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# Subaerially exposed Late-Quaternary basinal shelf of the inner Mersin Bay, Eastern Mediterranean: Paleoenvironmental evidence

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**Abstract** High-resolution seismic profiles and petrographic data from surface and subsurface sediment samples from Mersin Bay, together with lithologic data from boreholes, were used to determine the origin and distribution of the pre- or early-Holocene unconformities in Mersin Bay (eastern Mediterranean). Reflectors corresponding to unconformities separate the younger, unconsolidated, marine transgressive sediments (Holocene) from the underlying, relatively coarser, consolidated sediments (Plio-Pleistocene). These unconformities correspond mainly to the erosional and subaerially deposited or later subaerially weathered land surfaces. These unconformities are probably related to the latest Pleistocene or earliest Holocene sea-level low stands.

## Introduction

In recent years, a number of high-resolution seismic-profiling and sedimentologic investigations have been carried out on the presently buried, pre-Holocene erosional surfaces of continental shelves in many parts of the world seas (e.g., Suter et al. 1987; Canals et al. 1988; Kelley and Belknap 1991). This involves seismic stratigraphic analysis of the depositional sequences and related boundaries whereby seismic reflections are analyzed in terms of their geometry, continuity, amplitude, frequency, and interval velocity, as well as their external form and associations (e.g., Mitchum et al. 1977; Vail et al. 1977; Brown and Fisher, 1980). If combined with onshore geology and offshore subbottom lithologic data, the distinct and particular seismic reflection configurations can provide the identification and mapping of the late Quaternary paleogeography and the typically subaerial exposure of the coast/shelf during lows of sea level (e.g., Park and Yoo 1988; Perissoratis and Van Andel 1988; Evans et al. 1992).

Recent investigations have provided much new evidence, particularly field observations and offshore borehole and seabed excavation activities, that enable correlation of the seismic reflection boundaries and pre-Holocene exposures of the continental shelf of Mersin Bay (Bodur and Ergin 1992; Ergin et al. 1992a,b), which mostly resulted from the last major sea-level changes.

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## Study area and general setting

The inner Mersin Bay is a shallow shelf situated in the northeastern part of the Mediterranean Sea, immediately off the southeastern Turkish coast (Fig. 1). It is bordered to the north by a narrow coastal plain that widens in the northeast–east towards the large fluviodeltaic plains of the major Tarsus, Seyhan, and Ceyhan rivers. The narrow, alluvial Mersin plain, in the southwest, is composed of small alluvial fans and plains fed by the several mainly ephemeral streams, the largest of which are, from southwest to northeast, the Mezitli, Müftü, and Delicay Rivers.

In general, the Plio-Quaternary sedimentary history of Mersin Bay is controlled by the glacio-eustatic sea-level fluctuations, basin subsidence, and sediment supply (Evans 1973; Ergin et al. 1992a).

Two major types of soils occur on the Mersin coastal plains (Atalay 1987). While reddish to brown Mediterranean soils (terra rossa or alfisol soils) are prominent in the western part, the alluvial soils (azonal soils) are most common in the eastern parts of Mersin. The former soil types are usually developed in/on limestones, marls, conglomerates, serpentinites, and older alluvium deposits (Atalay 1987; Dinc et al. 1990). These soils exhibit plasticity when moist and are reddish to yellowish brown and slightly stiff to firm when dry (Dinc et al. 1990). The alluvial soils are usually derived from Neogene rocks and, thus, are white

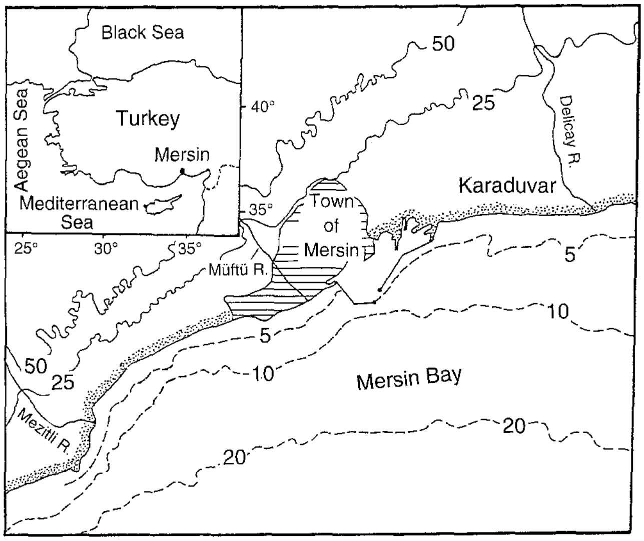



**Fig. 1** Location map showing the study area, Mersin Bay, in the eastern Mediterranean

to yellowish in color and consist of abundant silty clay and calcareous components (Dinc et al. 1990).

## Materials and methods

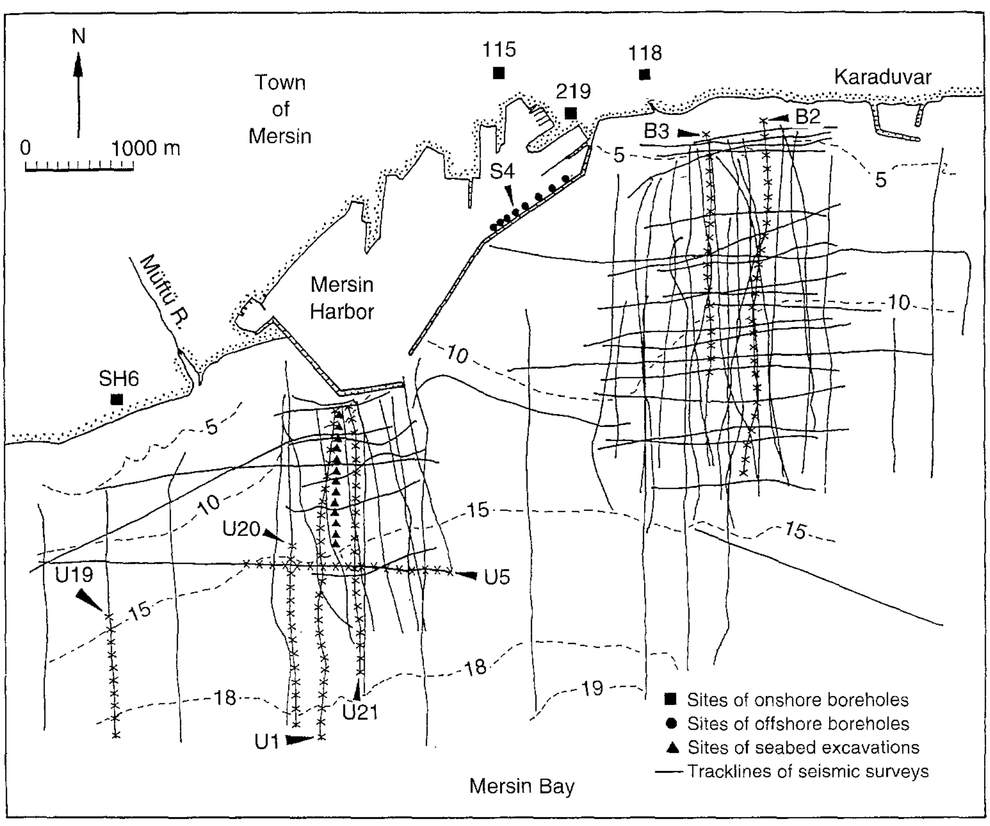
The seismic reflection profiles and surficial bottom sediments were obtained during several cruises of the *R/V Erdemli* and *R/V Lamas* between 1985 and 1991 on the continental shelf of inner Mersin Bay. High-resolution seismic-reflection profiling surveys (Fig. 2) were performed with a single-channel EG&G/Uniboom system (400 Hz–14 kHz, 100–300 J), with a resolution generally less than 30–50 cm and penetration as deep as 100 m. Velocities of 1500 m $s^{-1}$ were used for time–distance conversions in both water and sediment.

Analysis of seismic profiles has involved identification and correlation of the most important seismic facies units and stratigraphic sequences, as outlined by Payton (1977) and Brown and Fisher (1980). In this study, the term "depositional sequence" is used to identify a stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities or their correlative conformities (Mitchum et al. 1977). Unconformities are interpreted as surfaces truncated by subaerial or submarine erosion or nondeposition and generate reflections because they commonly separate strata with different physical properties or attitudes (e.g., Brown and Fisher 1980).

Surface sediment samples representing approximately the top 5–10 cm of the sea floor were taken with a Dietz-Lafonde grab sampler. The samples were analyzed for grain size by sieving for gravel (>2 mm) and sand (0.063–2 mm) and by settling tube for silt (0.002–0.063 mm) and clay (<0.002 mm). Total carbonate contents of the bulk sediments (expressed as $CaCO_3$) were determined by treating ground dry sample with 10% HCl and measuring the $CO_2$ released from the samples.

Lithologic log data were obtained from the commercial

**Fig. 2** The marine region off the coast of the town of Mersin. Dashed lines indicate water depths in meters. The crossed tracklines of the seismic surveys show the parts of the seismic profiles used in this study



boreholes drilled in the coastal zone (Fig. 2). In 1992, an opportunity became available to take subbottom sediment samples, from 9- to 13-m water depths and from 3 to 6 m beneath the sea floor, during excavation/dredging operations off Mersin Harbor, approximately 200–1500 m away from the coast (Fig. 2).

## Results and discussion

### Coastal land lithofacies distribution

Coastal plain lithofacies of the Mersin Bay are dominated by Plio-Quaternary sedimentary cover of alluvial and fluvial clastic sequences that typically overlie the Miocene basement of marls (Figs. 2 and 3). The thicknesses of these Plio-Quaternary deposits vary considerably (holes SH6, 115, and 219; Fig. 3). Much thicker sequences of Plio-Quaternary age are found on the wide coastal plains of alluvial plain–deltaic regimes east of Mersin. In this region (e.g., holes 115, 219, 118), the Plio-Quaternary sequences reached thicknesses of up to 140 m (Fig. 3). The downhole variations in the distribution of fine- and coarse-grained Plio-Quaternary deposits (e.g., Fig. 3) suggest marked fluctuations in the types and mode of sediment/soil transport due to changes in the water energy. This is a very common feature in most fluvial environments (Reineck and Singh 1975).

### Offshore subbottom sediment distribution

Offshore corings are almost unknown, and the only available lithologs are from the 10 boreholes drilled about 400 m off the town of Mersin, at 6- to 9-m water depths and down to 25–30 m beneath the sea floor (Fig. 3). It was discovered that the upper 2–3 m (e.g., hole 54) are comprised almost entirely of modern mud, greenish gray to grayish olive in color, although the thicknesses of these recent mud deposits must have been much greater prior to dredging activities. Between 8- and 14-m depths, shelly, slightly sandy, stiff clay sequences appear (Fig. 3), which are reddish to brown in color. With this sedimentologic limited information, it seems that these sections in the 10 boreholes S1–10 (Fig. 3) once must have been exposed and subjected to subaerial weathering, whereas the presence of shells would indicate marine depositional conditions, most probably greatly affected by the Quaternary sea-level changes. Below that, approximately down to 19-m depths, conglomeratic gravelly sand is dominant (Fig. 3), which suggests very shallow water regimes with possible beachrock formation. Further downhole, shelly, slightly sandy, stiff clay sequences that are reddish to brown in color appear again.

Surficial sediments of the sea floor off Mersin Harbor are greenish gray to grayish olive and composed mostly of detrital mud (53–93%) with lesser amounts of sand (7–46%) and gravel (<1%), except in two small areas close to the breakwater, where sand (71–90%) with a small amount of mud (10–28%) is dominant (Bodur and Ergin 1988; Ergin et al. 1989).

The subbottom excavation/dredging materials taken from 3.8 to 5.3 m below the sea floor south of Mersin Harbor, about 300–900 m away from the breakwater and at 9- to 13-m water depths (Figs. 2 and 4), are comprised of 60–86% mud, 12–30% sand, <1–20% gravel, and 7–54% $CaCO_3$. These sediments are reddish to yellowish brown, stiff to firm when dry, cohesive and plastic when moist, and showed granular structure with some shell re-

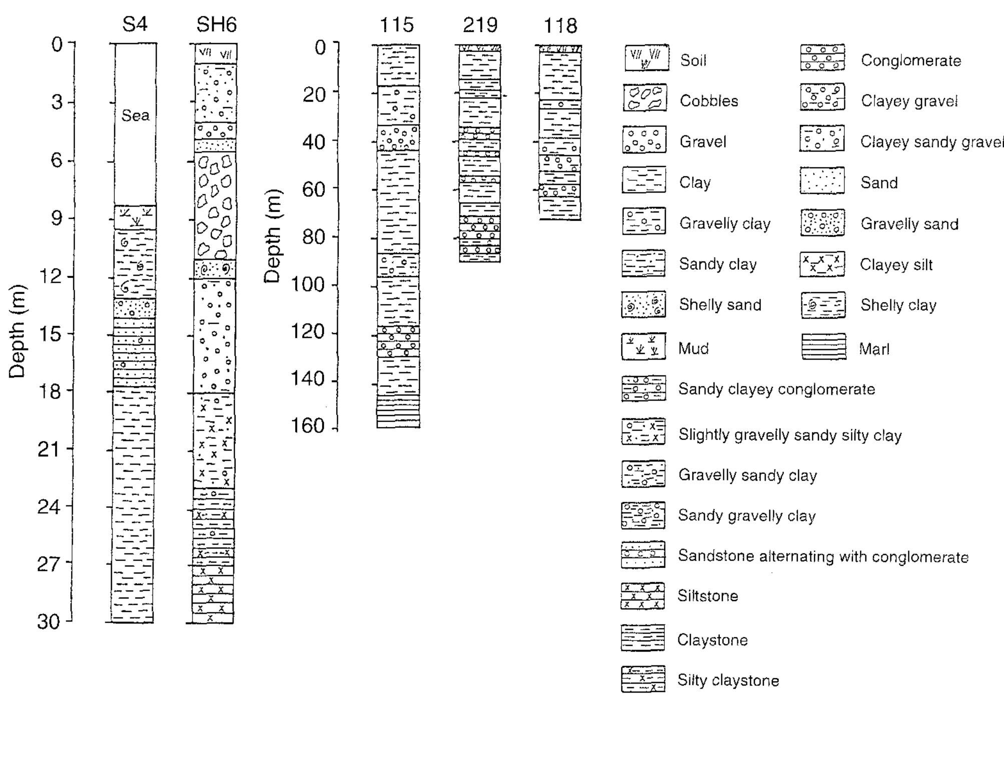



**Fig. 3** Typical lithologs obtained from boreholes drilled in the onshore and offshore regions of Mersin (compiled from various sources, e.g., DSI 1978). For locations see Fig. 4

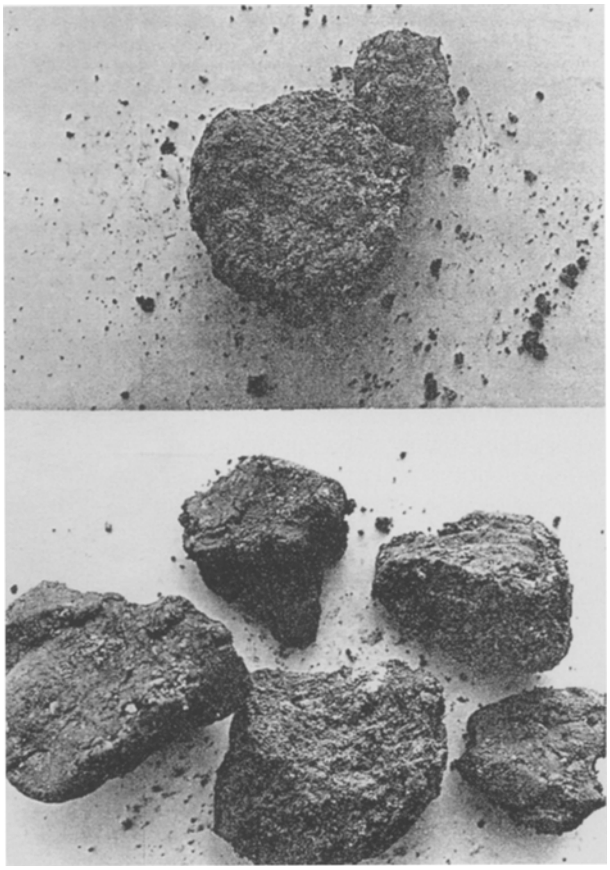


Fig. 4 Stiff to firm, bright to yellowish brown clayey soils recovered during the seabed excavations at 9- to 13-m water depths and beneath the sea floor off the Mersin coasts (200–1500 m away from the coast)

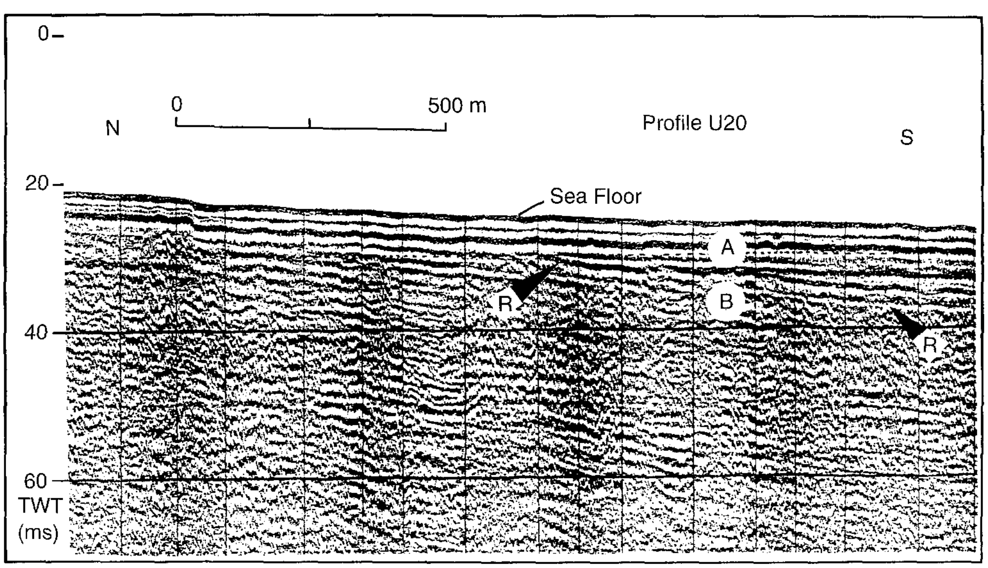
mains. They are separated from the overlying recent muddy sediments by a sharp contact (Fig. 4). Petrographic studies of these bright to brownish sediments or soil horizons have revealed the occurrences of local geological weathering products such as fragments from limestones, ultramafic–ophiolitic rock series, chert, sandstones, etc., which are commonly found alongshore and on the coastal hinterland. Similar surfaces or deposits underlying the recent marine sediments are also known from the other parts off Mersin (e.g., hole S4, Fig. 3). It thus appears that the excavated subbottom sediments from offshore waters of Mersin (Fig. 2) show textural and structural similarities to those soils drilled onshore. Other examples of such stiff and friable, and yellowish-brown to reddish, dark-brown-colored pre-Recent marine sediments on the inner continental shelves are reported from the outer Nile delta (Coutellier and Stanley 1987), northern Aegean (Perissoratis and Van Andel 1988), Gulf of Mexico (Curray and Moore 1963), and Delaware Bay (Moody and Van Reenan 1967); these deposits have been interpreted as soil horizons of the subaerially exposed and eroded shelf surfaces due to the fall of the sea level during the last glacial maxima.

For these reasons, it is thought that the excavated subbottom deposits off Mersin, below about 4–5 m of the present sea floor, were once exposed to produce the typical erosional, subaerially oxidized surfaces. They most probably resulted from the relative lowering of sea level in the shallower parts of inner Mersin Bay, between about 3000 and 8000 years ago, if we assume maximum lowering of sea level in the eastern Mediterranean at about 18,000 years ago (e.g., Milliman 1989; Ergin et al. 1992b).

## Seismic evidence for erosional surfaces

High-resolution seismic-reflection profiles obtained in the two regions typically showed the two distinct, major depositional sequences, A and B, separated by a strong reflector R (Fig. 5). The upper sequence A with its top, the present sea floor, have previously been interpreted to correspond mainly to the Holocene in this region (Bodur and Ergin 1992; Ergin et al. 1992a). The most important characteristic of sequence A is the general parallelism (acoustically simple stratified nature) of seismic reflections. Such a par-

Fig. 5 High-resolution seismic-reflection profile U20 obtained south of the town of Mersin (see caption of Fig. 4 for more detail). Note the acoustically simple stratified nature of seismic sequence A (mainly Holocene) underlain by the complex stratified reflections of seismic sequence B (mainly Plio-Pleistocene). An irregular reflector R separates both sequences (A and B) and represents a pre- or early Holocene erosional surface subaerially deposited or later subaerially weathered during the last low stands of sea level



allel arrangement with high continuity of reflections within sequence A is attributed to the dominance of continuous strata in a widespread and uniform shelf environment, while variable (medium to high) amplitudes may reflect changes in the sediment composition such as interbeddings of sands, silts, and clays in variable portions in both lateral and vertical extent (e.g., Brown and Fisher 1980; Canals et al. 1988; Park and Yoo 1988). This is in good agreement with the surficial sediment data, which shows considerable variation in the grain size compositions of samples. In most profiles (e.g., Fig. 5), lower sections of sequence A locally display interruptions in the continuity of reflections. The discontinuity of parallel reflections is normally considered to suggest changes in the depositional conditions, such as deposits in very shallow waters or from fluvial currents that are generally less continuous than those deposited under marine conditions. Seismic sequence A also tends to exhibit an onlapping nature that is marked by shoreward-thinning continuous reflections grading landward into coastal/alluvial facies. This landward pinchout should have been formed during the last major marine transgression (Flandrian) in the region.

The thickness of sequence A (mainly Holocene) is locally quite variable; it is approximately 4 ms ($\approx 3$ m) to 17 ms ($\approx 13$ m) off Mersin Harbor (Fig. 5).

Sequence B underlies sequence A and is characterized by complex stratified (mainly chaotic) reflections with an internal pattern of discontinuous and discordant to hummocky to wavy subparallel reflections and variable but usually high amplitudes, suggesting a disordered arrangement of reflection surfaces (Fig. 5). The reflections are interpreted as heterogeneous (poorly sorted) and mostly coarse-grained strata deposited in a variable, relatively high-energy setting or irregular bottom surfaces (disruption of beds after deposition), as shown by Mitchum et al. (1977), Canals et al. (1988), and others.

Off Mersin, this conclusion is supported by the results of petrographic analysis of the excavated seabed materials (Fig. 4), which revealed the presence of stiff to friable (semiconsolidated to consolidated), bright to yellowish brown, reddish to dark brown, and fine- to coarse-grained admixtures with common limestone, marl, and ultramafic fragments. This is at least true for in the upper sections of sequence B, as discussed earlier. The textural comparison between the two sequences has revealed that sediments of sequence B are coarser-grained (1–20% gravel) than those of sequence A (<1%) although sand (7–46% in sequence A and 12–30% in sequence B) and mud (53–93% in sequence A and 60–86% in sequence B) contents in sediments of both sequences show nearly similar distribution, except for the somewhat different petrography (i.e., color, compaction strength). Therefore, off Mersin, the differences in the seismic reflection configurations of upper sequence A and lower sequence B appear to have been caused not only by the differences in compaction (i.e., sequence B is denser than sequence A) but also by the grain-size effect. Unfortunately, the actual thickness of this sequence is not known because of the limited penetration of most of the seismic profiles.

Particular attention was paid to the occurrence and distribution of a strong, continuous, and irregular basal reflector R, which normally underlies the Holocene sequence A and, consequently, forms the upper boundary of the depositional sequence B (Fig. 5). Reflector R, which implies a large difference in acoustic impedance between the upper (sequence A) and lower (sequence B) depositional sequences, defines numerous small channels that now are filled and/or buried under the recent deposits. The presence of such an irregular bottom surface with a clearly erosivs and discordant character underlying the transgressive sediments, has been commonly interpreted as the late Pleistocene erosional surface or unconformity due to subaerial exposure and weathering of the continental shelf at lowered sea levels (e.g., Suter et al. 1987; Canals et al. 1988; Kelley and Belknap 1991).

## Conclusions

Taking into consideration all available onshore geological and offshore borehole and seabed excavation evidence, the following conclusions can be presented: I feel justified in regarding the occurrence of a bright to yellowish brown, stiff to firm, gravelly and sandy mud contact underlying the dark, greenish gray, unconsolidated mud sequence off Mersin coasts as the former land surface exposed during the last late Pleistocene or early Holocene low stands of the sea. These pre-Holocene marine deposits have been encountered in boreholes and seabed excavations or dredgings. However, the unconformities or their correlative truncated surface reflections that separate the younger, recent shelf sediments from the underlying, pre-Holocene sediments could be produced mostly by subaerially exposed and later weathered erosional shelf surfaces, formed probably during sea-level changes at the late Pleistocene/early Holocene boundary.

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