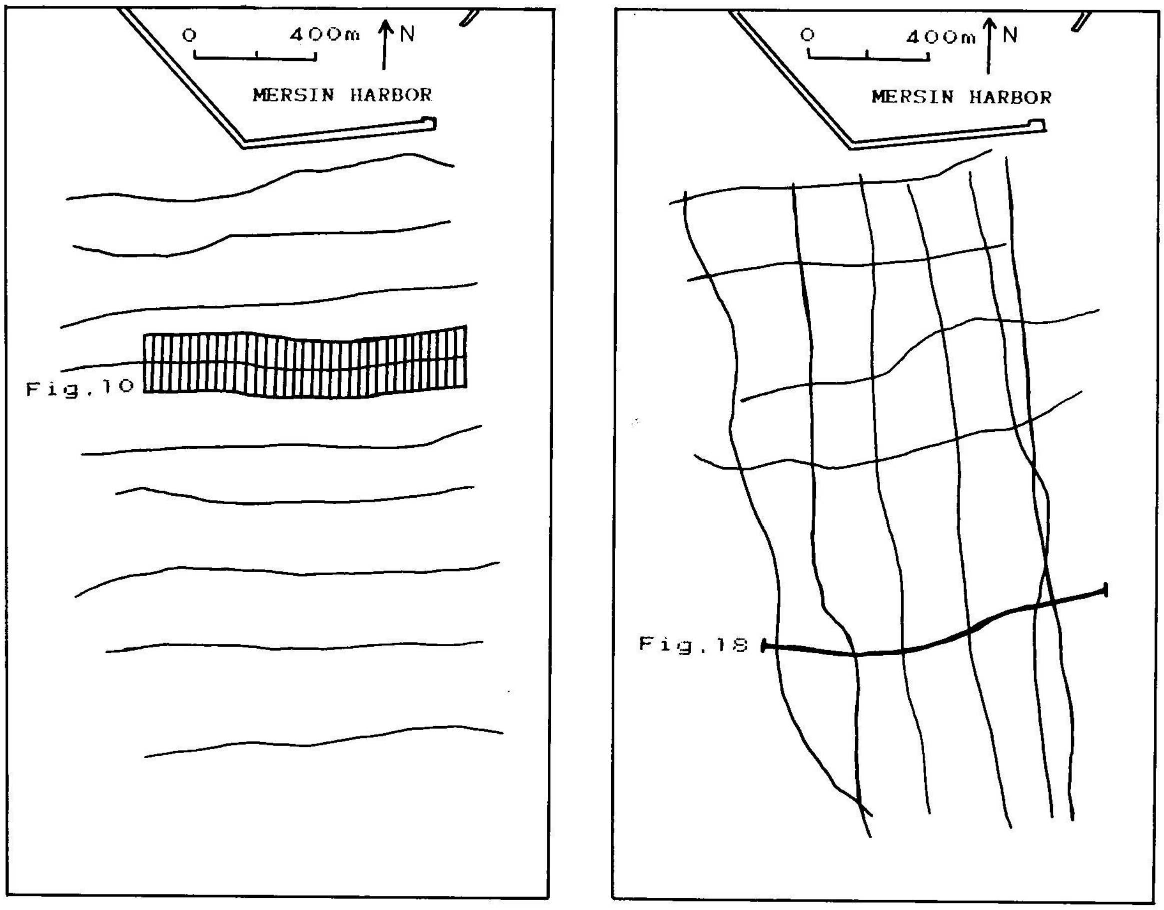


Fig. 6. Trackline map of seismic reflection profiles (right) and sidescan sonar surveys (left) off the town of Mersin (off Mersin Harbor).

sediment type on the floor of the studied marine areas, although there are significant variations in the bottom features among the three studied areas (Fig. 14).

Off the Pozcu coast, except for some irregularly distributed small-scale sand and gravel patches which are usually found at 10–15 m depths, gravelly-shelly beachrocks (Figs. 15 and 16) outcrop in the form of a narrow belt (100–150 m in width) lying parallel to the shore, at a distance of about 600–700 m (Fig. 14) and water depths of 7–10 m. The observed occurrences of such beachrocks (sand and gravel cemented by carbonate) towards the shore in the Pozcu area support this finding. This area is interpreted to be the site of former beach deposits (possibly relict or palimpsest on the present nearshore bottom, according to Swift et al., 1971; Chin et al., 1988), most probably formed during lowstands of sea-level at some time in the Late-Holocene (i.e. 7000–5000 yrs B.P.) when the sea level was 7–10 m lower than at present (Curray, 1965).

The muddy sand facies off Mersin Harbor are also associated with rocky components of conglomeratic beach rocks consisting largely of cemented sand and gravel (Figs. 10 and 14). Comparable sedimentary structures have been found off the Pozcu coasts (Fig. 14).

Off the Karaduvar coast, the occurrences of nearly symmetrical gravel waves between the tabular and longitudinal patches of sandy mud or muddy sand (Figs. 11, 12 and 14) are of particular

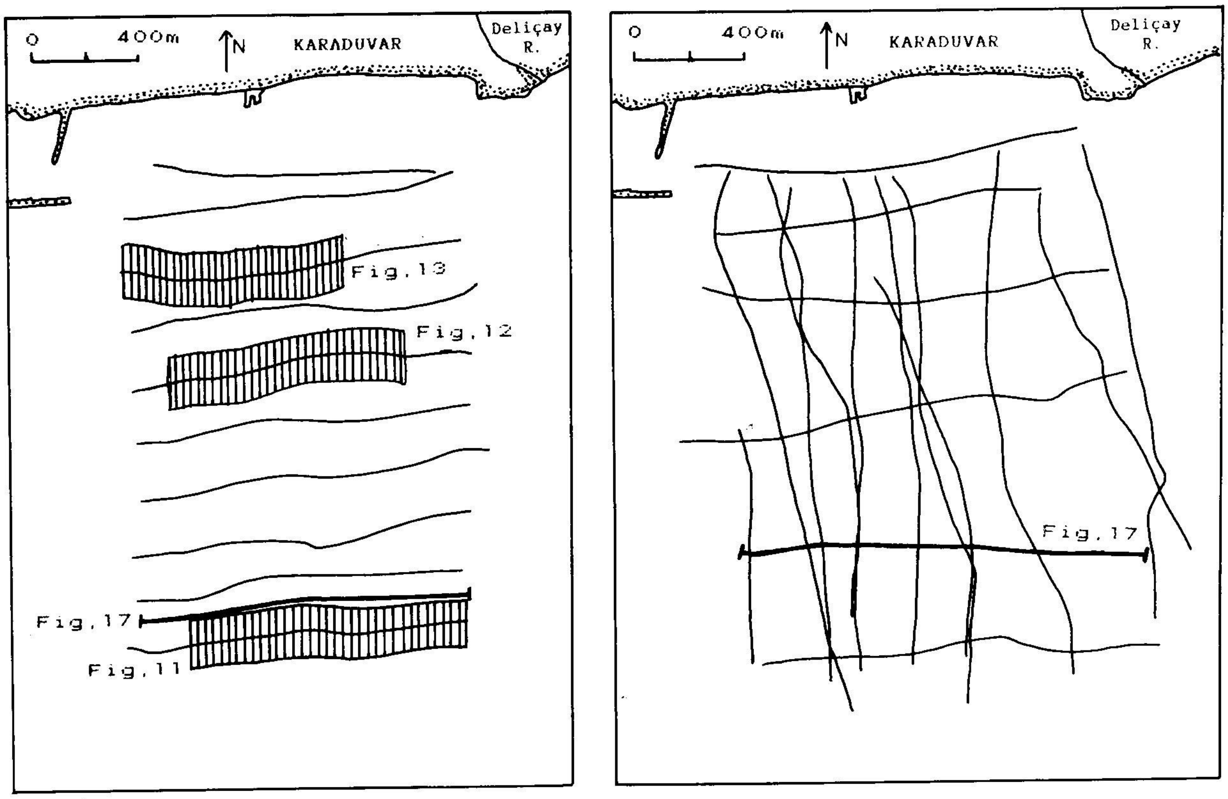


Fig. 7. Trackline map of seismic profiles (right) and sidescan sonar surveys (left) off the Karaduvar coast.

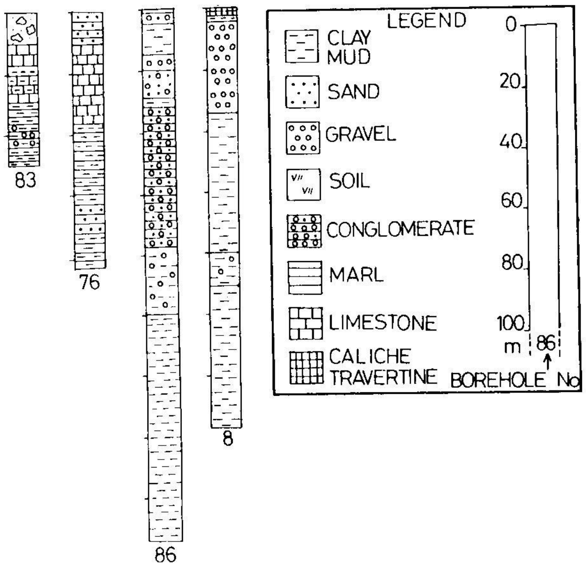


Fig. 8. Lithological logs from soil borings on the coasts of Mersin Bay (modified after DSİ, 1978). See Fig. 1 for location of the drilled boreholes. Note the top fill in Hole 83 is by man-made materials.

importance because they are not seen in the other two areas surveyed. This is probably due to the presence of a breakwater which apparently modifies the intensity and nature of water movements between the Pozcu and Karaduvar coasts. The transverse sandy patches are seen on sonographs (Figs. 11 and 12) as light toned bodies against a darker toned background. The latter probably represents the coarse basal gravel of the Holocene transgression. The nature of these sand and gravel bodies is also indicated by echosounder profiles (Fig. 17). These bedforms have been described from a number of wave-dominated shelves (e.g. Kenyon, 1970; Stride and Chesterman, 1973; Belderson et al., 1982; Kenyon and Flather, 1986). They are believed to have formed at the present day and to be an indicator of transport by large storm-wave induced currents (N.H. Kenyon, pers. commun., 1991). Sand patches associated with sand movement are thought to be due to the combination of storm-induced currents and wave effects (Belderson et al., 1982).

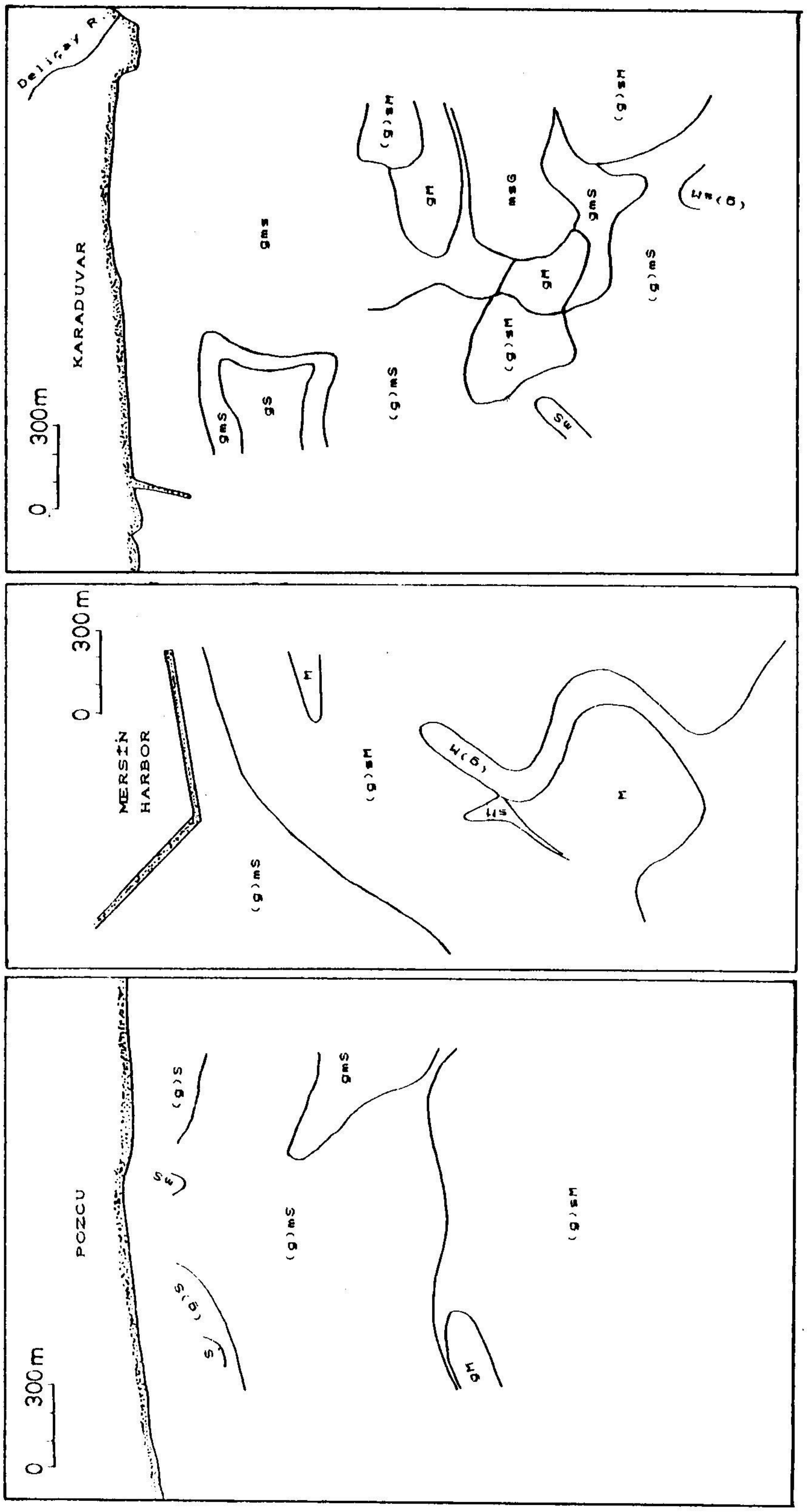


Fig. 9. Distribution of sediment facies on the seafloor off the Pozcu, Mersin Harbor and Karaduvar coasts. Based on sediment texture. Legend: s = sand; ms = muddy sand; $(g)mS$ = slightly gravelly-muddy sand; $(g)S$ = slightly gravelly sand; gmS = gravelly muddy sand; $(g)sM$ = slightly gravelly sandy mud; M = mud; sM = sandy mud; $(g)M$ = slightly gravelly mud; gS = gravelly sand; gM = gravelly mud; msG = muddy-sandy gravel.

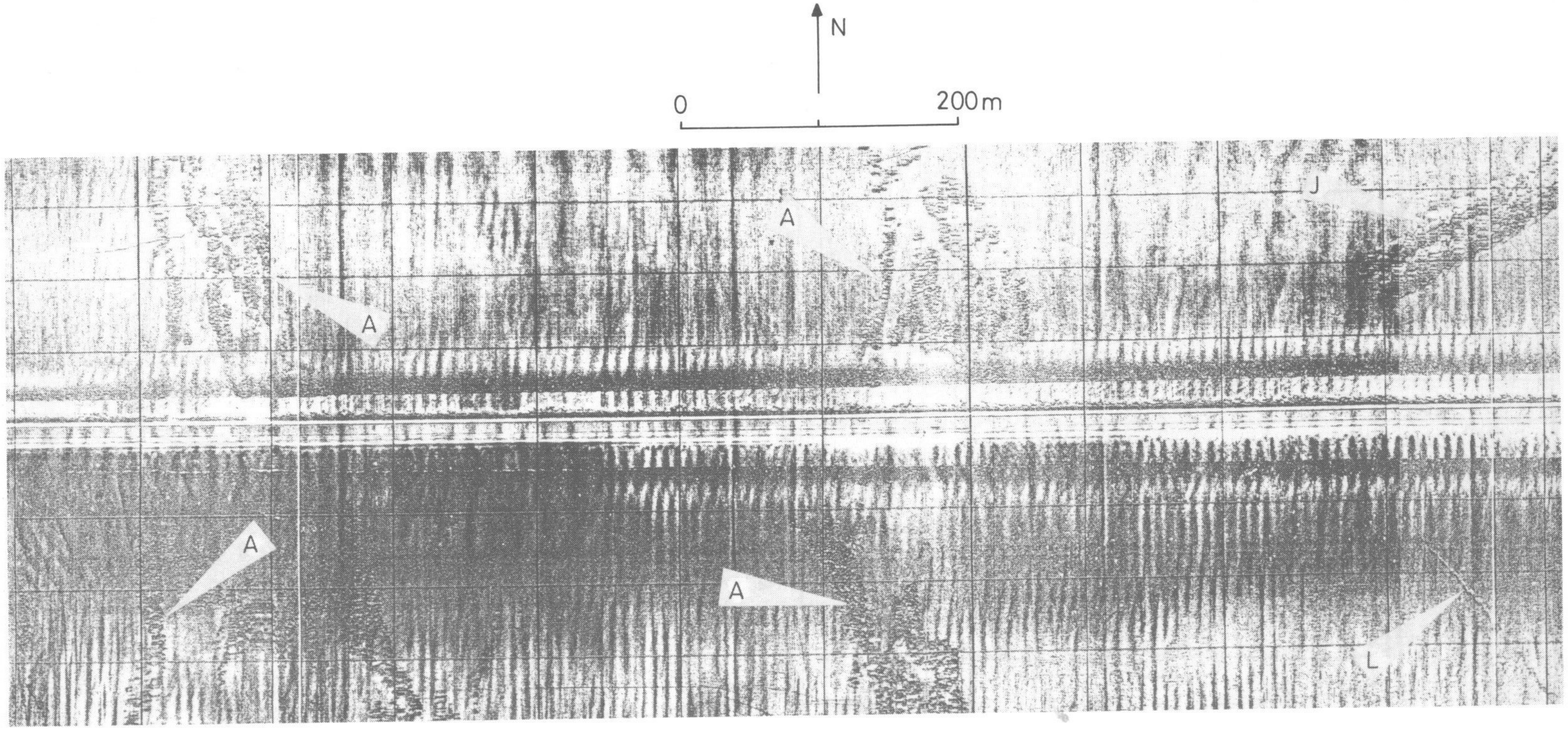


Fig. 10. Sonograph showing patches of gravel (*A*) and rocky surfaces (*J*) on the sandy mud-muddy sand floor off Mersin Harbor. Trackline location shown in Fig. 6 (entire profile). Range distance lines are 25 m apart. *L* represents anchor dredging. The white bands running along the length of the figure are areas where there is no sound illuminating the sea bed.

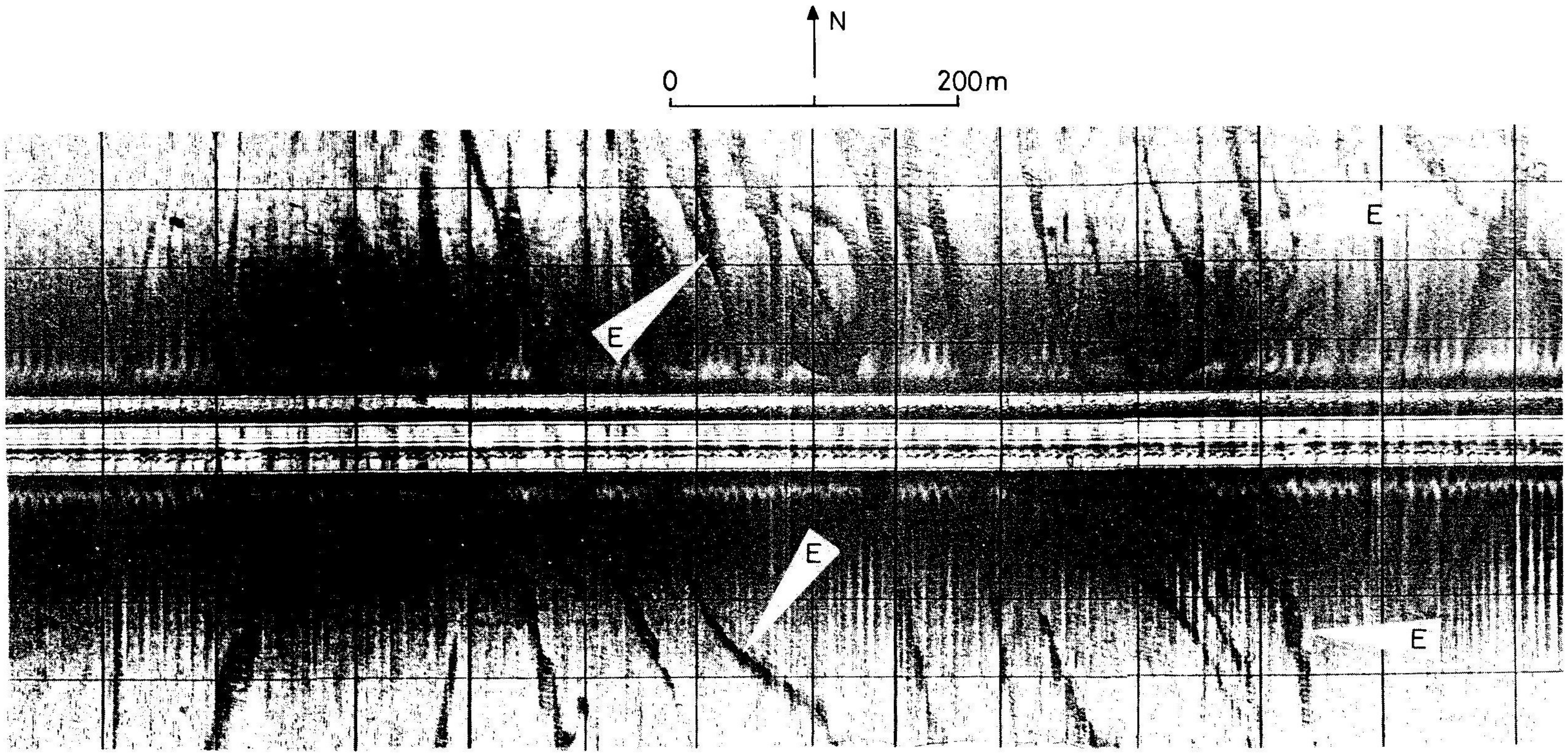


Fig. 11. Sonograph showing nearly symmetrical gravel waves (E, dark tone) between the tabular, longitudinal sand patches (light tone) orientated normal to the main current direction, off the Karaduvar coast. These bedforms are probably an indicator of transport by large storm wave induced currents. Trackline location shown in Fig. 7. Range distance lines are 25 m apart. The white bands running along the length of the figure are areas where there is no sound illuminating the sea bed.

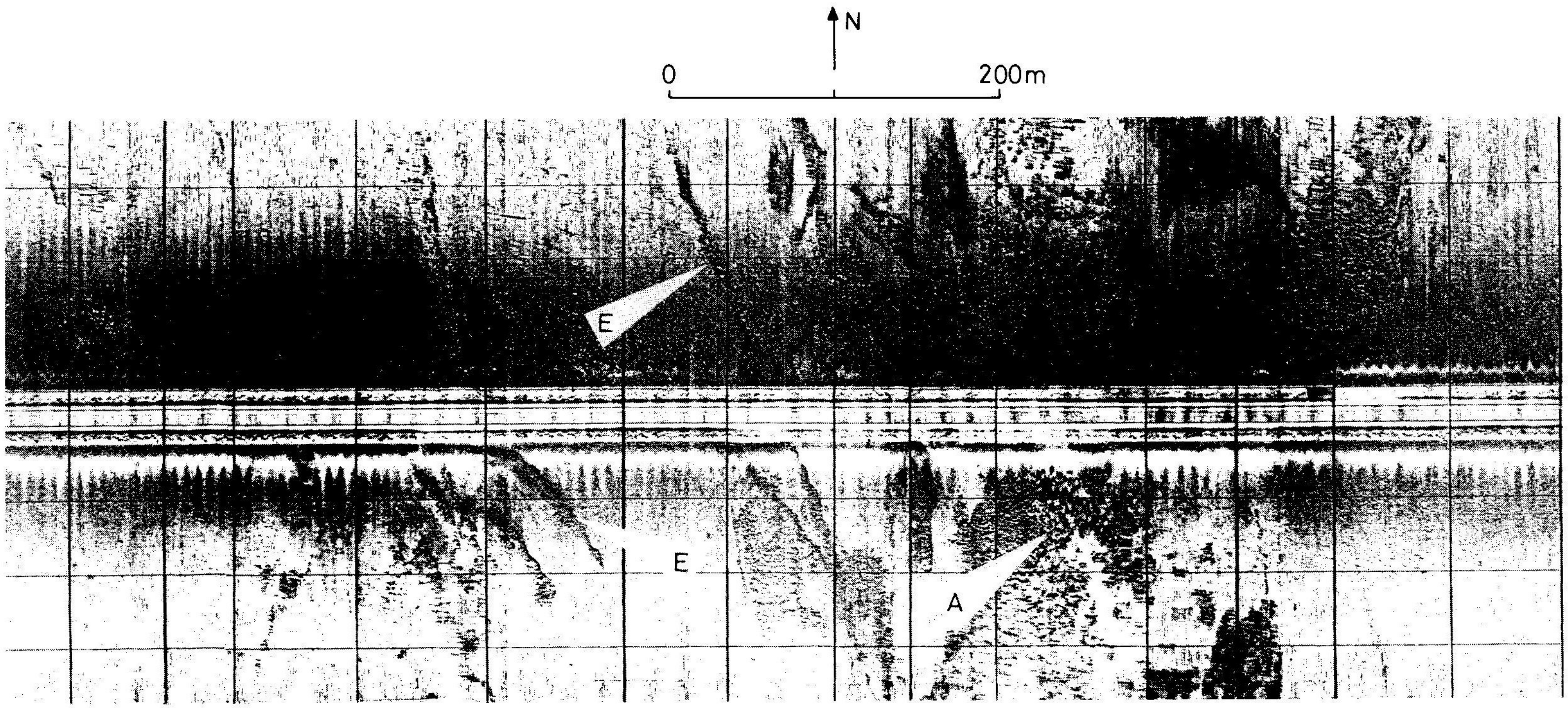


Fig. 12. Sonograph showing gravel waves (*E*) and sand patches (*A*) off the Karaduvar coast. Trackline location is depicted in Fig. 7. Range distance lines are 25 m apart. The white bands running along the length of the figure are areas where there is no sound illuminating the sea bed.

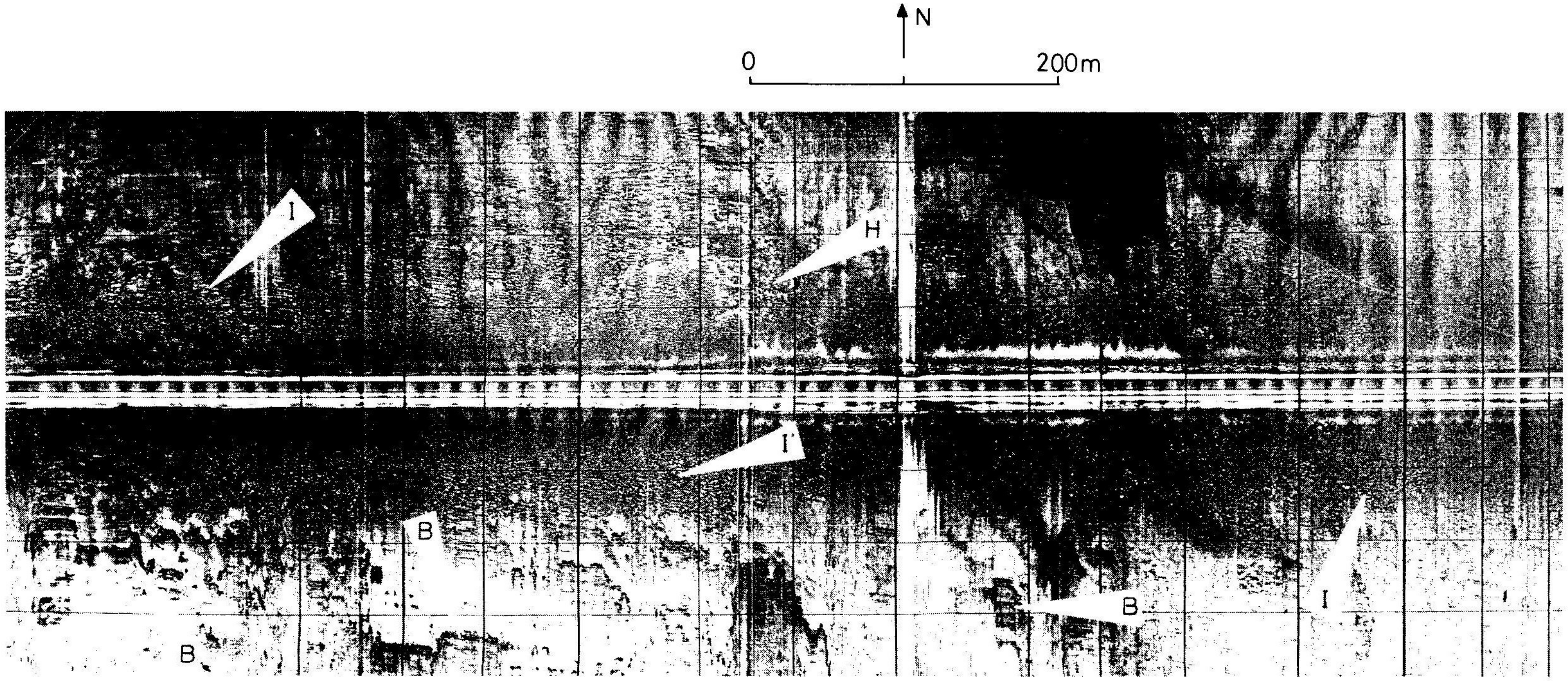
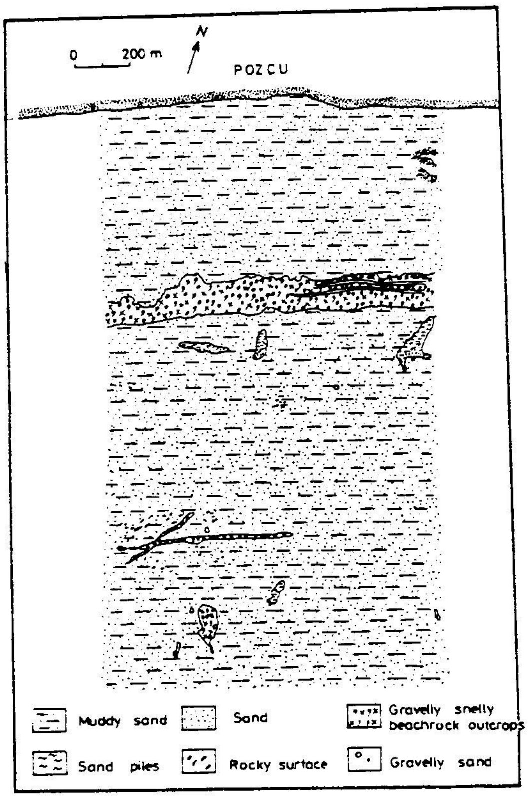


Fig. 13. Sonograph showing gravelly sand patches (*B*) and shell/shelly gravel fragments (*H*, *I*) off the Karaduvar coast. Trackline location is depicted in Fig. 7. Range distance lines are 25 m apart. The white bands running along the length of the figure are areas where there is no sound illuminating the sea bed.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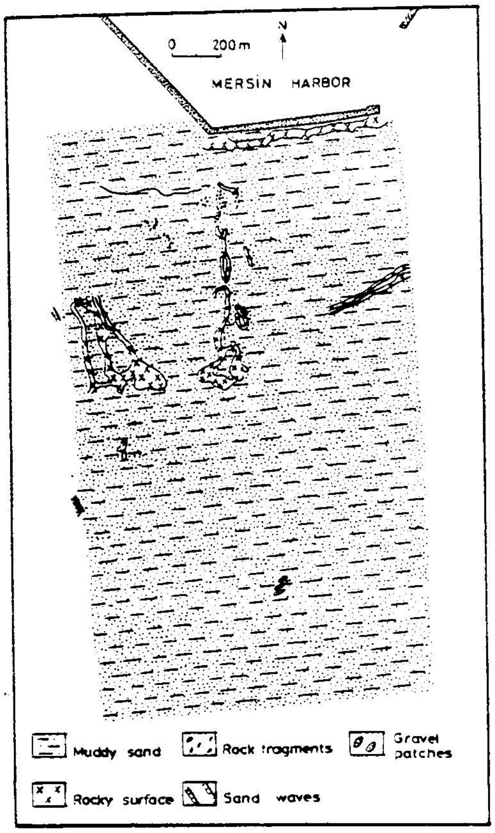
POZCU
Muddy sand
Sand
Gravelly shelly beachrock outcrops
Sand piles
Rocky surface
Gravelly sand


0 200 m
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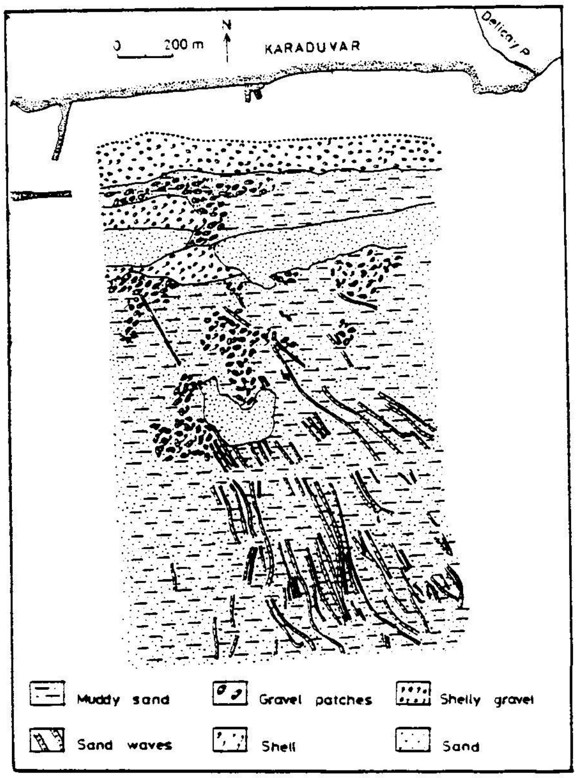
MERSİN HARBOR
Muddy sand
Rock fragments
Gravel patches
Rocky surface
Sand waves


0 200 m
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Muddy sand
Gravel patches
Shelly gravel
Sand waves
Shell
Sand

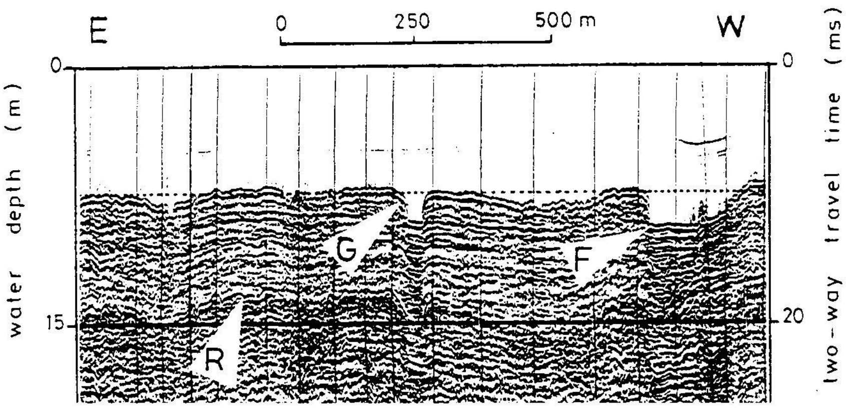

Fig. 15. High resolution seismic profile orientated parallel to the coastline off Pozcu showing a submarine ridge-furrow system (*F*,*G*) cut into beachrock. The mid-reflector (*R*) marks the pre-Holocene surface. Trackline location (entire profile) is shown in Fig. 5. See text for explanation.

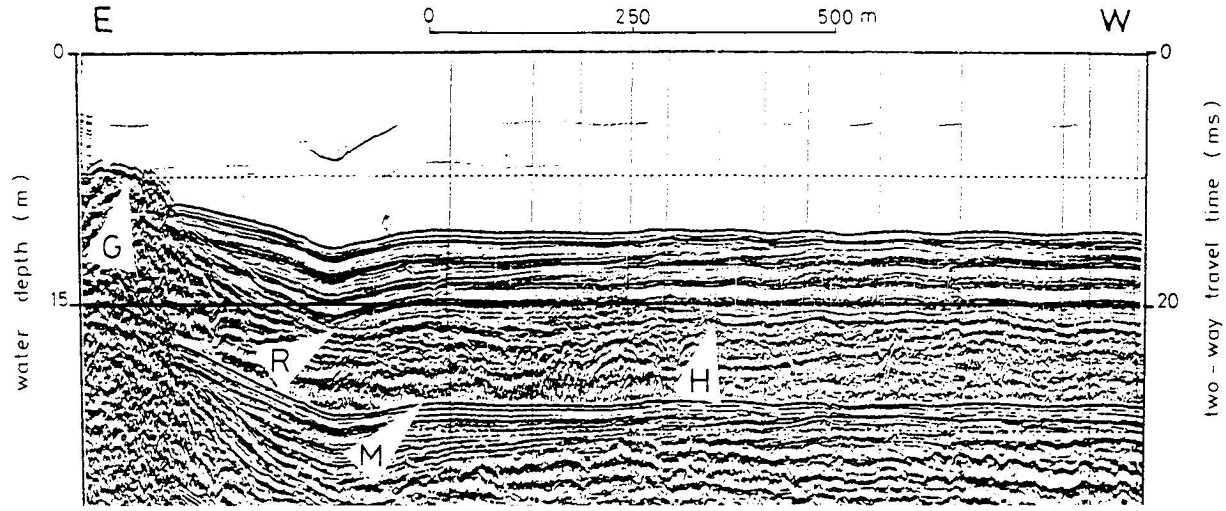

Fig. 16. High resolution seismic profile orientated parallel to the coastline off Pozcu showing two major sedimentary sequences separated by a mid-reflector (*R*) which is a pre-Holocene erosional surface. Trackline location (entire profile) shown in Fig. 5. *G* = submarine ridge, *M* = multiple, *H* = hyperbolic to chaotic/hummocky reflections indicative of poorly stratified, inhomogenous, coarse material. See text for explanation.

In the nearshore zones, much sediment transport takes place partially as the result of wave action and also as the result of currents which are directly or indirectly the result of waves (Davis, 1983). Based on ripple morphology (Reineck and Singh, 1975), both symmetrical and asymmetrical wave ripples (showing well developed bifurcation of their crests) and current ripples (with irregular crests and no bifurcation) may occur in the studied areas, although it is sometimes difficult to distinguish between those two types. These bedforms have an average height of 20–60 cm (Fig. 17) and are commonly concentrated at about 1–2 km from the shore with crests orientated in NW–SE direction, nearly transverse to the mean currents in this part of Mersin Bay. The ripple lengths of the gravel

Fig. 14. Distribution of sedimentary facies on the seafloor from nearshore waters of eastern Mersin Bay. Based on sonograph interpretation and sediment texture.

waves are 0.5–1 m, with ripple-crest trains from 50 to 500 meters in length. According to Belderson et al. (1972), high current speeds (40–100 cm/s) are required for the generation of such ripples in sandy environments; this is also applicable to the study areas where currents up to 60 cm/s are reported (IMS-METU, 1986). This suggests that temporary, high speed currents were present and that at least part of these gravel waves and sand patches are an expression of the superposition of wave-induced oscillatory water movements of varyious strengths and durations under the influence of various meteorological conditions. The shelly sand and gravel sediments (Figs. 9 and 14) are mainly confined to the areas close to the shore (Fig. 14) where waves and currents are most active. These sediments are commonly bored and encrusted with worm tubes, barnacles and bryozoans.

Coastal plain deposits

The drilled boreholes from sites inside the coastal areas show great thicknesses (over 160 m) of the Plio-Quaternary hinterland sequences (Fig. 8; Holes 86 and 8) in the east of Mersin, whereas to the west Neogene sequences (mainly limestones and marls) are nearly exposed at the surface. Here, boreholes (Holes 83 and 76) contain limestone units from 10 m downwards (Fig. 8). The extrapolation and interpretation of sonographic data and palaeolithic information from the available borehole (Hole 76) reveal fragments of the conglomeratic beachrocks on the seafloor off the Pozcu coasts (see Fig. 15). Taillefer (1964; cf. Alexandersson, 1972) also described such beachrock formations on degrading beaches on the Pozcu coasts (e.g., from Viranşehir).

Seismostratigraphic sequences

The sedimentary column on most of the studied seismic profiles can be divided into two main stratigraphic sequences which are separated by a strong mid-reflector (R) occurring at depths between less than 1 and 10 m below the seafloor (Figs. 15,16,18, and 19). It can be traced over most of the areas and represents an erosional unconformity which has been recognized on most of the seismic profiles by truncation of the stratified internal structure of the underlying sedimentary sequence. Such truncation is evidence of an erosional hiatus (Mitchum et al., 1977a; Vail et al., 1977). The mid-reflector (R) is recognized in the study area as the pre-Holocene surface as it is the first sub-bottom reflector of regional extent, representing the last shelf-wide regression (Ergin et al., 1992b). The same type of mid-reflector has been reported in many coastal areas, e.g. along the Korean Peninsula (Song and Park, 1984), offshore Mersin Bay (Ergin et al., 1992a), on the Rhone continental shelf (Tesson et al., 1990), and in the North Sea (Salge and Wong, 1988), and represents the pre-Holocene surface.

Sediments deposited in the upper sedimentary sequence overlying the mid-reflector tend to be generated parallel to gently divergent reflection configurations with a widespread sheet, or wedge-shaped, external form (Fig. 19). Hummocky and chaotic reflection patterns which occasionally interrupt the upper Holocene sequence (e.g. Figs. 16 and 19) are interpreted to indicate the presence of a disordered arrangement of reflection surfaces resulting from spatial and temporary variations in the depositional settings and energies. The interbedded, coarser, poorly sorted and/or gas-charged deposits probably account for this.

The beachrock outcrops observed off the Pozcu coasts (Fig. 14) and Mersin Harbor occasionally show ridge–furrow systems up to 2 m deep (Figs. 15 and 16). Where the gradient of a beach is steep and the backwash is strong, corrasion by wave action often cuts a rock surface into a system of nearly equispaced, subparallel ridges and furrows (McLean, 1967; Alexandersson, 1972). Beachrock occurrences have been reported from many localities in near-coastal areas of the eastern Mediterranean and their formation is related to the direct precipitation of carbonates from seawater within the pre-existing, eroded beach sediments (e.g. Alexandersson, 1972). For this study, it is difficult to attribute this kind of cementation to a specific process, such as the evaporation of highly saline seawaters, upward-migrating groundwaters and/or the mixing of fresh and saline waters, although all of these favourable conditions are or were present in the study areas, most probably at times of the

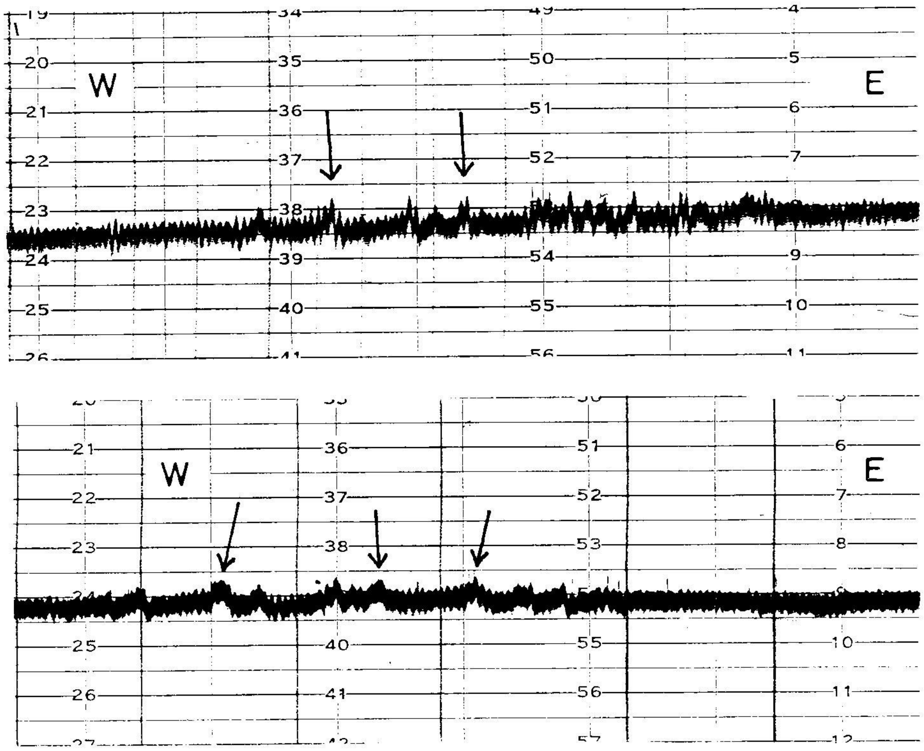

Fig. 17. Echo sounder profiles run parallel to the shores off Karaduvar. Trackline location shown in Fig. 7 (above, below, entire profile), both from the southern part of the study area. The arrows indicate the gravel waves between the tabular sand patches. Water depths are about 9–0 metres. See also Figs. 11 and 12.

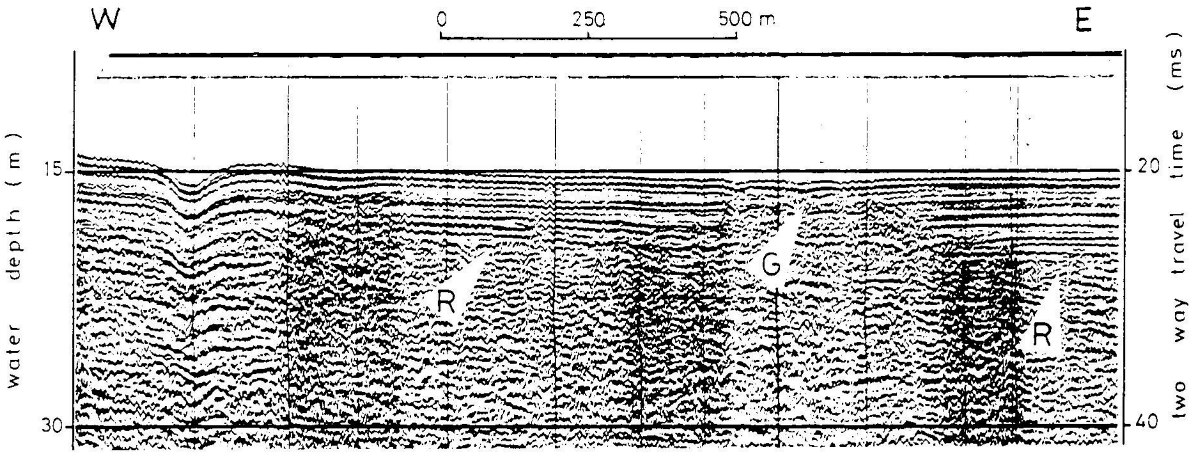

Fig. 18. High resolution seismic profile orientated parallel to the coastline off Mersin Harbor showing a buried ridge (*G*). Trackline location (entire profile) shown in Fig. 6. *R* = pre-Holocene erosional surface. Note the small depression in the topmost left of figure due to changes in the ship's course. See text for explanation.

prevailing lowstands of sea levels. Figure 18 shows a beach-ridge now covered by the Late Holocene sediments off Mersin Harbor.

The deposits of the lower sequence underlying the pre-Holocene mid-reflector are characterized by complex stratified reflection configurations, of which the chaotic seismic facies consisting of irregular and discontinuous parallel reflection patterns

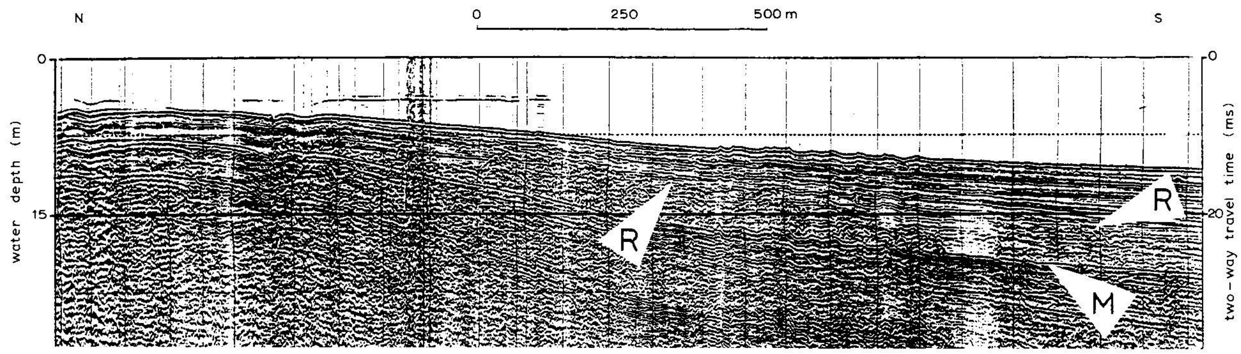

Fig. 19. High resolution seismic profile orientated normal to the coastline off Karaduvar showing pre-Holocene erosional surface (*R*) with hyperbolic to hummocky reflections indicative of poorly stratified coarse material. Trackline location (entire profile) shown in Fig. 7. M = multiple. See text for explanation.

are most common (Figs. 16, 18 and 19). The top of the pre-Holocene sequence is commonly hummocky with some hyperbolic/wavy reflections (Figs. 16 and 19) showing various erosional truncation features and cut-and-fill units. It must have resulted from the strong wave and current activity at lowstands of sea level. The hyperbolic reflectors normally show an irregular and poorly stratified bottom with inhomogenous, coarse materials.

The total thickness of sediments, mainly Holocene in age, is shown in Fig. 20 as isopach maps. Generally the high sediment accumulations occur away from the shore; this is typical of transgressive processes under shallow marine conditions where erosion and reworking is more important than deposition. The thicknesses of the possible Holocene sediments range from less than 1 m around the beachrock and gravel exposures up to 10 m at greater distances from the shore (Fig. 20).

Conclusions

Holocene sediments up to 10 m in thickness have been deposited on a subaerially exposed Late Pleistocene surface in the nearshore waters of eastern Mersin Bay. This is represented on the seismic profiles by the presence of two major sequences separated by unconformity of erosional truncation, the mid-reflector. The occurrences of gravel waves, sand/gravel patches and beachrock outcrops on the seafloor suggest shallow marine depositional conditions in a wave-current dominated environment where the reworking and redistribution of pre-existing sediments have been prominent processes in the Holocene.

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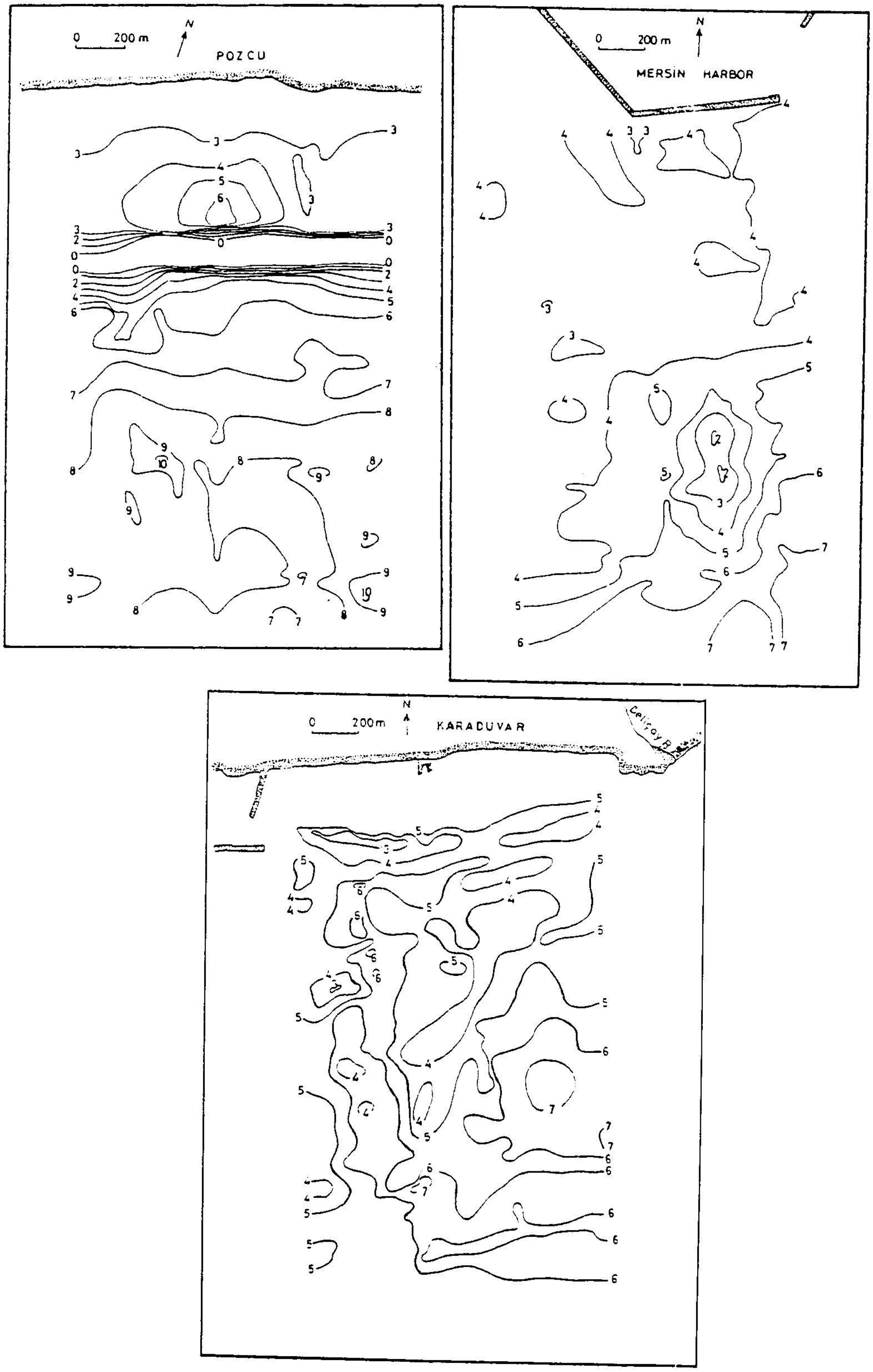
Fig. 20. Isopach maps showing the thickness of Holocene sediments (the sequence overlying the reflector, R) in the nearshore waters of eastern Mersin Bay. Contours in metres.


0 200 m
N
POZCU
MERSIN HARBOR
KARADUVAR

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