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Sedimentary Structures of Beach and Dune Deposits: Mustang Island, Texas

MARCUS E. MILLING¹ AND E. WILLIAM BEHRENS

*Institute of Marine Science
The University of Texas
Port Aransas, Texas*

Abstract

Sedimentary structures of beach and dune deposits of a modern barrier island were studied in a series of trenches along Mustang Island, Texas. The following zones are characterized by distinctive stratification: 1) the foreshore by smooth, even low angle, planar cross-strata dipping gently (2 to 7 degrees) seaward; 2) the backshore by irregular strata, burrows, and locally steeply dipping (9 to 16 degrees) trough cross-strata; 3) the wind-shadow dunes by long (1 to 4 m), smooth, even, convex-concave cross-strata; and 4) the foredune ridge by large scale, smooth, even, trough cross-strata.

The sedimentary structures observed are produced chiefly by: 1) the agent of deposition, its competence and variability; 2) the shapes and configurations of depositional and erosional surfaces; and 3) the intensity of biologic activity. The beach and dune environments are dominated by physical forces, so primary stratification predominates over biologically and chemically produced secondary structures.

The vertical succession of sedimentary structures as shown in the trenches across the beach and foredune ridge suggest an offlap sequence such as would result from prograding of the shoreline. However, the succession observed may also be the result of normal sequential development of a beach following a high storm or hurricane tide.

Introduction

The interpretation of the depositional environments of sedimentary rocks is one of the major objectives of many stratigraphic and sedimentologic studies. Faunal and floral assemblages, textural variations, mineral composition, and sedimentary structures have all been used as environmental indicators. In many instances, especially in unfossiliferous rocks, sedimentary structures constitute perhaps the best evidence available for reconstruction of conditions at the site of deposition. The purpose of this study is to describe, differentiate, and relate the sequence of sedimentary structures in the beach and dunes of a modern barrier island to their environments of deposition and processes of formation. It is hoped that the data presented here will contribute to the understanding and interpretation of ancient sedimentary rocks deposited in similar environments.

The field studies were made on Mustang Island, Texas (Fig. 1). At each of seven stations 4 or 5 L-shaped trenches 2 to 4 m long and approximately 1 m wide were oriented so as to expose sections both parallel and perpendicular to the trend of the beach. The depths of the trenches were limited by the water table which was encountered from less than 0.5 to more than 1.5 m below the surface. The walls of the trenches were allowed to dry, lightly brushed, and photographed. The thickness, apparent magnitude and direction of dip of the stratification was then measured on these walls.

According to Thornthwaite's (1948) climatic classification the area is located in a

¹ Present address: Department of Geology, University of Iowa, Iowa City, Iowa.

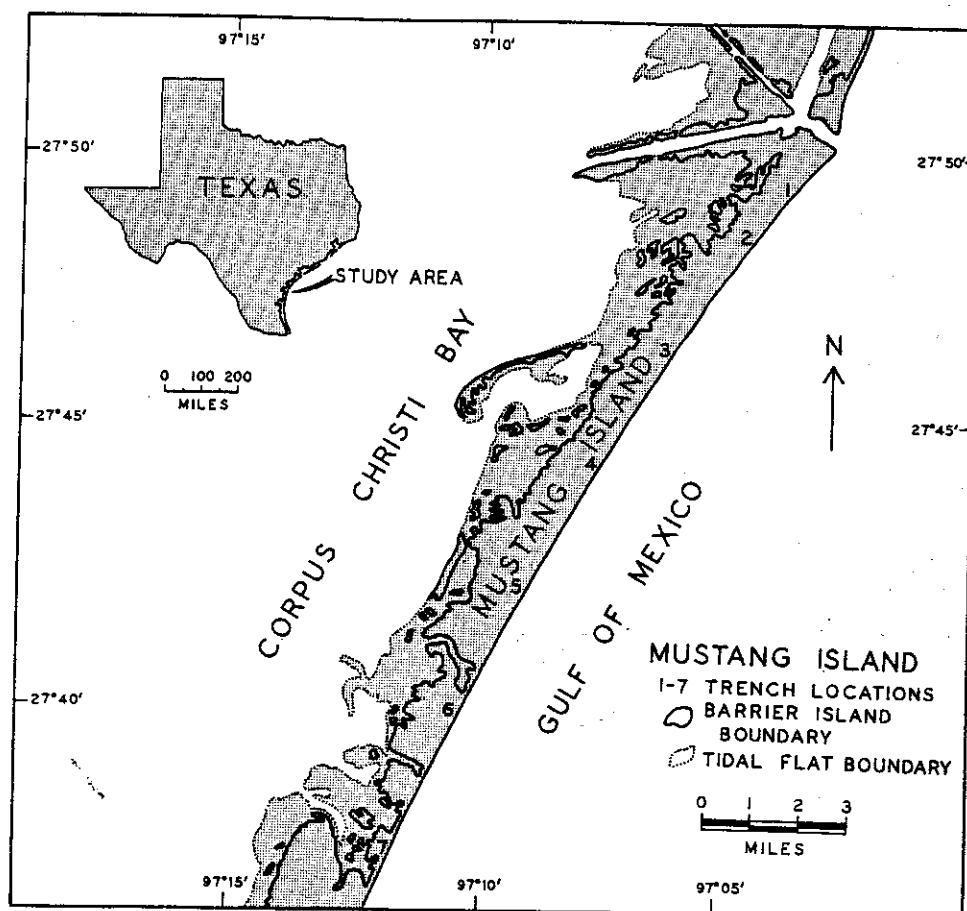


FIG. 1. Index map showing location of stations along Mustang Island.

gradational zone between the semi-arid climate of extreme south Texas and the dry, sub-humid climate of south-central Texas. Southeasterly (onshore) winds predominate most of the year, but occasional strong northerly winds accompany southward moving cold fronts (northers) in the winter months. Lunar tides range between daily and semi-daily and are generally less than 1 m. Waves along the Gulf beach are usually 0.5 to 1 m in height. However, during hurricanes and storms tides may reach 5 m above mean sea level and waves may be 3 to 5 m high.

Tourism is the major industry of the island, and human activities which may effect beach structures include regular automobile traffic on both the foreshore and backshore and camping and picnicking chiefly on the backshore.

GEOMORPHOLOGICAL ZONATION

Mustang Island can be subdivided morphologically into five major zones (Fig. 2). From the Gulf landward they are: 1) shoreface (submerged seaward portion of the

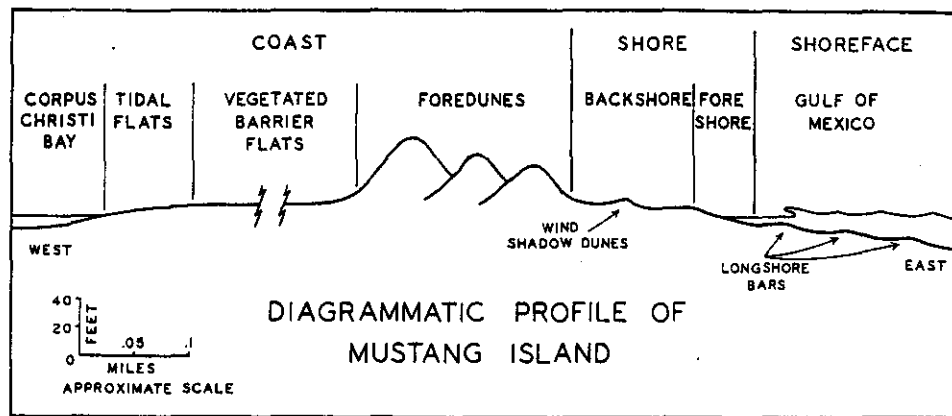


FIG. 2. Diagrammatic profile perpendicular to trend of Mustang Island showing the major topographic sub-divisions.

barrier); 2) beach (foreshore and backshore); 3) foredune ridge; 4) barrier flat (sometimes dune covered); and 5) tidal flat. The sedimentary structures were studied in detail in zones 2 and 3.

The foreshore, as defined by Johnson (1919), is that portion of the shore over which the waterline migrates as the tide changes. However, because the tide range changes daily, weekly, monthly, and seasonally, the defined limits are rather ephemeral. The zone is characterized by a width of 25 to 50 m and a smooth, regular surface sloping 3 to 6 degrees seaward. The lower and upper limits of this surface correspond closely to, and thus should perhaps be defined by, mean low water and mean high water respectively. The inner margin of the foreshore, the beach face, lies 0.5 to 1 m above mean sea level and is marked by a slight decrease in slope referred to as the berm. This is sometimes accentuated by a line of shells and other debris deposited at the crest during high tide, but at other times the beach face merges imperceptibly with the backshore without apparent discontinuity. In many instances former berm crests are denoted by sand ridges of low relief (less than 20 cm) paralleling the beach. Beach cusps sometimes develop on the foreshore; their flanks form a series of surfaces sloping (0.5 to 3 degrees) sub-parallel to the trend of the shore. The cusps are usually spaced 15 to 20 m apart.

The backshore extends from the berm crest landward to the seaward base of the foredune ridge and ranges from 50 to 200 m in width. The backshore is characterized by a relatively flat, horizontal to slightly sloping (landward or seaward) surface which is 1 to 2 m above mean sea level. This zone is inundated only by high spring tides or those accompanying storms or hurricanes. The surface is not so smooth and regular as that of the foreshore. Whereas the foreshore is usually damp, the backshore is usually dry. Sand can commonly be seen being carried across the backshore landward by the predominating southeasterly onshore winds. Northers carry sand in the opposite direction during the winter, but net movement is landward leading to the formation of the foredune ridges.

In several localities small dunes have formed on the backshore in the lee of patches of vegetation. These wind-shadow dunes are tear shaped in outline ranging in length

from less than 1 to more than 6 m, in width from less than 0.5 to more than 2 m, and in height from less than 0.5 to more than 1 m. The blunt end of the dune faces seaward and has a triangular shaped tail of sand extending landward. The trends of the tails of the dunes range in azimuth from 300 to 320 degrees indicating a net transport of sand in this direction. Slip faces have developed on the tails at oblique angles (southwest and northeast) to the wind direction. The crests of the tails slope landward from 2 to 10 degrees; slopes on the slip faces range from 20 to 30 degrees.

The foredune ridge complex ranges in width from 75 to more than 300 m. There are two foredune ridges which parallel the beach. In many places a third, small (1 to 2 m above the berm) ridge has been formed by the landward migration and coalescence of wind-shadow dunes. Landward of this the primary ridge is stabilized by vegetation, well defined, and extends the length of the island reaching elevations of 5 to 8 m. The other ridge which appears from its most landward position to be oldest, is confined to the northern end of the island. These dunes are heavily vegetated and reach elevations of 8 to 12 m.

The sands comprising Mustang Island are fine to very-fine and well sorted but are not very well rounded. Mineralogically, the sands are predominantly composed of quartz with secondary amounts of feldspar, chert, and opaque minerals, and according to Folk (1954) would be classified as a texturally mature subarkose.

Sedimentary Structures

Due to the high degree of sorting, monomineralic character, and small percentage of dark, heavy minerals, the deposits forming Mustang Island lack conspicuous stratification. The observed stratification results for the most part from slight differences in textural properties of individual strata.

FORESHORE

The stratification of the foreshore is similar to that reported by other authors (Thompson, 1937; McKee, 1957; van Straaten, 1959; Bernard, LeBlanc, and Major, 1962; Soliman, 1964). It is characterized by smooth, even, low angle, planar cross-strata dipping gently seaward. The apparent dips observed in the trench walls oriented normal to the shoreline range from 2 degrees landward to 7 degrees seaward, the average is 4 degrees seaward. Dips of similar amounts at oblique angles to the beach result from regularly spaced beach cusps. High angle (20 to 30 degrees) landward dipping cross-strata like those described from the foreshore of Sapelo Island, Georgia (Hoyt, 1962) were not observed.

The cross-strata are thinly laminated to very thinly bedded (classification of McKee and Weir, 1953) ranging in thickness from 3 to less than 0.05 cm. Generally they can be grouped into several sets separated by erosion surfaces. In most cases the sets of seaward dipping cross-strata are truncated by the less steeply dipping (1 to 2 degrees) erosional surfaces. The sets thicken or thin seaward giving them a wedge-shaped appearance (Fig. 3).

In the lower portions of several trenches fine shell cross-strata dip 2 to 4 degrees seaward. These were easily recognized for they coincide with planes of weakness along

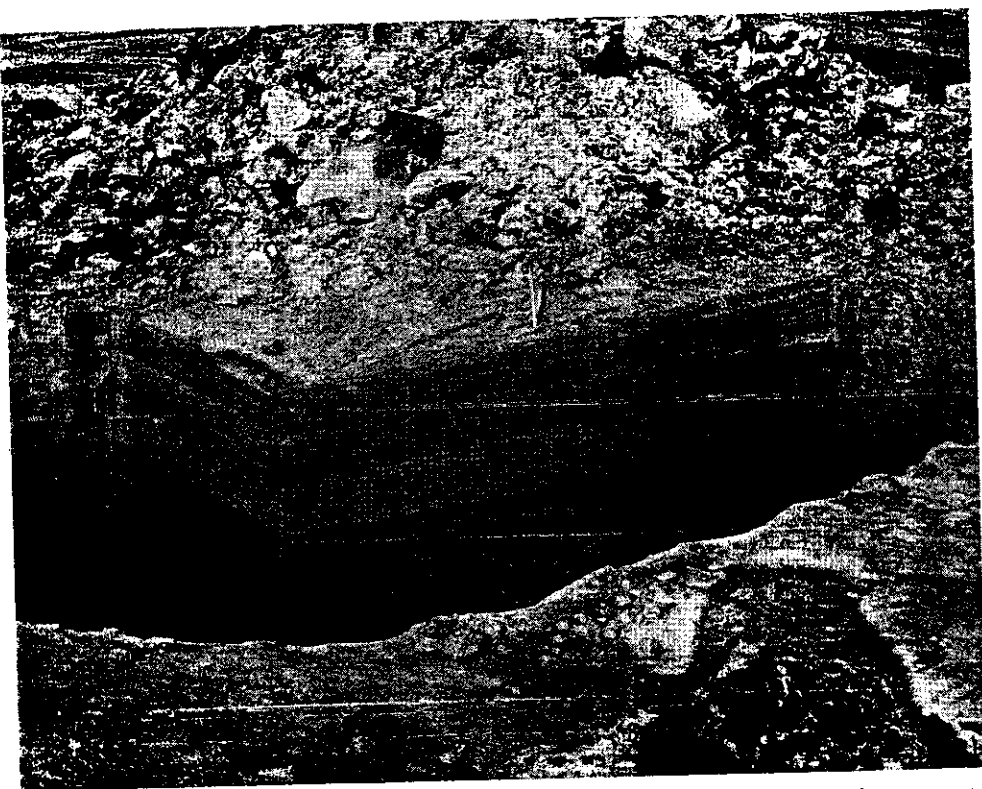


FIG. 3. Trench in lower foreshore at Station 1 showing a wedge-shaped set of low angle cross-strata dipping (2 to 4 degrees) and thickening seaward (to the right). Pencil lies above face perpendicular to beach.

which parting surfaces develop (Fig. 4). These layers resemble the very fine shell hash which covers that portion of the beach which is exposed only during maximum low tides (the uppermost shoreface). The superposition of foreshore deposits over shoreface deposits in many of these trenches suggests a prograding shoreline.

BACKSHORE

The stratification of the backshore deposits is characterized by irregularities and locally steeply dipping cross-strata. Apparent dips range from 9 degrees landward to 16 degrees seaward. The cross-strata range in thickness from 2 to less than 0.1 cm and on the average appear to be thicker than those of the foreshore. Sets range in thickness from 3 to 36 cm and also appear to be thicker than those of the foreshore. The sets can be distinguished from one another by gently dipping (1 to 2 degrees) erosion surfaces which truncate the more steeply inclined cross-strata. The stratification consists basically of two types: 1) low angle (less than 12 degrees) planar cross-stratification and 2) intermediate angle (12 to 20 degrees) trough cross-stratification which is locally abundant. Numerous burrows commonly result in mottling and irregular sedimentary structures (Fig. 5).

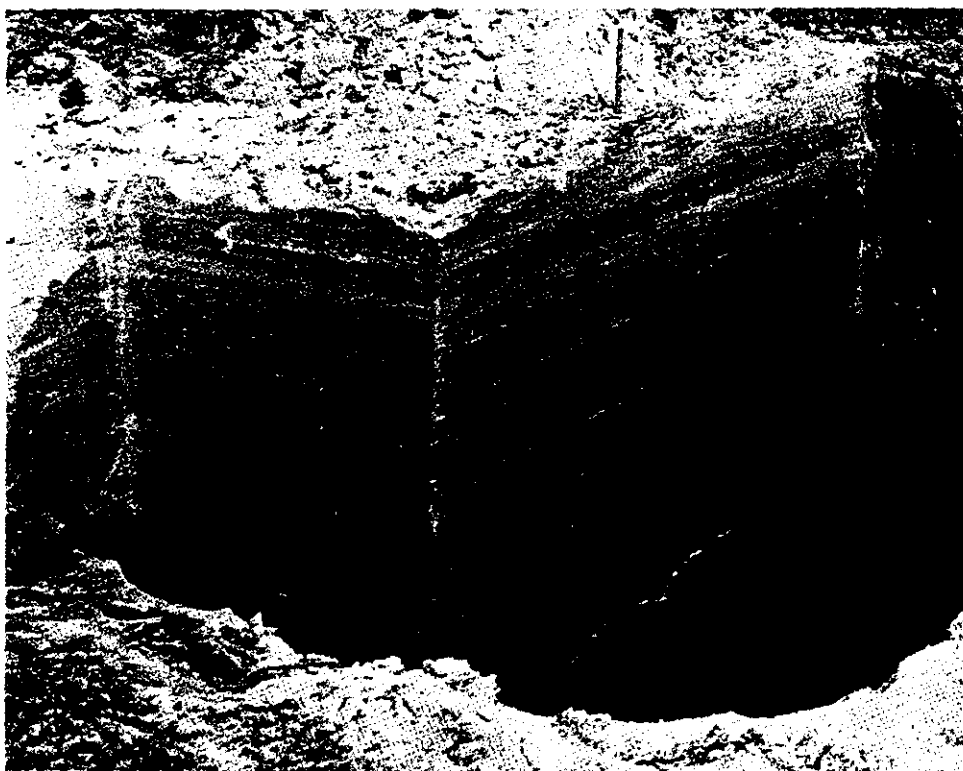


FIG. 4. Trench in upper foreshore at Station 1. Pencil is above face perpendicular to beach. Note parting surfaces developed along upper shoreface cross-strata near bottom of trench in face parallel to beach and burrow above them. The Gulf is to the upper right of the photograph.

In many instances, especially in the trenches of the backshore and dunes, dark grayish-black sand smelling slightly of hydrogen sulfide is encountered near the bottom of the trenches. The upper surface of this sand seems to coincide with the water table surface. The dark coloration probably is due to reduction of some material such as sulfates or organic matter below the water table, because after several hours exposure to the atmosphere the dark sand becomes much lighter and can scarcely be distinguished from the sands at the surface.

WIND-SHADOW DUNES

The stratification of wind-shadow dunes is characterized by long (1 to 4 m), smooth, even, convexo-concave cross-strata. The individual cross-stratum in a longitudinal section consists of three elements: 1) near the top of the dune the cross-stratum is convex upward; 2) toward the leeward side it is straight along its mid-length; and 3) in its lower portion it is concave upward and is truncated by overlying cross-strata (Fig. 6). The sets are wedge-shaped, being thicker near the top of the dune and thinner leeward. Strata dipping at oblique angles to the predominant wind direction correspond to slip surfaces on either side of the crest of the dune tail. Apparent dips on these strata range

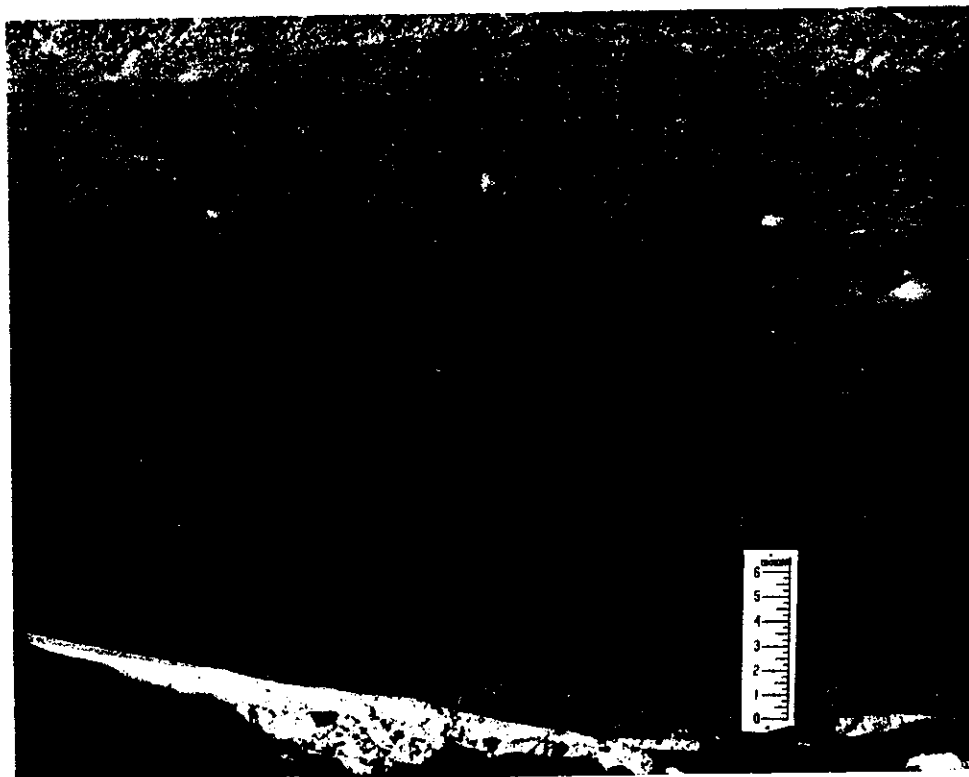


FIG. 5. Trench face perpendicular to beach in backshore at Station 2. Note set of low angle planar cross-strata dipping gently (2 degrees) seaward near top of cut, underlain by set of trough type cross-strata dipping 16 degrees seaward, underlain by set of gently dipping (2 degrees), planar cross-strata which in turn is underlain by massive to irregularly stratified and burrowed sand. Also note *Ocyropsis* burrow (in extreme left of photograph) filled with sand at boundary between set of trough cross-strata and lower set of planar cross-strata.

from 10 to 33 degrees. Vegetation made it impossible to observe stratification on the windward sides of these dunes. Thicknesses of individual cross-strata range from 0.1 to 4.5 cm and on the average are greater than those of the beach. The sets range in thickness from 10 to 66 cm.

In the lower portions of all trenches cut through the wind-shadow dunes, structures characteristic of the backshore were observed (Fig. 6). The maximum thickness of the eolian sand above the uppermost beach deposits varies between 1.5 and 2 m. In many places a layer of coarse shell material, similar to that observed covering some localities of the backshore (Fig. 7) is encountered at the base of the eolian sand.

FOREDUNE RIDGE

The stratification of the foredune ridge is characterized by large scale, smooth, even, trough type cross-strata (Fig. 8). Apparent dips on the cross-strata range from 2 to 42 degrees. According to McBride and Hayes (1962, p. 547, Fig. 1) the direction of dip is bimodally distributed (WSW and N).



FIG. 6. Trench perpendicular to beach displaying longitudinal section through a wind-shadow dune at Station 1. Note relatively high angle, convexo-concave cross-strata dipping 10 to 19 degrees landward underlain by low angle, planar cross-strata of the beach facies dipping 1 to 3 degrees seaward.

The thickness of individual cross-strata ranges from less than 0.1 to more than 5 cm. Thickness of individual sets range from 8 to 45 cm, being similar in thickness to the sets of the wind-shadow dunes. Locally the cross-strata are disrupted due to roots and numerous animal burrows (Fig. 8).

Discussion

Primary sedimentary structures such as those reported herein are basically a function of: 1) the characteristics of sediments being supplied (both mineralogic and textural); 2) the rate of supply; and 3) the types, intensity, and variability of the physical depositional processes. Because of the last factor, these structures are of special value in environmental reconstruction.

In the area studied, dominantly quartz sands are transported southwestward by long shore drift (Bullard, 1942; van Andel, 1960), and the rate of supply is not extremely variable. Therefore the primary stratification of these deposits is principally the result of periodic variations in the sorting ability and competence of the transporting medium. Furthermore, the beach environment is dominated by the energy released by physical

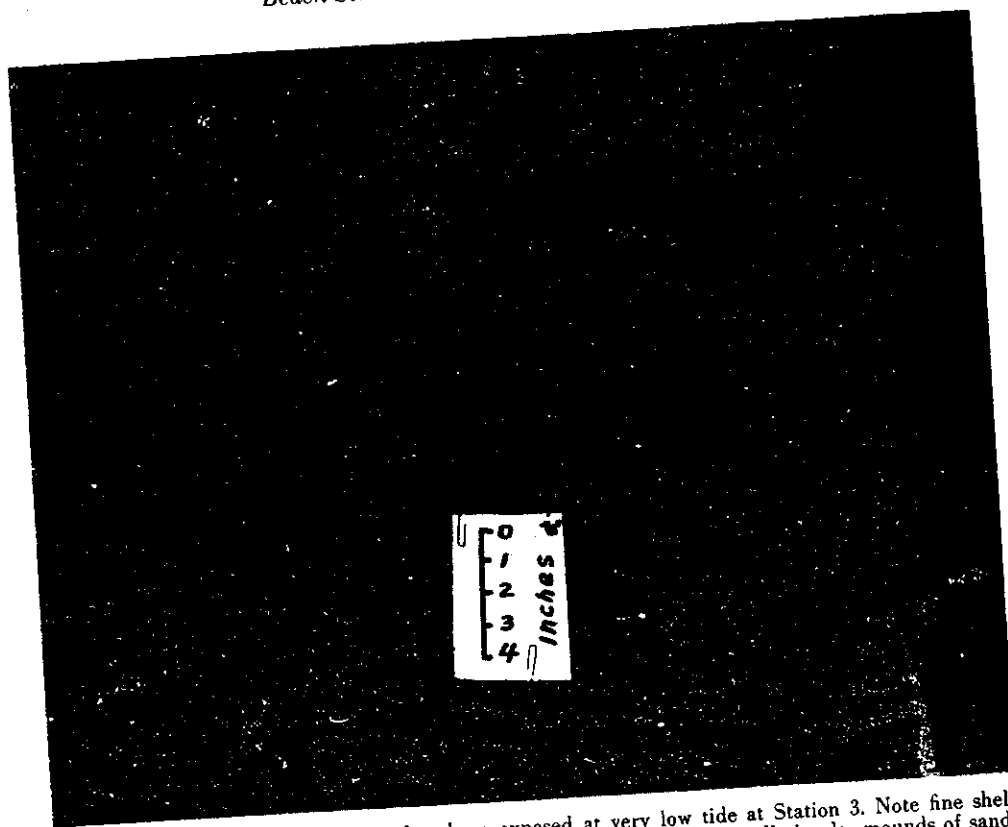


FIG. 7. Surface of extreme lower foreshore exposed at very low tide at Station 3. Note fine shell hash covering much of the surface, *Callianassa* burrows surrounded by small circular mounds of sand, and ill defined rhomboid "ripple marks" in center foreground. The Gulf is to the right of the photograph.

processes so that their effects—primary structures—predominate over secondary structures such as those produced by chemical diagenesis or burrowing organisms.

FORESHORE

The stratification of the foreshore deposits conforms very closely to the configuration of the surface of this zone. It is concluded that the primary stratification results from wave action which can be seen continuously modifying this sloping surface. The wave energy varies directly with wind velocity and direction and thereby changes both daily and seasonally. The effects of these changes can be seen in the texture of mineralogically identical cross-strata. Size analyses show the sand of a relatively dark colored set of cross-strata to have a mean grain size diameter of 2.84ϕ (0.138 mm) and an inclusive graphic standard deviation of 0.33ϕ , while the corresponding values for a lighter colored set were 2.78ϕ (0.146 mm) and 0.35ϕ . The color discrepancy between the two sets is believed to be related to differences in moisture content and/or drying ability, since, when the samples were dried in the laboratory no color differences could be detected. The regularity of the stratification is contributed to by the lack of ripple marks which



FIG. 8. Large scale trough cross-strata in trench near top of foredune ridge at Station 5. Scale attached to a root on trench face perpendicular to beach. The Gulf is to the right of the photograph.

generally form only on the extreme lower foreshore and upper shoreface and are exposed only at maximum low tide. Likewise marine organisms causing biogenic structures are restricted by the necessity for continuous submergence to the lower portions of the foreshore for the most part. They can extend up the foreshore to some extent, however, because the intertidal, beach community is entirely infaunal and can subsist in interstitial water. This community is dominated by the pelecypod *Donax* which may be as abundant as 32,000 individuals per linear yard of beach (Loesch, 1957). However, the burrows of this and the other common mollusks (*Polinices*, *Terebra*, and *Oliva*) generally extend only a few centimeters below the surface, and wave action continuously reworks the sand destroying the secondary structures and replacing them with primary, regular stratification.

Burrows of a more permanent nature are made by the shrimp *Callinassa*. Most of the burrows are surrounded on the surface by a small circular mound of sediment (Fig. 3). They are commonly over 4 feet deep and are stabilized by an organic mucus which the animal secretes into the walls. When the sediment surrounding the burrow is eroded, the burrow will stand temporarily a few inches above the surface of the beach. The exterior of the burrow then reveals a characteristic knobby or coarsely corn-cob appearance. Although very few structures referred to burrowing organisms were seen in the foreshore trenches (Fig. 4), they are probably more common in the lower part of the beach where continuous saturation beneath the water table prevented trenching.

Deformational and cut and fill structures such as those reported by Emery (1945), Palmer (1948), and Soliman (1964) were not observed.

BACKSHORE

An observed sequence of events in the development of a backshore is depicted diagrammatically in Fig. 9. The backshore is periodically eliminated by hurricane tides which raise sea level until the shoreline reaches the foredune ridge which may then be deeply eroded. The whole beach, in effect then, becomes the foreshore and very probably develops primary, regular stratification. When the water recedes to its normal level, deposition occurs in the upper part of the intertidal zone creating a berm and redefining a backshore zone. Within this zone, then, the following processes take place.

- 1) Waves breaking over the berm crest at high tide carry sand landward and deposit it in regular, gently landward dipping cross-strata.

- 2) Water is temporarily ponded between the berm crest and the dunes. Ripple marks and consequent cross-strata may result when a) the berm is breached and the water flows back to the sea, or b) wind creates oscillation ripples in the standing water.

- 3) Terrestrial organisms such as the abundant ghost crabs (*Ocypode*) burrow into the sand; the abandoned burrows sometimes collapse to produce irregular structures and sometimes are filled with sand from above producing distinct mottles (Fig. 5).

- 4) Onshore winds winnow sand and silt from the surface leaving a lag concentrate of shell and other coarse debris (Fig. 10). The winnowed sand accumulates usually around vegetation and other obstacles forming wind-shadow dunes on the most landward portion of the backshore. These dunes often coalesce producing complex eolian cross-stratification. Northerly (offshore) winds redistribute part of this material seaward probably forming irregular or discontinuous strata on the shelly backshore surface.

- 5) Terrestrial vegetation invades the zone from the foredunes, and its roots tend to destroy primary structures and produce a more homogeneous sediment.

Subsequent high tides ranging from only slightly above average spring tides to full hurricane tides may destroy part or all of the results of these processes and begin a partially or completely new cycle.

FOREDUNE RIDGES

The trough type cross-strata observed in trenches in the vegetated, stabilized foredune ridges along with their morphology and position are the same as for active dunes on other parts of Mustang and Padre Islands and thus clearly indicate a primary, eolian origin for the sedimentary structures. The presence of beach sands beneath the dune sand has been reported (Johnson, 1919; Price 1958; Bernard *et al.*, 1962), but the trenches studied were too shallow to verify this or to add other new data pertaining to the origin and development of this zone.

Summary and Conclusions

The sands of the foreshore, backshore and dune deposits of Mustang Island are very similar both mineralogically and texturally. However, these zones may be differentiated locally on the bases of the percentages of heavy minerals (Bradley, 1957) and certain

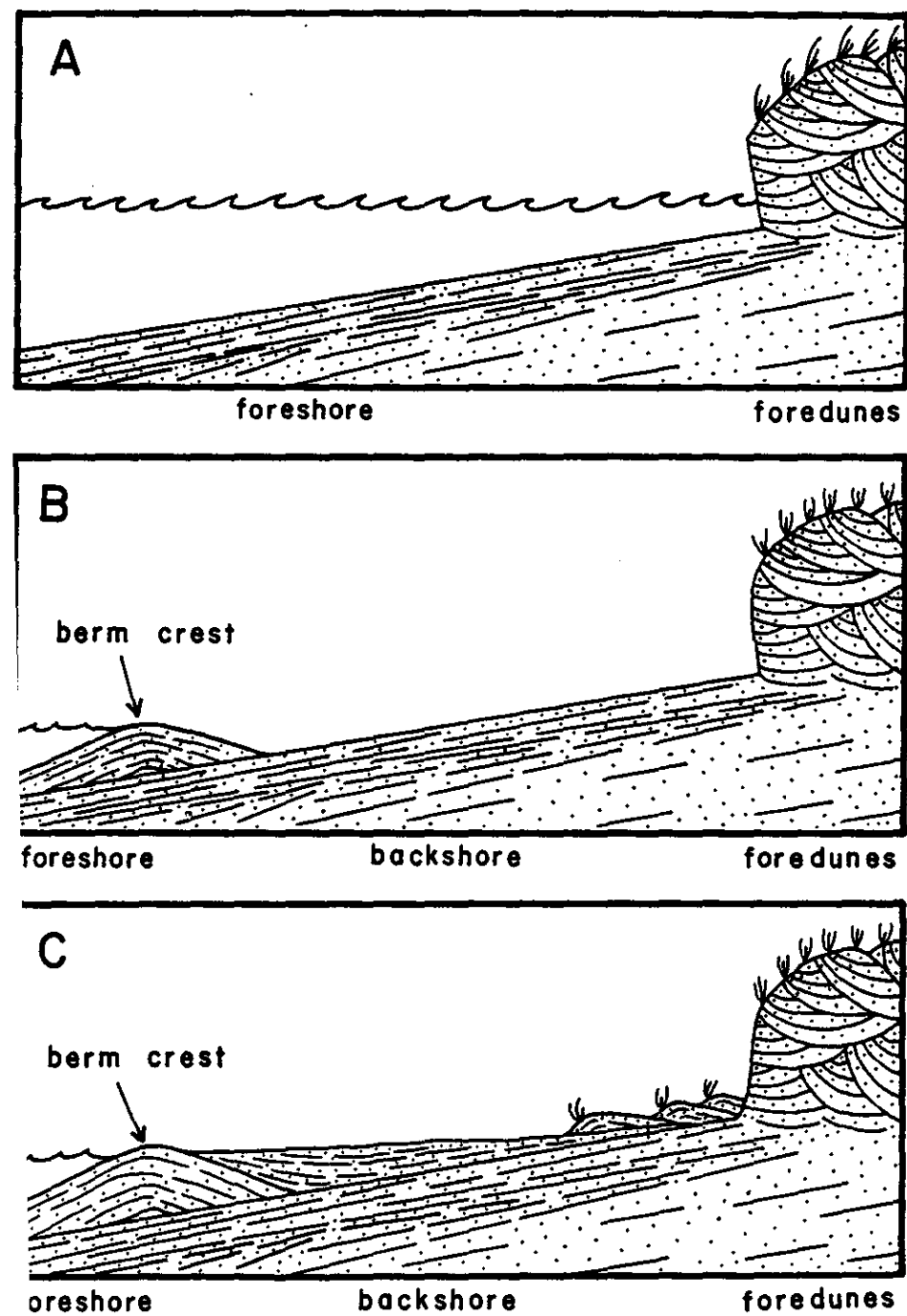


FIG. 9. Development of beach subsequent to a hurricane tide; A) hurricane tide reaches fore-dune ridge planing off entire beach into a foreshore; B) water level returns to normal, berm deposits redefining a backshore; C) high tides and winds combine to fill in backshore and develop shadow dunes.

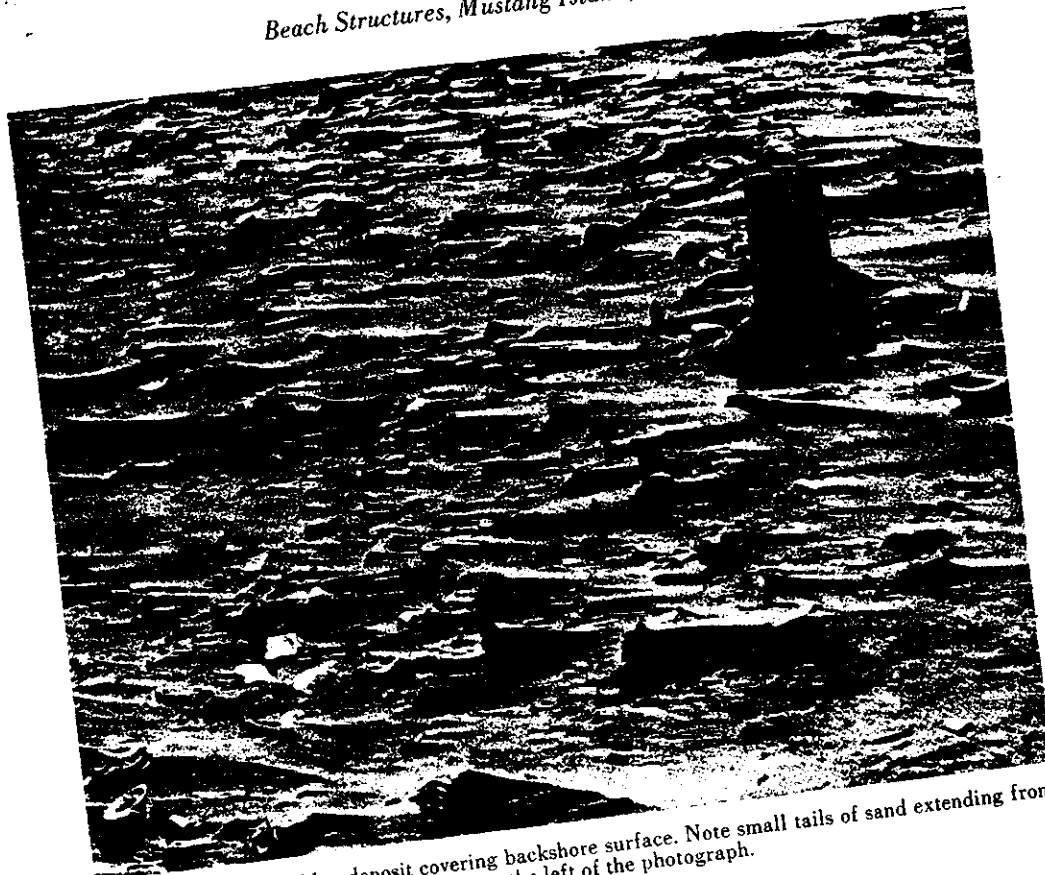


FIG. 10. Close up of lag deposit covering backshore surface. Note small tails of sand extending from the leeward side of the shells. The Gulf is to the left of the photograph.

textural parameters (Beal and Shepard, 1956; Mason and Folk, 1958). From data presented in this study and by McKee (1957) it has been shown that these zones can also be distinguished on the basis of their sedimentary structures.

The resulting sedimentary structures in each of the zones is determined chiefly by:

- 1) The agent of deposition, its competency and variability;
- 2) the form of the depositional or erosional surface upon which deposition takes place; and
- 3) the intensity of biologic activity.

The stratification of the foreshore is principally the product of the sorting ability of the wave swash and backwash currents with relatively little modification by secondary agents. On the other hand, backshore stratification is the result of both wave and wind action with deposition at times on an irregular surface and significant modification by organisms. The dune stratification is predominantly the product of wind action with some modification by vegetation and burrowing organisms.

In each trench, surface material seems to be underlain by deposits of the next seaward zone. This vertical succession suggests an offlap sequence resulting from prograding of the shoreline. The succession observed, however, may also be the result of normal, sequential development of a beach following a hurricane tide. Further conclusions concerning beach growth and development must await the invention of better methods of sampling the water-saturated, unconsolidated sand deeped within barrier islands.

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