RECONSTRUCTION OF LATE QUATERNARY SHORELINES IN THE EASTERN MERSIN BAY (NORTHEASTERN MEDITERRANEAN SEA) INFERRED FROM HIGH-RESOLUTION SEISMIC RECORDS AND KNOWN SEA-LEVEL CURVES

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Summary. Analyses of an extensive grid of Late Pleistocene/Holocene erosional surfaces from seismic reflection profiles along with previously published sea-level curves and sedimentary environment information from the eastern Mediterranean permit an outline of the paleogeography of the eastern Mersin Bay (northeastern Mediterranean Sea) during the late Pleistocene and Holocene changes of sea-level. Taking a reduced deviation from accuracy into consideration; when combined with suitable global average sea-level curves not seriously affected by tectonic or isostatic complications, the high-resolution shallow-seismic profiles enable us to construct not only the positions but also the ages of the formerly subaerial and lowered late Quaternary shores in the Mersin Bay. A number of uncertainties in the rates of sea-level fluctuations, which are difficult to quantify, still remain. Nevertheless, we believe that, with the results presented here, it is possible to interpret the late Pleistocene to present paleogeography of the continental shelf of eastern Mersin Bay.

Riassunto. La paleogeografia della parte orientale della baia di Mersin (Mediterraneo orientale) durante i cambiamenti del livello marino nel tardo Pleistocene ed Olocene, è stata delineata grazie all'analisi di un esteso grigliato di superfici erosive tardo pleistoceniche/oloceniche definite attraverso profili sismici a riflessione integrati con analisi di curve del livello marino già pubblicate ed informazioni sull'ambiente di sedimentazione del Mediterraneo Orientale. In prima approssimazione si può considerare che i profili sismici ad alta risoluzione combinati a curve di variazioni del livello marino su scala globale (non seriamente affette da effetti tettonici o isostatici) consentono di costruire nella baia di Mersin non solo le posizioni, ma anche le età delle spiagge un tempo subaeree e quindi ribassate nel tardo Quaternario. Rimane tuttora una certa incertezza nel definire il rateo delle fluttuazioni del livello marino, che è difficile da quantificare. Tuttavia si suppone che con i risultati qui presentati è possibile interpretare la paleogeografia della piattaforma continentale della parte orientale della baia di Mersin dal tardo Pleistocene al presente.

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1. Introduction

Over the past decades, there has been increasing interest in the significance of marine geophysical techniques as a tool for investigating relative changes of sea-level and related depositional sequences in many parts of the world (Mitchum et al., 1977; Vail et al., 1977; Stefanon, 1985; Nummedal et al., 1987; Christie-Blick et al., 1990; Brambati and Colantoni, 1991). Specifically, they permit the identification and mapping of Late Quaternary shores as related to sea-level changes through the application of shallow-penetration and high-resolution seismic-profiling techniques (Curray and Moore, 1963; Van Andel and Sachs, 1964; Moody and Van Reenan, 1967; Van Andel and Lianos, 1984; Piper and Perissoratis, 1991).

1.1. Eustatic sea-level changes during the Late Quaternary

Studies in paleogeography, paleoclimatology and paleoecology have suggested that the world sea-level during the late Pleistocene interglacial times (Würm II/III), about 28000 to 35000 years ago, had already reached a position similar to the present one (Curray, 1965; Milliman and Emery, 1968; Clark et al., 1978; Barusseau and Giresse, 1987; Fairbanks, 1989). Following global cooling and subsequent massive glaciation, with a Würm glacial maxima at about 14000-20000 years ago (Ruddiman and McIntyre, 1981; Inman, 1983; Frihy and Stanley, 1987; Milliman, 1989), the sea-level in the eastern Mediterranean fell to about 95-140 m less

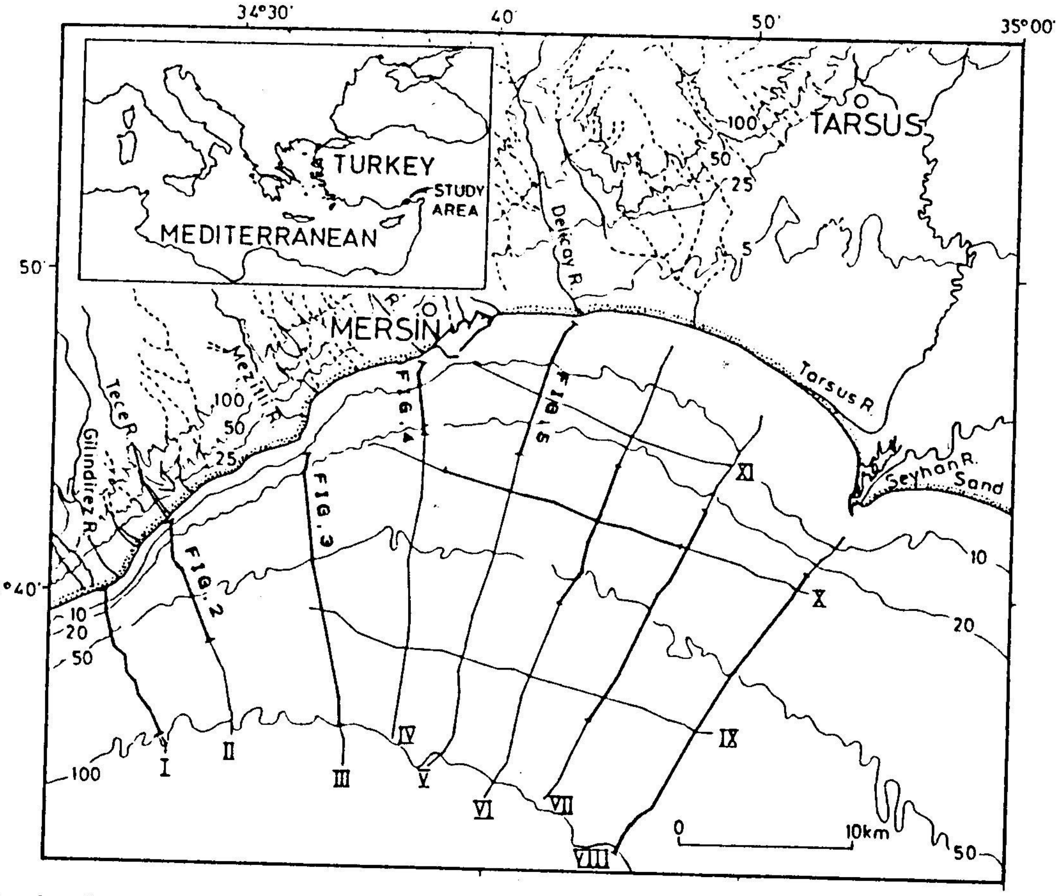

Fig. 1 — Location map of the seismic-surveyed marine region east of Mersin Bay. The seismic reflection profiles used in this study (Figs. 2-5) are given on tracklines (I-XI). Water depths are in meters.

than at present (Erinç, 1978; Van Andel and Lianos, 1984; Aksu et al., 1987; Herman, 1989; Vergnaud-Grazzini et al., 1989), as known from many parts of the world (Emery et al., 1988; Fairbanks, 1989). Then as a result of global warming and subsequent deglaciation, the sea-level rose rapidly until about 6500 years ago (Curray, 1964; Milliman and Emery, 1968; Clark et al., 1978; Buckley et al., 1982; Van Andel and Lianos, 1984; Aksu et al., 1987; Milliman, 1989). It continued to rise but slowly until a time of maximum transgression (post-Glacial Climatic Optimum), about 6500-4000 years ago (Erinç, 1978; Pirazzoli, 1991; Pirazzoli et al., 1991). Then followed a slow regression (Kraft et al., 1980; Erol, 1981; In: Prirazzoli, 1991), until the present sea-level was established around 3000-2000 years ago (Mörner, 1971; Erinç, 1978; Stanley and Blanpied, 1980). Since then, in the study area, any minor sea-level fluctuations would have been produced mainly as result of increased sedimentation/coastal progradation (Evans, 1973 and 1979; Erol, 1983; Bal and Demirkol, 1987/88).

1.2. Causes of relative sea-level changes

In the eastern Mediterranean, the relative sea-level must have changed during the Quaternary -apart from eustatic effects- mainly as result of tectonics, sediment compaction and basin subsidence. Of these, the tectonic factors which have prevailed during the late Quaternary, are largely confined to the Aegean shelves (Aksu et al., 1990; Chronis et al., 1991; Piper and Perissoratis, 1991) and southwestern Mediterranean coasts of Turkey (Flemming, 1978), whereas the southeastern coastal areas of Turkey such as the eastern Mersin Bay are very little affected by tectonics (Flemming, 1978). Pirazzoli et al. (1991) have found Holocene raised

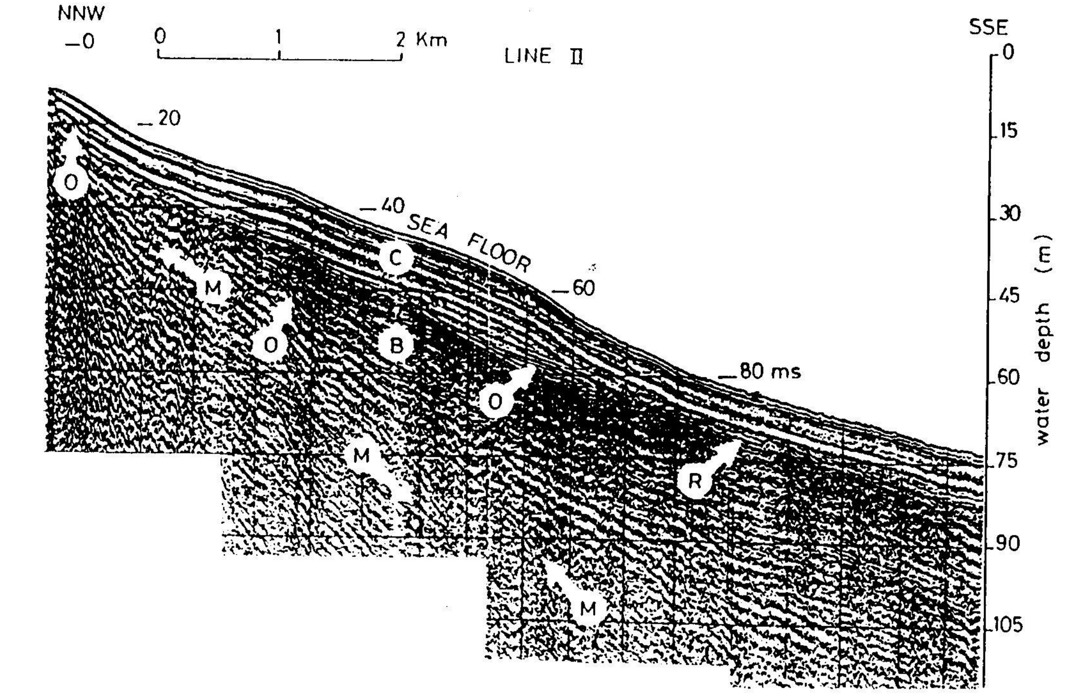

Fig. 2 — High-resolution seismic profile off the Tece River mouth. Profile is 0.3-8 km from the coast. Note the shallowing upward (onlap) sequence of a gently prograding shelf/delta system over an erosional surface (R) and the Plio-Pleistocene sequence (B) below it. O = onlap fill; C = mainly Holocene. The irregular and uneven surface of sequence C downdip indicates slope facies with possibly distal and proximal turbidites. M = multiple; (after Ergin et al., 1992).

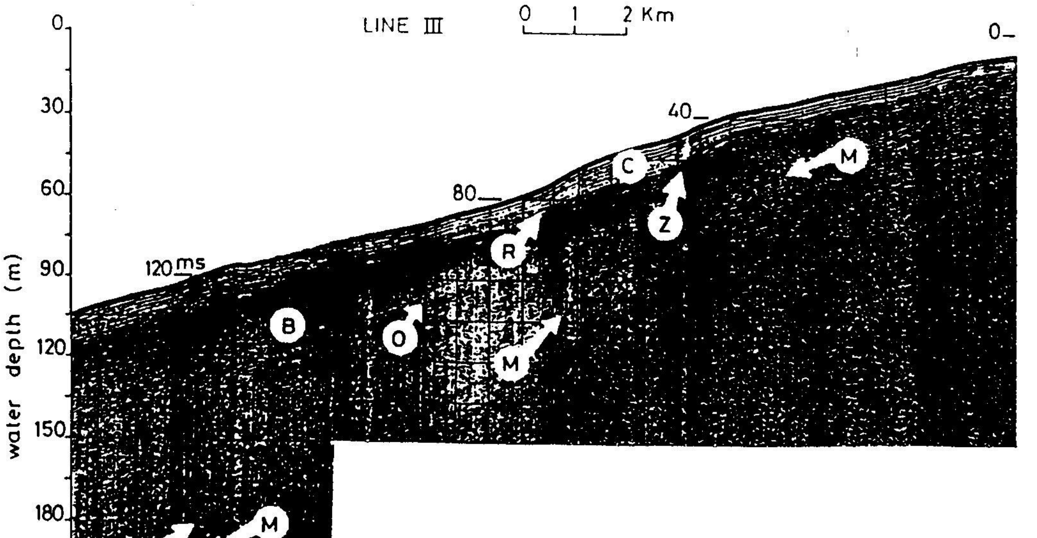

Fig. 3 — High-resolution seismic profile off the Mezitli River mouth showing widespread sheet of parallel/divergent to gently sigmoidal reflections indicating rather uniform deposition (C) over a pre-Holocene (B) surface (R). Note the opaque zone of gaseous layers (Z). Profile is 1.3-19.3 km from the coast. Note also the repetetive sequences with marine onlap configuration (O) reflecting cyclic sedimentation patterns during pre-Holocene times (B). M = multiple; (after Ergin et al., 1992).

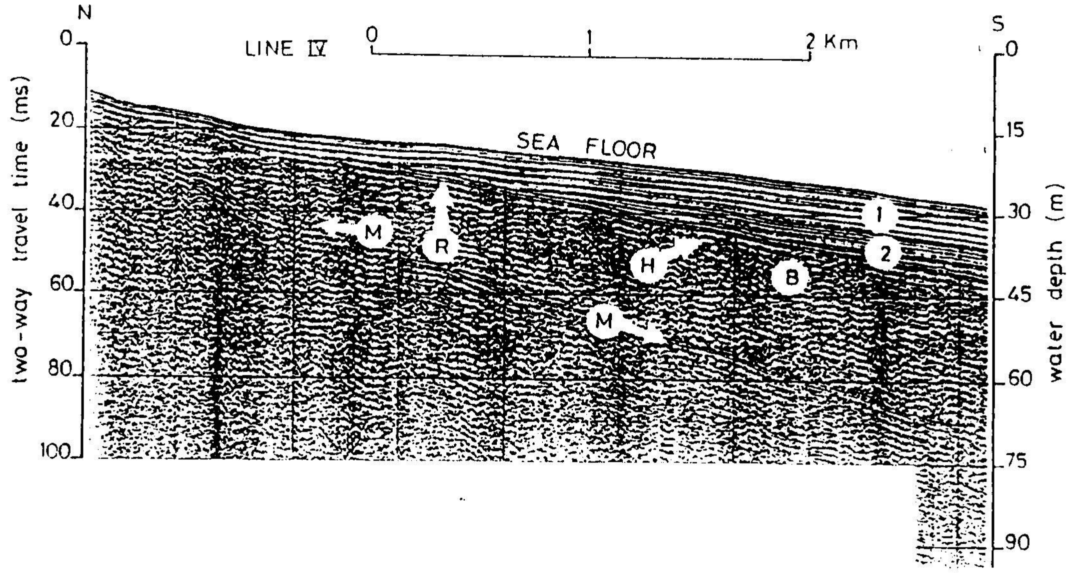

Fig. 4 — High-resolution seismic profile off the Kizildere River mouth. Note the shallowing upward sequences (onlap) of progradational delta facies on an erosional (H) pre-Holocene surface (R). The underlying angular unconformity of Unit 1 is onlapped by the marine transgressive facies (Unit 2). The profile is 0.4-4.5 km from the coast. M = multiple; (after Ergin et al., 1992).

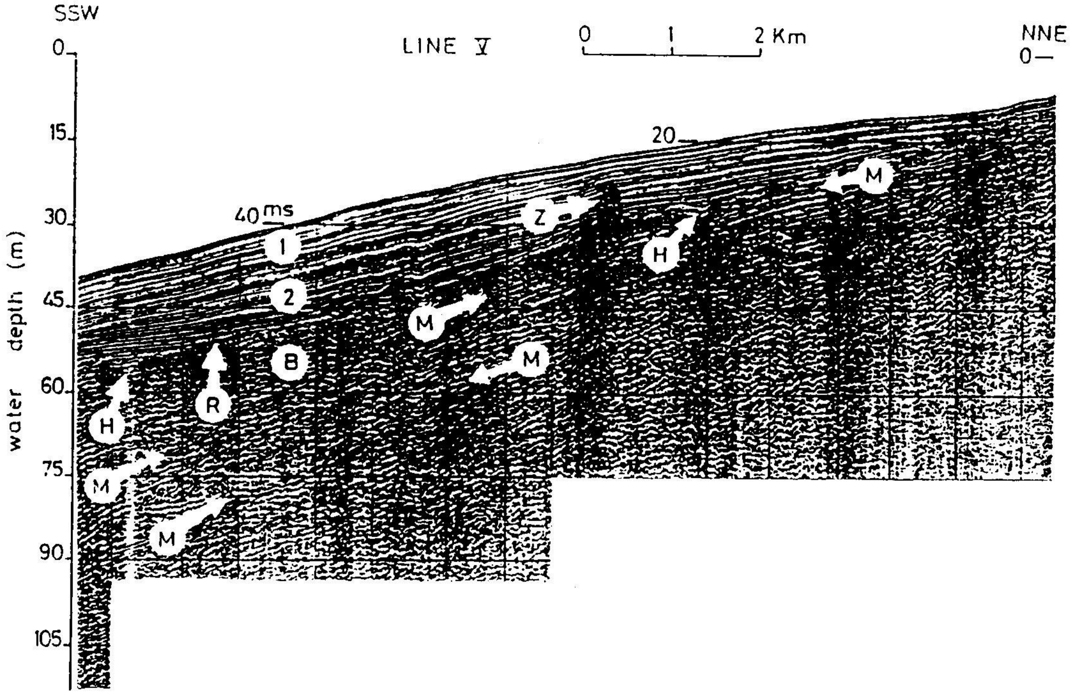

Fig. 5 — High-resolution seismic profile off the Deliçay River mouth showing the shallowing upward sequences (onlap) of prograding delta facies (Units 1 and 2) on an erosional (H) pre-Holocene (B) surface (R). Profile is 0.4-11 km from the coast. Z = opaque zone possibly due to gas or fluid occurrences; (after Ergin et al., 1992).

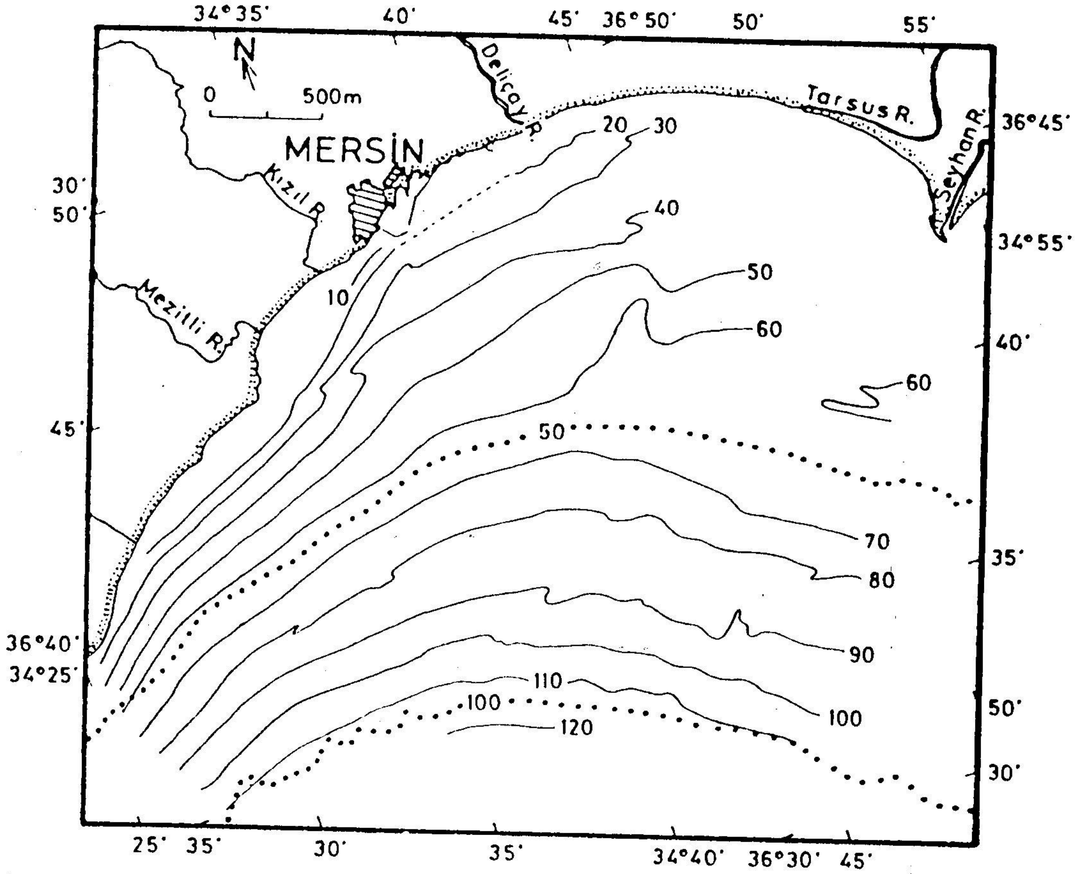

Fig. 6 — Depth of the contour map below present sea-level to the latest Pleistocene erosional surface (basal alluvial reflector) based on calculations from the seismic reflection profiles obtained in this study (i.e., Figs. 2-5). Dotted lines are present day water depths. Contours are in meters.

shorelines along the Hatay coasts, east of Mersin Bay, which had an elevation of about +1.2 to +2.2 m which is of minor importance compared to the eustatic sea-level rise of about 95-140 m. Furthermore, Flemming (1978) reported that no significant Holocene subsidence has occurred along the Mersin Bay coasts due to tectonics. By contrast, tectonically controlled vertical movements such as graben subsidence are highly pronounced along the Aegean Sea shelves where subsidence rates are found to be 0.3-5.0 mm/year (Aksu et al., 1990; Chronis et al., 1991; Piper and Perissoratis, 1991). Also, estimates for the maximum rates of sea-level fluctuation responding to plate tectonics and thus to horizontal plate motion are approximately 0.01 mm/y, clearly important on a geological time scale if persistent, but not significant on recent time scales (Aubrey and Emery, 1988).

More importantly, however, sediment compaction and basin subsidence are known to be more pronounced in the river deltas, primarily due to the withdrawal of pore fluids under the last of freshly deposited sediments (Emery and Aubrey, 1991). For example, subsidence rates were estimated at 1-3 mm/y off the Po River, 1-2 mm/y off the Rhine River, and 1.5 mm/y off the Thames River (cf. Emery and Aubrey, 1991). In consequence, the isostatic subsidence and compaction calculated for the delta margin of the Nile (0.4 to 2.5 mm/y; Stanley, 1990 and Arbouille and Stanley, 1991) would require relative sea-level changes in the order of 4-25 m during the last 10000 years. However, the delta of the Nile which is situated south of the Mersin Bay, is the largest delta of the northeastern Mediterranean and receives much more terrigenous material via river-runoff than do the Seyhan and Tarsus Rivers of the study area together. It is therefore obvious that the subsidence rates in the Mersin Bay due to compaction

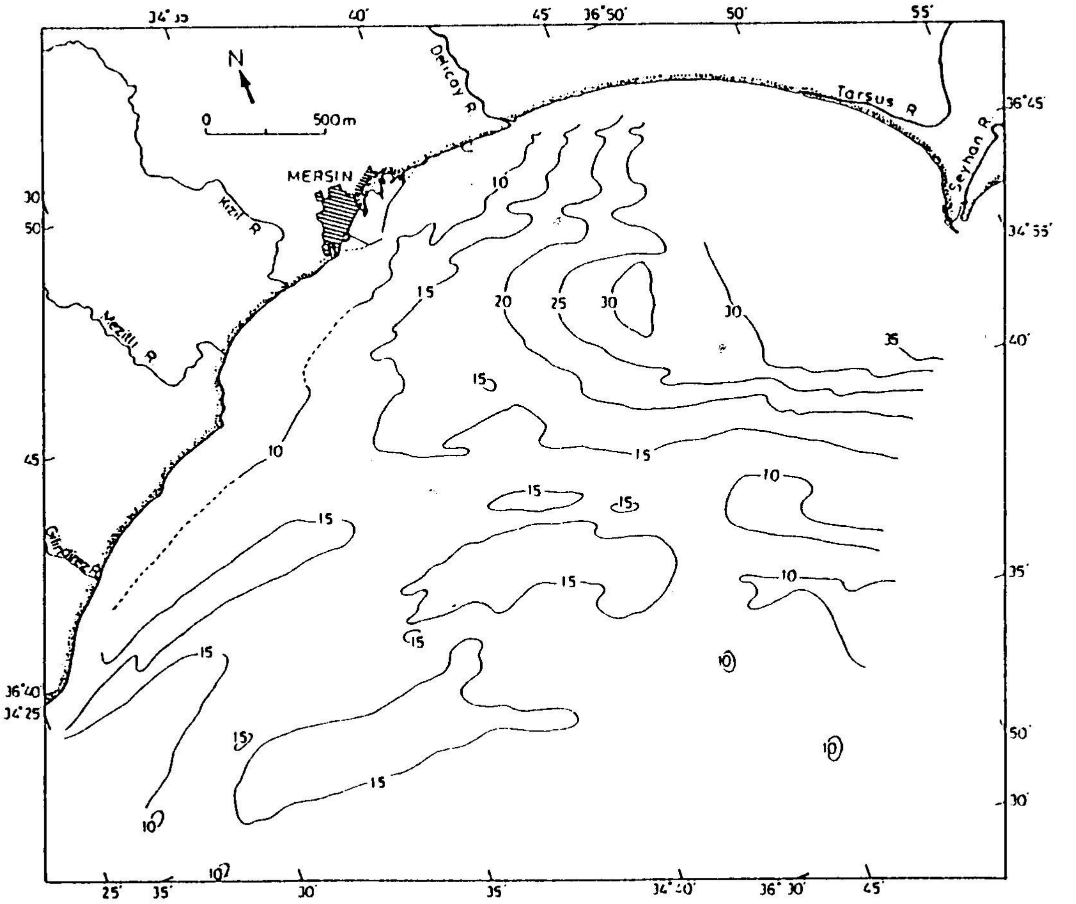

Fig. 7 — Isopach map showing the thicknesses of Holocene sediments (sequence C) on the inner and mid-shelf areas of the eastern Mersin Bay. Contours in meters; (after Ergin et al., 1992).

(compression/dewatering) must be much lesser (> 1.5 ± 1.0 mm/y) than those calculated for the Nile Delta. Nevertheless, such values are still low to consider for major corrections in water depths down to 120 m in the study area.

The sea-level changes in the eastern Mersin Bay (northeastern Mediterranean) have been balanced by sedimentation and tectonic uplift and thus, it is reasonable to assume that sea-level has been nearly stable for the past 4000 years (Erol, 1990). From the investigations above, we see that the Holocene sea-level changes in the Mersin Bay must be related largely to glacioeustatic influences, and the vertical tectonic and compaction movements appear to be less significant in the late Quaternary.

1.3. Stratigraphic patterns of continental shelf sedimentation affected by sea-level changes

In many regional studies, it has been determined that, accompanying the relative fall of sea-level, the pre-existing shorelines migrated seaward and the shelf was exposed to subaerial erosion and induration (Vail et al., 1977; Coutellier and Stanley, 1987; Knebel et al., 1988; Maldonado and Nelson, 1990; Nelson and Maldonado, 1990). In high-resolution seismic-reflection profiles, such lowstand erosional surfaces of late Pleistocene (Nummedal et al., 1987; Rodrigues et al., 1991) are usually characterized by a strong and continuous basal alluvial reflector displaying irregular relief, which is dissected by numerous channel-like fluvial features. Examples of erosional shore features underlying the Holocene transgressive deposits have been identified on many continental shelves (Milliman et al., 1982; Van Andel and Lianaos, 1984; Nummedal et al., 1987; Penland et al., 1988; Saito, 1989; Sha, 1989; Bodur and Ergin, 1992; Ergin et al., 1992).

In this work, we present an attempt to evaluate and to map the sea-level history of the Mersin Bay, as inferred from seismic-stratigraphic features (such as depths of erosional surfaces) and published sea-level curves.

2. Methods and materials

The high-resolution, seismic-reflection profiles we report here were collected along a 260-km grid of 11 tracklines on the continental shelf of the Mersin Bay, northeastern Mediterranean during the cruise of the R/V Lamas in 1989 (Fig. 1). The profiles were obtained by using an EG&G Uniboom seismic system (100-300 joules) with a resolution of about 0.15-0.30 m. We assumed a seismic velocity of 1500 m/s to derive water depths and 1600 m/s to derive thicknesses of the unconsolidated Holocene sediments (Ergin et al., 1992). In the seismic profiles (i.e., Figs. 2-5), we have determined the topography of the depths of late Pleistocene erosional surfaces below the present sea-level (Fig. 6) by converting acoustic velocities (two-way travel time) to meters.

3. Seismic stratigraphy and Late Pleistocene/Holocene sequences

Recognition of depositional sequences and interpretation of the resulting seismic stratigraphy along with data from lithologic logs from numerous boreholes along the coastal zone are presented in detail elsewhere (Ergin et al., 1992).

It has been found that seismic reflection profiles show at least two distinctive depositional sequences (C and B) separated by an irregular mid-reflector (R) (i.e., Figs. 2-5). Sequence C represents the relatively younger sedimentary deposits overlying the reflector R and is characterized by a simple-to complex-stratified reflection configuration on the seismic profiles (i.e., Figs. 2, 3). The top of this sequence forms the present seafloor. The depositional sequence C can be divided locally into two major units (Unit 1 and Unit 2) on some seismic sections (i.e., Figs. 4 and 5), whereby Unit 1 is characterized by much thicker parallel reflections in contrast to Unit 2 with relatively thinner reflections. This can probably be explained in terms of changes in the depositional conditions during the earlier (Unit 2) and later stages (Unit 1) of this sequence C. Occasionally, the paralel patterns of continuous reflections of Unit 2, especially at or near its base, are associated with or disturbed by sigmoidal-obliquely inclined and hummocky-disrupted horizons (i.e., Figs. 2-5) which can be interpreted as being due to the high-energy environments, rapid sea-level changes and large sediment input from streams and rivers, or combination of these factors at some time during the early Holocene (Ergin et al., 1992). On the other hand, because of its wide, relatively uniform lateral extent, Unit 1 is interpreted as having been deposited at fairly uniform rates on a relatively stable surface, most probably during the later stages of the Holocene (Ergin et al., 1992).

Sequence B which underlies sequence C is characterized by chaotic reflection configurations (i.e., Figs. 2-5). The top of this sequence (reflector R) shows various valley-and channel-like depressions cutting the underlying surfaces now filled with parallel to oblique reflectors which onlap onto the channel margins (i.e., Figs. 2-5). Such vertical boundary relationships and related unconformities are usually indicative of pre-Holocene surfaces produced by subaerial fluvial erosion of the continental shelves (e.g., Van Andel and Sachs, 1964; Moody and Van Reenan, 1967; Stefanon, 1985; Coutellier and Stanley, 1987).

Therefore, we interpret with confidence the basal reflector R in the seismic profiles of this study as a late Pleistocene and early Holocene erosional land surface at a lowered sea level now buried under the sediments of the subsequent post-glacial (Flandrian) transgression (Ergin et al., 1992). Thus, the sedimentary sequence B is thought to represent roughly the Pleistocene while sequence C is interpreted as the Holocene.

Fig. 7 shows an isopach map of the total thickness distribution of Holocene sediments (sequence C) in the Mersin Bay. Maximum sediment accumulation occurs in the areas off the mouths of the Deliçay, Tarsus and Seyhan rivers, where Holocene sequences reach a thickness of up to 35 m (Ergin et al., 1992). The thickness of sequence C generally decreases seaward,

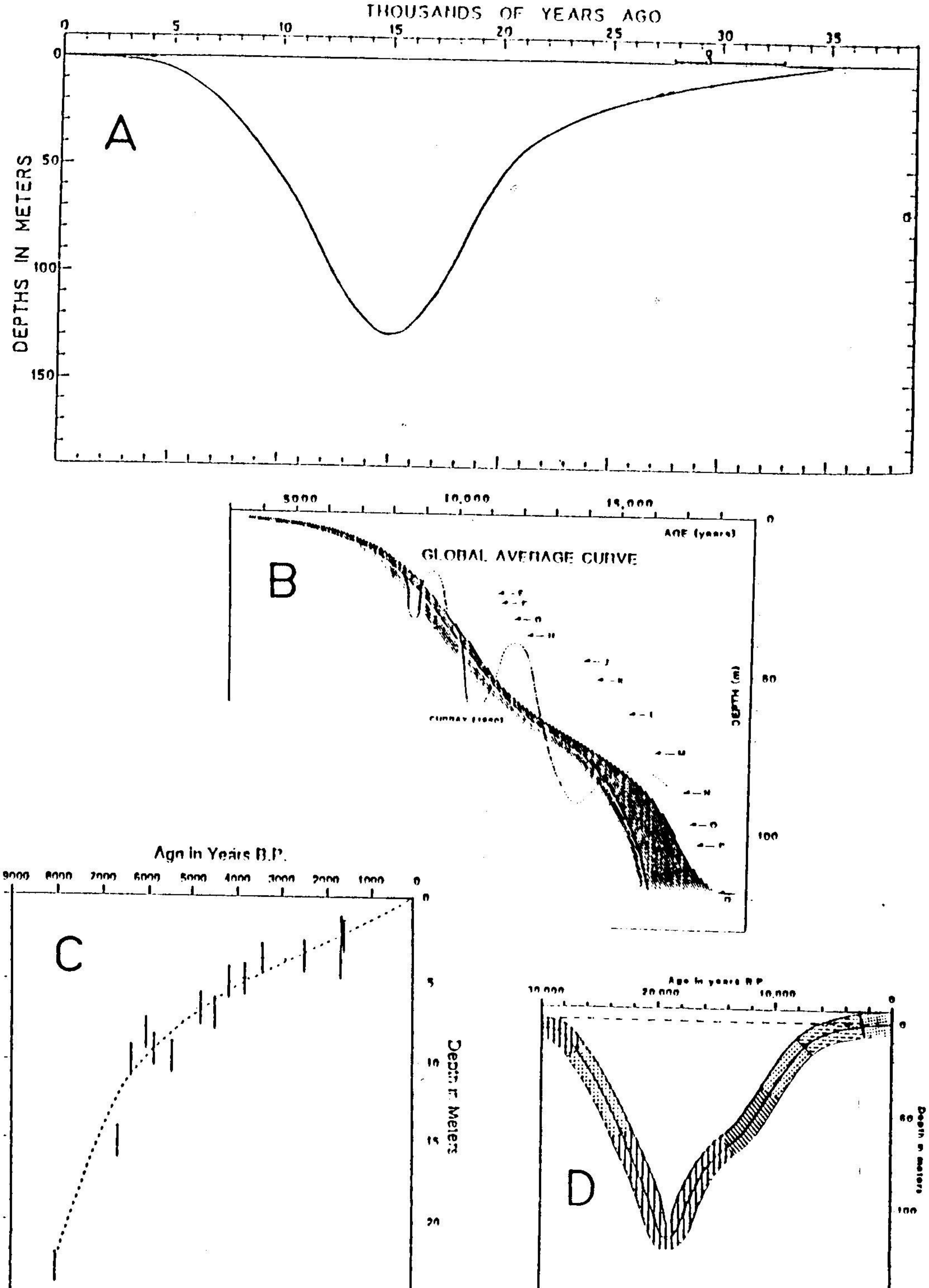

Fig. 8 — Eustatic sea-level curves: A: after Milliman and Emery (1968); B: after Bloom (1977); C: after Arbouille and Stanley (1991); and D: after Curray 1965 and Fairbanks 1989 (Adapted from Arbouille and Stanley, 1991). See text for explanation.

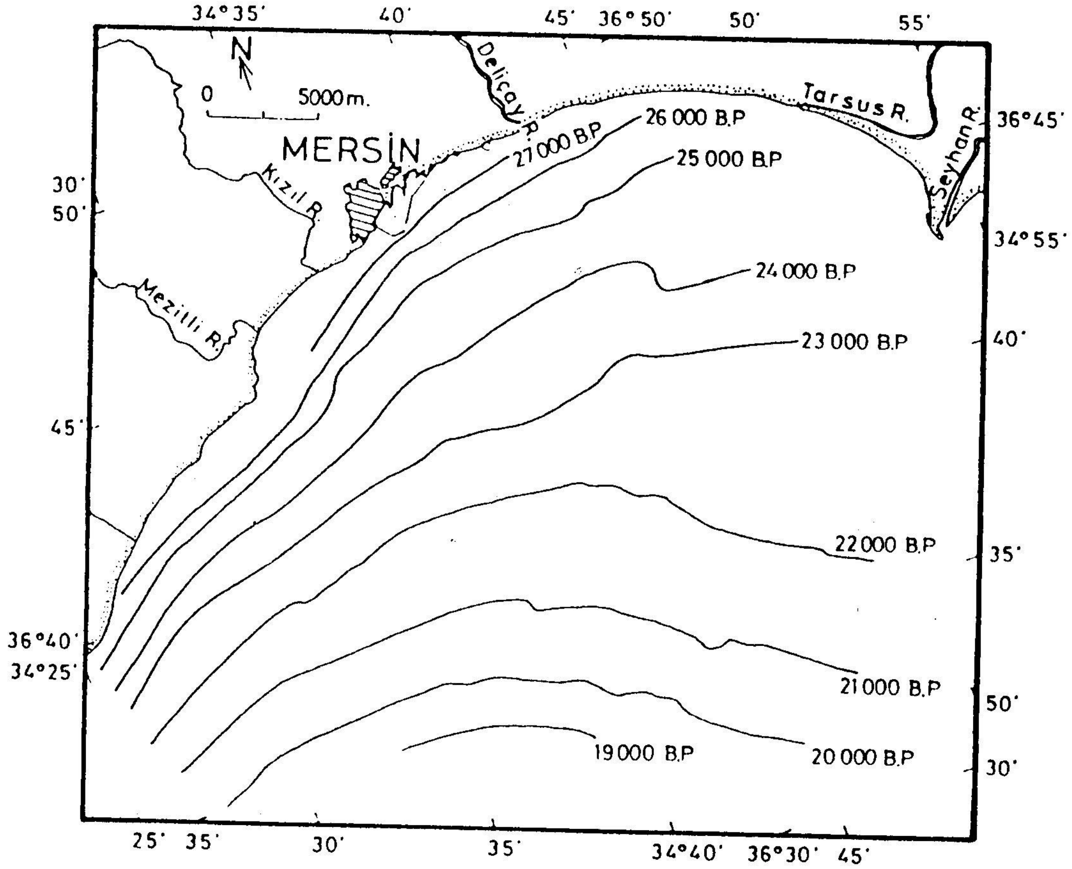

Fig. 9 — Isopach map of the late Pleistocene shorelines of the Mersin Bay which lasted from about 27,000 to 19,000 yrs. B.P. based on calculations from seismic reflection profiles (Ergin et al., 1992) and eustatic sea-level curves (after Curray, 1965 and Fairbanks, 1989).

with thicknesses of approximately 10-15 m in most of the offshore areas (Fig. 7).

4. Semi-quantitative estimates of the paleoshorelines

Given the presently available late Quaternary histories for the northeastern Mediterranean Sea, as aforementioned, we felt confident that the published global average sea-level curves (Fig. 8) (Curray, 1965 and Fairbanks, 1989. In: Arbouille and Stanley, 1991) used here are sufficient to reflect major sea-level changes and their distribution in space and time. We do not intend to debate here the merits of one or other of the curves, in view of the possible local effects of isostatic compensation (Clark et al., 1978). The only problem stems from the fact that we have no local sea-level curves presently available. However, since the sea-level cannot have fallen in one part of the world and risen in another, it is clear that what we see here is a relative land motion (Milliman, 1989).

With all this in mind, we have dated the late Quaternary shores of Mersin Bay (Figs. 9 and 10) by extrapolation of the age/depth positions of known sea-level curves (Milliman and Emery, 1968; Bloom, 1977) (Fig. 8) to the late Pleistocene erosional surfaces (Fig. 6) obtained from the seismic records (i.e., Figs. 2-5; Ergin et al., 1992). The isopach map of the late Quaternary (25000-16000 yrs BP) shorelines in the eastern Mersin Bay (Figs. 9 and 10) has shown that during the last Glacial Maxima (approx. 18000-17000 yrs BP) the sea-level dropped to about −90 to −110 m below that at present. These findings are nearly consistent with those reported for the eastern Mediterranean (e.g., Van Andel and Lianos, 1984; Aksu et al., 1987; Frihy and Stanley, 1987). On the other hand, following the Flandrian transgression accompanied

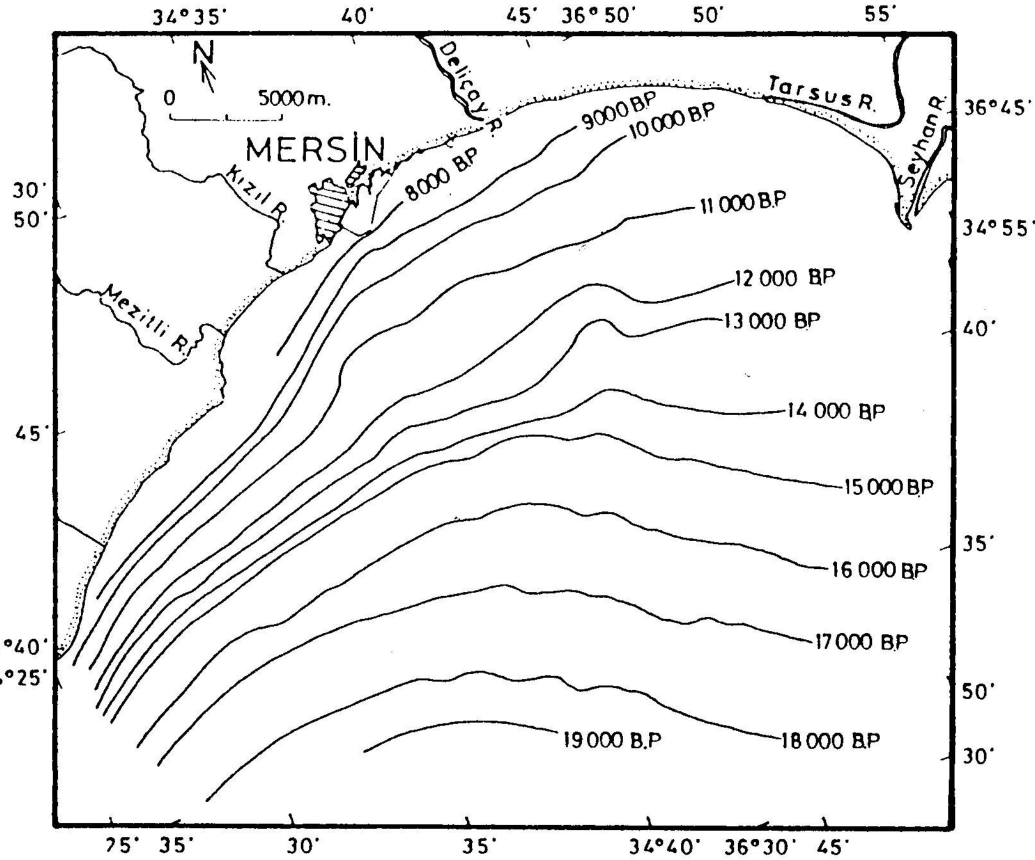

Fig. 10 — Isopach map of the Holocene shorelines of the Mersin Bay which lasted from about 19,000 to 8,000 yrs. B.P. based on calculations from seismic reflection profiles (Ergin et al., 1992) and eustatic sea-level curves (after Curray, 1965 and Fairbank, 1989).

by some possible fluctuations, the sea-level was roughly —50 m about 12000 yrs BP (Figs. 6 and 10), which seems to be reasonable in comparison to other results (e.g., Kraft et al., 1980 and Erol, 1981. In: Pirazzoli, 1991; Van Andel and Lianos, 1984; Aksu et al., 1987; Frihy and Stanley, 1987; Arbouille and Stanley, 1991) for the eastern Mediterranean.

Even if these paleogeographic models (Figs. 9 and 10) are preliminary, what we have developed for this part of the Mediterranean should be an important starting point.

5. Conclusions

Based on the seismic-stratigraphic features (such as depths of pre-Holocene erosional surfaces) and published reasonable eustatic sea-level curves supported partly by other paleoceanographic parameters, we have attempted to predict the paleoshorelines of the eastern Mersin Bay. Investigations into literature presently avaialable show no important changes of sea-level due to tectonics, and sediment compaction/basin subsidence are believed to be of more influence on the relative sea-level changes during the Late Quaternary evolution of the study area.

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