Journal of Sedimentary Petrology, Vol. 41, No. 4, p. 1105–1111
Figs. 1–6, December, 1971

ORIGIN OF SHELL BEACHES, PADRE ISLAND, TEXAS[1]

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ABSTRACT

Central Padre Island, Texas is the site of a convergence of littoral drift which causes shell and sand from the entire coast to accumulate in the convergence area. Shell material is then concentrated on the beach by aeolian deflation of finer grained terrigenous sand which blows inland to contribute to the extensive infilling of Laguna Madre by wind-tidal flats, and perhaps ultimately to contribute to the aeolian sand plain of the mainland.

Ancient shell beaches of the Pleistocene (?) Ingleside Complex of the mainland shore of Laguna Madre bear great similarity to the modern shell beaches of Padre Island suggesting that the general coastal configuration and wind patterns were similar to modern patterns at the time of their formation.

It must be concluded that some large carbonate accumulations can occur solely as the result of a sorting process in an area of great terrigenous sediment supply.

INTRODUCTION

Central Padre Island, Texas is the site of beaches which are composed of up to 80 percent shells and shell fragments. Since this zone of shell accumulation is located in the center of a major terrigenous province and since it coincides with the location of a postulated convergence of nearshore Gulf of Mexico currents and littoral drift, I decided to attempt to determine the mode of formation of the shell beaches, in order to explain the apparent anomaly of the existence of carbonate beaches in a terrigenous province.

The study area consists of beaches on Padre and Mustang Islands (fig. 1). Mustang Island is terminated to the north at Aransas Pass and to the south by the intermittently open Corpus Christi Pass, which separates it from Padre Island. Brazos Santiago Pass terminates Padre Island at the south. Mansfield Pass, an artifically created and maintained pass, is located on south-central Padre Island about 90 miles south of Aransas Pass. In this investigation beach sediments have been studied from Aransas Pass to Brazos Santiago Pass, and a detailed study was made of the 60 miles of beach immediately north of Mansfield Pass (fig. 1).

Numerous rock outcrops occur along the mainland shore of Laguna Madre adjacent to central Padre Island. These rocks apparently are lithified equivalents of the shell-rich beach sediments of Padre Island, but are a part of the ancient Ingleside Beach Complex (fig. 1). It is probable that these ancient shell beaches formed by the same mechanism as the modern shell beaches of Padre Island and a study of the origin of the modern shell beaches may provide the means for interpreting the current patterns which produced the ancient shell beaches.

[1] Manuscript received March 29, 1971.

SEDIMENT DISTRIBUTION

Terrigenous Sediments

Heavy minerals from rivers along the northern Texas coast have been transported to the south to mix with the heavy minerals of the Rio Grande in a transition zone along central Padre Island (Bullard, 1942; Van Andel and Poole, 1960). Hayes (1965 and 1967) found that he could trace a finer grain-size mode from the northern province and a coarser grain-size mode from the southern Rio Grande province to a central transition zone where they mix. These transition zones coincide and are located within the area of shell beaches on Padre Island.

Shell Sediments

Assemblage distribution.—Throughout the study area large accumulations of shell material are found only on the Gulf of Mexico beaches; only very small shell concentrations occur in the foredunes, active dune fields, barrier island flats and wind-tidal flats. Two distinct shell assemblages occur along the beaches of Padre Island. The southern sedimentologic province (from 38 miles north of Mansfield Pass southward to the Rio Grande) is characterized by *Eontia ponderosa* Say, *Mercenaria campechiensis* Gmelin, and *Echinochama arcinella* Linne (fig. 2). The northern sedimentologic province is composed almost entirely of *Donax variabilis* Say. The transition zone between the northern and the southern sedimentologic provinces is characterized by a lower total shell content and a somewhat greater accumulation of *Anadara braziliana* Lamarck, *A. ovalis* Bruguiere, and *A. baughmani* Hertlein,

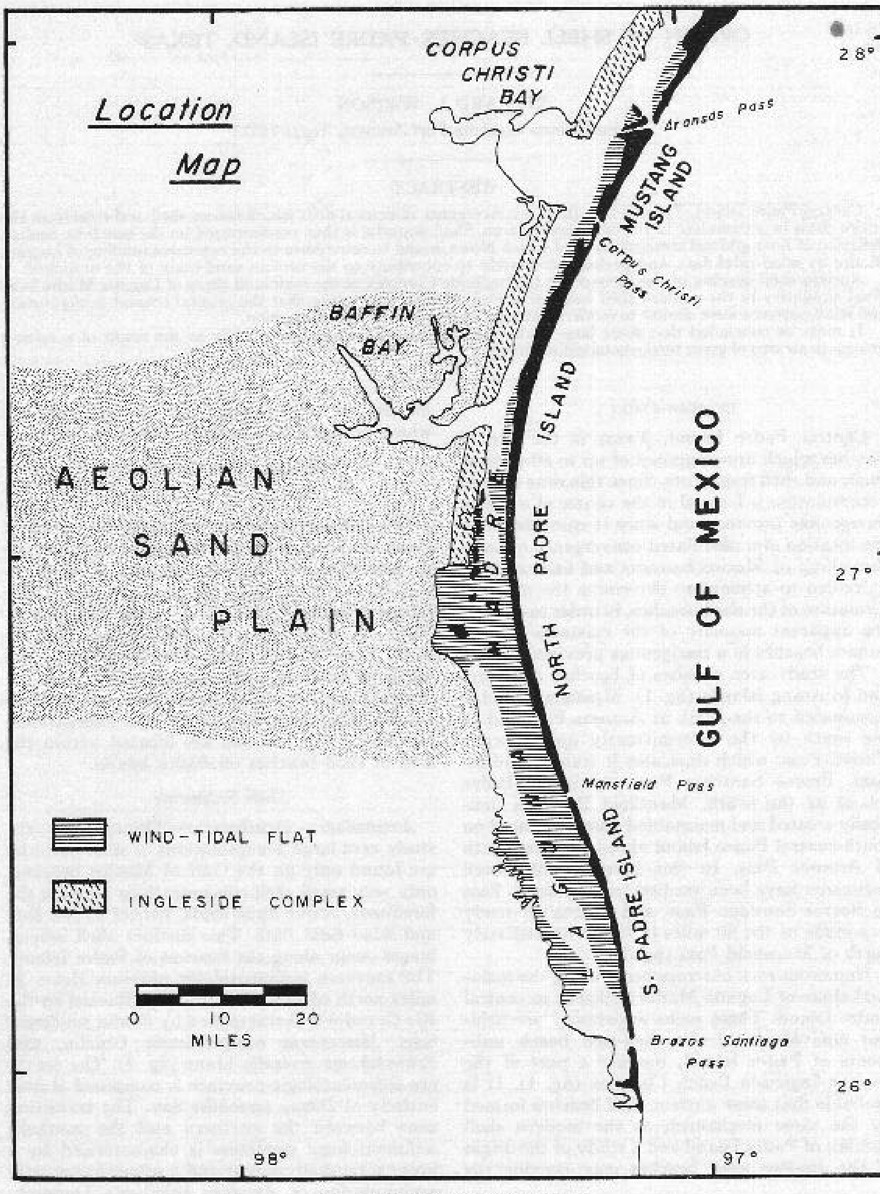

FIG. 1.—Geographic location map.

three species which are common to both provinces.

With the exception of *Donax*, the exact source of each species is uncertain. During the course of the study *Donax* was observed to live in the edge of the surf in dense colonies all along Mustang Island south to the southernmost limit of the northern sedimentologic province on Padre Island. As can be seen from the shell percent curve (fig. 2) there is no accumulation of *Donax* or any other species north of 55 miles north of Mansfield Pass. Thus *Donax* appears to live and die in the surf zone throughout the northern sedimentologic province and is carried south to accumulate near the southern end of the northern province. The *Anadara* probably live throughout the study area in the shallow shelf zone either within the surf or slightly beyond it. The *Mercenaria*, *Eontia*, and *Echinochama* common to the southern province probably represent an older, reworked shell assemblage. In looking at thousands of specimens of each, I have never found a fresh specimen or an unabraded valve. The *Mercenaria* are highly discolored and have been dated with ten dates ranging from 1240 to 7180 years old (personal communication E. William Behrens, 1971). The *Echinochama* usually live attached to a hard substrate in youth. Adjacent to the southern province offshore are numerous submerged ridges of sandstone. This is a likely source for the *Echinochama* or they may be reworked from an unknown source.

Even though the source for the southern assemblage is unknown, the distribution of abraded valves of the species present indicates their alongshore direction of transport. Northward to about 25 miles north of Mansfield Pass, whole but abraded valves of *Mercenaria* are common. The percentage of whole valves decreases to the north. Still farther north whole

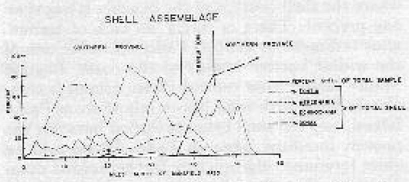

FIG. 2. Shell assemblage distribution. Note that the abundance of the species of the southern province decline in the transition zone and are virtually nonexistent in the northern province. *Donax* makes up most of the northern province but declines in abundance in the transition zone and is not found in the southern province except in one small colony about 20 miles north of Mansfield Pass. The transition zone based on shell assemblage corresponds with a low in shell content. The shell percent curve is the second derivation of a three point moving average.

Mercenaria valves disappear and only abraded plates remain. Finally, as one passes through the transition zone into the northern province, it becomes impossible to find even small fragments of *Mercenaria*. Thus distribution and changing character of the assemblages suggest that the *Mercenaria*, *Eontia*, and *Echinochama* assemblage has a source to the south and is being transported north, the *Donax* assemblage has a source to the north and is being transported south, and the *Anadara* group has a wide source and is being introduced into both the northern and southern provinces.

Shell concentration alongshore.—In order to separate the ephemeral effects of sorting in the foreshore from the more important long-term shell concentration by longshore drift, samples were taken by scraping a pint container evenly up the side of a 2 foot trench in the storm berm, since the shell concentrations in the berm are more uniform than in the foreshore. Samples were collected by this method at ½ mile intervals from Mansfield Pass to the north end of the shell beaches 55 miles north of Mansfield Pass. Samples were also collected at three-mile intervals from Mansfield Pass to 30 miles south of Mansfield Pass. In order to distinguish regional trends a three-point moving average was calculated. As this did not remove local variation to a satisfactory extent, a second 3 point moving average was calculated from the results of the first moving average. These data are plotted as the shell percent curve in Figure 2 which reveal several well defined trends. Approaching the study area from the north, the shell content abruptly increases from less than one percent to nearly 50 percent in a distance of only 4 miles. The northernmost high shell concentration between 55 and 45 miles north of Mansfield Pass is composed of the shell assemblage of the northern sedimentologic province. From 40 miles north of Mansfield Pass to about 30 miles north of Mansfield Pass there is another high in shell content corresponding to an accumulation of the species common to the southern province. Except for a low concentration at Mansfield Pass, the shell content fluctuates around 20 percent in the remainder of the area to the south. Thus within the area of shell beaches there are three major zones based on shell concentrations. These correspond with the three shell assemblage zones.

Local correlation with dune topography.—A study of the topographic maps of Padre Island shows a central belt of high foredunes which roughly corresponds with the zone of maximum shell content. A careful study of the location of the many local maxima on the shell content graph (fig. 2) and the location of high and continuous portions of the foredune ridge shows a

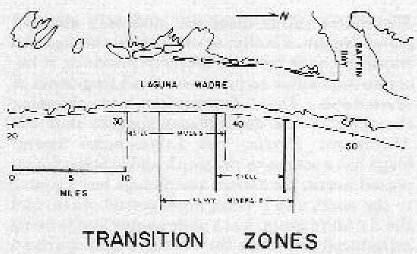

FIG. 3.—Transition zones shown by grain-size, heavy minerals, and shell content. The transition zones for heavy minerals (Bullard, 1942, and Van Andel, 1960), grain-size modes (Hayes, 1965), and for shell percent and assemblage distribution (this study) are shown. The numbers along the shore of Padre Island indicate the distance in miles north of Mansfield Pass.

nearly perfect correlation. That is, where the dunes are high and continuous there is a local maximum in shell content. Where the dunes are low or where there is a hurricane channel or washover fan there is a local minimum of shell content. The high, continuous dunes serve as an impenetrable wall to all but the most powerful storms. All shell that is deposited on the beach in the vicinity of these dunes must remain there because no physical process can remove it. The wind is competent to remove only the finer material which is predominantly terrigenous sand. In contrast, where this wall is breached by hurricane washovers, the shell is periodically removed at least in part by being washed into the interior of the barrier island. This process is self-reinforcing. Where the dunes are the highest and most continuous and the shell content is high, the backshore elevation is usually very high and may show one or more terraces related to the height reached by various storms since the coarser grained shell material builds steeper beaches than the fine terrigenous sand. Due to the high backshore produced by the high dunes, only the largest storms with very high tides can reach the foot of the dunes. Thus protected, the dunes can build still higher and become stronger and better able to resist future wave attack. It should not be inferred that the regional maximum in shell content is a result of the presence of high and continuous dunes. Elsewhere on Mustang and Padre Islands there are similar areas of well developed foredunes adjacent to beaches with less than one percent shell material. Positive correlation between shell content and foredune development occurs only in the littoral drift convergence area.

Transition zones.—A map of the postulated longshore drift convergence area (fig. 3) shows the transition zones determined by Bullard (1942), and Van Andel and Poole (1960) for heavy minerals and by Hayes (1965, 1967) for grain-size modes. The transition zone based on shell assemblage and shell content falls within the limits of Bullard's samples and only a short distance to the north of the transition zone as defined by Hayes. The shell data may be somewhat more accurate, because of the close sample spacing. All of these data support the suggestion that there is a sedimentologic transition zone produced by longshore drift convergence in the central part of Padre Island. The shell assemblage and shell content data limit the width of the transition zone to about eight miles.

Shell concentration normal to shore.—Shell content was determined on ten traverses across the beach normal to the shoreline. The shell distribution seaward of the storm berm is irregular. Nearly pure shell deposits occur in parts of the active berm crest and in the horns of active cusps. The storm berm contains either the maximum or nearly the maximum shell content in a profile across the beach. The shell content then diminishes toward the foredunes (fig. 4). The foredunes, vegetated flats, and wind-tidal flats further inland are composed nearly completely of terrigenous materials.

SEDIMENTARY PROCESSES

There are three possible ways to produce a high shell concentration such as is found on Padre Island; extremely high shell supply, extremely low terrigenous sediment supply, or some sorting phenomenon leading to a shell concentration. There is no evidence of an extreme abundance of living communities. In fact, the greatest abundance of living *Donax*, the main contributor to the northern assemblage is on Mustang Island, and northern Padre Island where the shell content of the beaches is less than one percent. There is surely no lack of terrigenous sediment as central Padre Island is one of the widest barrier islands of the coast, Laguna Madre inland from central Padre Island is completely filled with sand blown inland from Padre Island, and old shell beaches buried between the present foredune ridge on Padre Island and an older foredune ridge slightly farther inland demonstrates that the island has accreted seaward during its history, all good evidence for an abundant terrigenous sediment supply to central Padre Island. Therefore, the shell concentration on Padre Island must be a sorting phenomenon.

Longshore Drift

There is abundant evidence for a convergence of littoral drift on central Padre Island in addition to the sedimentologic evidence of the three transition zones described above. According to Lohse (1955), the currents of the north Texas coast move to the south and the currents of the south Texas coast move to the north to a meeting place at about lat. 27° N. Curray (1960) correctly observes that the convergence is not actually stationary, but migrates north and south along the coast in response to seasonal changes in wind direction. Drift bottle data for the Texas and Louisiana coasts indicate that most of the currents are directly wind driven (Kimsey and Temple, 1962 and 1963; and Watson and Behrens, 1971).

Monthly wind data collected by the U.S. Weather Bureau station at Corpus Christi for the years 1951–1960 give the average velocity and duration for each of 16 compass directions. I determined monthly, annual, and 10 year vector resultants for both velocity and velocity

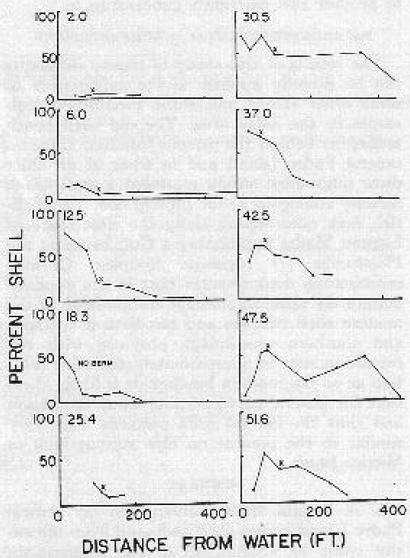

FIG. 4.—Shell distribution along traverses perpendicular to the shoreline. The shell concentration versus distance landward from the edge of the water is plotted for a series of 12 traverses across the width of the beach throughout the study area. The number in the upper left-hand corner of each graph is the distance in miles that the traverse is north of Mansfield Pass. The small x by the trace of the graph denotes the approximate location of the crest of the storm berm on each traverse. Note the irregularity in shell content seaward of the storm berm and the decrease in shell content landward from it.

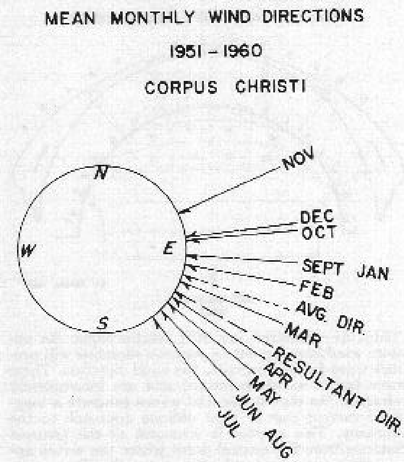

FIG. 5.—Mean monthly wind directions for Corpus Christi 1951–1960. Directions shown represent the average of the monthly vector resultants determined for 10 years of wind data collected at Corpus Christi. The RESULTANT DIR. shown is the vector resultant for the entire 10 year period. The AVG. DIR. is the average of all of the monthly vector resultant directions for the 10 year period. Note that the resultant direction and the average direction separate the winter regime of northers from the summer regime of strong southerlies if March is taken to be a transitional month.

squared for the Corpus Christi data (fig. 5). The annual resultant for the 10 year period ranges between 111° and 135° with a 10 year resultant of 121°. The resultant for V^2 ranges between 110° and 135° with a 10 year resultant of 123°. Data for 1965 and 1966 fall within the limits of the 10 year data described above. In addition Price (1933) presented a vector diagram of the wind direction, duration, and square of the velocity for the period 1923–1930. The annual vector sum derived from this diagram is 120°. Thus several different computations of the vector sum of the winds for Corpus Christi all provide an annual vector sum of about 120°.

A wind blowing into a concave shoreline such as the south Texas coast will produce waves which in turn will produce a convergence of longshore drift at the point where the wind direction is normal to the shoreline (fig. 6). The direction of the net annual resultant wind for Corpus Christi is about 120°, which is normal to the shoreline in the vicinity of Aransas Pass. This suggests a net convergence of longshore drift in that area. Although at any one time sedi-

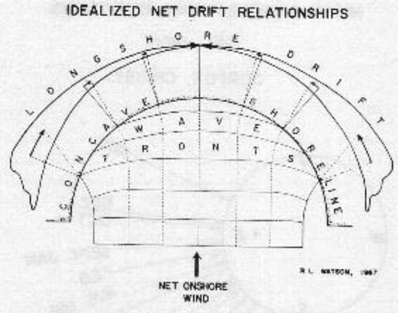

FIG. 6.—Idealized net drift relationships. An onshore wind blowing onto a concave shoreline will produce wave fronts normal to the wind direction. These wave fronts move shoreward and are incompletely refracted. As they break, the waves generate a longshore current due to their oblique approach to the shoreline. This current is strongest at the greatest distance from the central point where the waves approach the shoreline at the greatest angle. The current decreases in magnitude toward the center where it diminishes to zero because the wave approach parallel with the shoreline at the point where the wind direction is normal to the shoreline and no current is generated.

ment is either moving to the north or to the south through the entire area, the long term effect is the net convergence of longshore drift.

The convergence location determined by wind analysis at a single point is only approximate. Sedimentation at inlets can be used to estimate more exactly the location of the long-term convergence. The south jetty of Mansfield Pass has accumulated a huge fillet of sand while the beach just north of the north jetty is eroding. This indicates a strong net littoral drift to the north at Mansfield Pass. Aransas Pass had a history of migration to the south before stabilization (U.S. Army Corps of Engineers). Spit development at Corpus Christi Pass during closure demonstrates that the net drift at that point is to the south. Therefore, if the net littoral drift is to the south at Corpus Christi Pass and to the north at Mansfield Pass, then there must be a net convergence of littoral drift between these two points. This convergence provides the mechanism to supply large amounts of shell material to central Padre Island. However it will also provide a very large terrigenous supply as well. In fact, it should result in the greatest total sediment supply of any beach anywhere along the coast since sediment is being brought in from the south and from the north, and once into the convergence area littoral drift can no longer carry it away.

Wind Deflation

Within the convergence area shell is concentrated on the beach by wind deflation of finer grains. The much finer terrigenous sand can be blown inland to form the foredunes, vegetated flats, and the wind-tidal flat infill of Laguna Madre. Some of the excess sand may also eventually contribute to the aeolian sand plain on the mainland (fig. 1). Since the coarse shell material cannot blow inland and cannot be removed by littoral drift it concentrates on the beaches of the convergence area. Only small amounts are washed inland on hurricane washover fans where the foredune ridge is poorly developed. Thus the combination of a convergence of littoral drift and subsequent wind deflation of the finer terrigenous sand results in a huge accumulation of shell material in the center of an abundant supply of terrigenous sediment. Abundance of organisms, or lack of terrigenous sediments is not necessary to provide this carbonate concentration.

PALEOENVIRONMENTAL INTERPRETATIONS

The results of this study of recent sediments can be directly applied to the explanation of some other recent and some Pleistocene sediments in the same area. The old shell beach sediments behind the present foredune ridge on central Padre Island and in front of an older dune ridge must surely represent a shell beach direcly analogous to the present one. The shell-rich rock outcropping along the west shore of Laguna Madre is probably a Gulf beach of the Pleistocene (?) Ingleside complex. Cursory examination demonstrates that it has approximately the same assemblage composition as the modern shell beaches and has both a northern and southern assemblage province with the transition zone in approximately the same location as on the modern beaches. It is likely then, that the general configuration, wind circulation and thus the littoral drift patterns were very similar to the present on this ancient Gulf of Mexico beach.

SUMMARY

1. A littoral drift convergence on central Padre Island causes shell and sand from the entire coast to accumulate in the convergence area.

2. Shell is concentrated on the beach by aeolian deflation of finer grained terrigenous sand.

3. The excess sand is blown inland to contribute to the extensive infilling of Laguna Madre by wind-tidal flats, and perhaps ultimately to contribute to the aeolian sand plain of the mainland.

4. The great similarity of the Pleistocene shell beaches of the Ingleside complex suggests that

the general coastline configuration and wind patterns were similar to modern wind patterns at the time of their formation.

5. Large carbonate accumulations can occur as a result of a sorting process in an area of great terrigenous sediment supply.

ACKNOWLEDGMENTS

This work was completed as part of the requirements of a Master's thesis at the University of Texas at Austin. My thanks go to Dr. E. William Behrens who supervised the work and to Dr. Alan J. Scott and Dr. Earle F. McBride for serving on the thesis committee. Dr. Ralph Hunter provided much useful criticism in editing this manuscript. Finally, I would like to express appreciation to the many graduate students who aided in field work and to the Marine Science Institute at Port Aransas for their support during completion of the study.

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