HISTORICAL CHANGES AND RELATED COASTAL PROCESSES, GULF AND MAINLAND SHORELINES, MATAGORDA BAY AREA, TEXAS

J. H. McGowen and J. L. Brewton

BUREAU OF ECONOMIC GEOLOGY
The University of Texas at Austin
Austin, Texas 78712
W. L. Fisher, Director

IN COOPERATION WITH

THE GENERAL LAND OFFICE OF TEXAS
Bob Armstrong, Commissioner

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FOREWORD

Change, both natural and man induced, is a significant and defining element of the Coastal Zone. Man-induced change, by definition, can be controlled if desired. The work of nature, however, is altered and modified with much more difficulty, if at all, and attempts to do so commonly lead to unintended results.

Prudent use and adequate management of the Coastal Zone must consider natural changes. These changes are expressed primarily in changes of natural boundaries—changes in position of shorelines, changes in position of lines of vegetation, and changes in boundaries of wetlands, among others. These changes assume particular significance when an eroding (and changing) shoreline transgresses coastal structures or when natural boundaries that are also legal boundaries, such as those marking line of vegetation or boundaries between fresh and tidal wetlands, change.

The best assessment of change is over the long term. In such manner, distinctions can be made between temporary variations and long-term change. In this report, the technique of historical monitoring has been specifically developed. Through mapping of specific, significant boundaries on vintage photographs and charts, taken at varying periods over the past 125 years, long-term direction, amount, and extent of change are determined. Through comparable historical monitoring or mapping of land use and land use activities, man-induced changes can be determined and, importantly, distinguished from natural change. A more accurate evaluation of man's impact can be made.

In 1971, the Texas General Land Office and the Bureau of Economic Geology, The University of Texas at Austin, initiated on a cooperative basis a comprehensive pilot study of Matagorda Bay and environs. The first phase of that study was an analysis of historical changes and the related coastal processes, herein reported. Techniques of historical monitoring developed in this study have been utilized by the Bureau of Economic Geology to determine long-term changes of the entire Texas Gulf Coast. The second part of the Matagorda pilot study addressed in detail the biologic, physical, and chemical characteristics of sediments in Matagorda Bay.

We believe that this project, historical in its orientation, gives us a better ability to make intelligent decisions for the future.

Bob Armstrong
Commissioner, General Land Office

W. L. Fisher
Director, Bureau of Economic Geology

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HISTORICAL CHANGES AND RELATED COASTAL PROCESSES, GULF AND MAINLAND SHORELINES, MATAGORDA BAY AREA, TEXAS

J. H. McGowen and J. L. Brewton[1]

ABSTRACT

Most of the Gulf and bay shorelines of the Matagorda Bay area are in an erosional state. Historical shoreline monitoring, during the interval 1856-1957, and field measurements, made in 1971-1972, document direction and rate of shoreline change for a 116-year interval. Average erosional rates of 16 and 22 feet per year occur at Brown Cedar Cut and along the northeastern part of Matagorda Island, respectively. Erosional rates along bay shorelines range from less than 1 foot per year to 15 feet per year.

All shoreline segments are not erosional. Parts of central and western Matagorda Peninsula were either in equilibrium or in an accretionary phase during 1856-1957, as was Matagorda Island near the western limit of the area of investigation. Field measurements made in 1971-1972 indicated that most of the Matagorda Peninsula shoreline was erosional. Several bay shoreline segments exhibited net land gain for the 116-year interval. Such areas as bayhead deltas, spits which developed downcurrent from erosional headlands, and bay shores that are adjacent to spoil-disposal sites are currently accreting.

Marshes generally decreased in area during the period 1856-1957. Known causes of marsh decline are shoreline erosion which occurs under normal sea and storm conditions, inundation by sediments related to storm washovers, and burial of wetlands beneath dredge spoil. A few marshes have increased in size; the most notable expansion is the marsh associated with the Colorado delta. Most of the Colorado delta, which is some 7,000 acres in area, was constructed between 1929 and 1936.

Shoreline stability (accretion, equilibrium, or erosion) is a function of the interplay among several geological processes such as wind, waves, tides, the kinds and volumes of sediment contributed to bays and the Gulf of Mexico, storm frequency, and compactional subsidence, and slump which is restricted to the cliffed shoreline segments. Erosion dominates the coastal scene primarily because of a deficit of sand supplied to the area. In general, the shores of large bays are eroded more rapidly than those of small bays; the fetch of large bays is great and waves tend to be large. Also, bay shores that face into the prevailing wind erode rapidly. Shoreline erosion is relatively slow along high cliffed shorelines that lie in the lee of prevailing southeast winds. Northers are generally accompanied by high-velocity, short-duration winds. These winds generate rather large waves, which erode north-facing shorelines.

Exceptionally high tides and large waves are produced by hurricanes. Storm surge (storm tides) and large waves severely erode coastal barriers and peninsulas. Hurricane *Carla* (1961) eroded the shoreline of Matagorda Peninsula as much as 800 feet in a few hours. Low-relief barrier islands and peninsulas, such as Matagorda Peninsula, are easily breached by storm surge, and large volumes of sediment eroded from the shoreface and beach are transported into the bays. This volume of sediment is effectively removed from the sediment transport system operating in the nearshore zone of the Gulf of Mexico and is stored in the Matagorda Bay system. Erosion of the shoreline of the Modern Matagorda Peninsula by storms is irreparable.

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INTRODUCTION

The Texas Gulf Coast consists of erosional deltaic headlands and of peninsulas and barrier islands, which separate bays and lagoons from the Gulf of Mexico. There are about 367 miles of Gulf shoreline and about 1,425 miles of lagoon, bay, and estuary shoreline in Texas. Climate of the Texas Coastal Zone is mild with average annual temperature ranging from 69°F in the east to 74°F in the south. A mild climate, coupled with access to relatively wide sand beaches, fishing, and other water-related sports, makes the Texas Coast a prime tourist attraction. Natural resources within the coastal plain and the relative ease of transporting raw materials and finished products via intracoastal waterways have attracted industry to the region.

In recent years the Texas Coastal Zone has experienced a rather dramatic change. Approximately one-fourth of the State's population now resides in the region, and population is steadily increasing. Consequently, shoreline property is in exceeding demand for construction of permanent homes, second homes, condominiums, hotels and motels, and for recreational use. Similarly, industrial development is also expanding significantly.

Added to an increasing population and industrial expansion within the region are a decrease in supply of domestic oil and gas and a greater reliance on foreign oil imports to fulfill energy requirements. Deepwater ports or offshore monobuoy systems will be required to handle supertankers. Increased use of nuclear power for meeting energy needs will require a number of sites in the Coastal Zone. Construction in the region will expand with larger oil imports and a shift from fossil fuel to nuclear-powered generating plants.

The objectives of this study were: (1) to document the direction and magnitude of shoreline change; (2) to present some possible causes of change; and (3) to make this information available to those who might be interested in shoreline stability as it will affect man-made structures. Man's activities in the Coastal Zone have grown without an adequate knowledge of shoreline stability. About 60 percent of the Texas Gulf shoreline is now erosional, with rates up to 80 feet per year locally. Principal causes of erosion are natural, but certain of man's activities may have increased erosional rates. Natural causes of shoreline retreat, such as sand deficiency and relative rise in sea level, pose problems that cannot be readily solved. It is imperative, therefore, that rates and directions of shoreline change be measured and that man's Coastal Zone activities proceed in concert with this natural change.

The Matagorda Bay area was chosen for study because it is one of the segments of the Texas Coast that has been least affected by man's activities. A two-phase study of the Matagorda Bay area was undertaken to determine shoreline stability of Gulf and bay shorelines and changes in marsh area for the period 1856 through 1972, and to map the distribution of sediment types, total organic carbon, trace elements, and molluscs. This report presents the results of the first phase of the Matagorda Bay investigation by the Bureau of Economic Geology and the General Land Office, undertaken between October 1971 and May 1972.

ACKNOWLEDGMENTS

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Sam Valastro, Research Scientist, Radiocarbon Laboratory, The University of Texas at Austin, provided radiocarbon age determinations of molluscan shell and wood collected on Matagorda Peninsula and from Cedar Lake and Cow Trap Lakes.

The manuscript was reviewed by W. L. Fisher, L. F. Brown, Jr., E. G. Wermund, and J. R. Byrne, Bureau of Economic Geology, and W. D. (Red) Oliver, Peggy Harwood, and Rose Ann Rowlet, General Land Office. Cartographic preparation was by D. F. Scranton under the supervision of J. W. Macon, who also supervised drafting of the illustrations. Elizabeth T. Moore edited and typed the manuscripts; final editing was by Kelley Kennedy. The paper was composed by Fannie Mae Sellingsloh.

GENERAL SETTING

The Matagorda Bay study area consists of deltaic headlands, peninsulas and barrier islands, large bays and estuaries, and gently seaward-sloping uplands that form the mainland shoreline. Matagorda Bay system and environs are situated in parts of Matagorda, Calhoun, Victoria, and Jackson Counties (fig. 1). Size of the area is approximately 2,000 square miles, consisting of: (1) 1,470 square miles of uplands; (2) 455 square miles of bays and estuaries; and (3) 75 square miles of peninsulas, barrier islands, and tidal deltas.

Gulf beaches in the area are about 65 miles long. They range in composition and texture from terrigenous fine sand to shell and rock fragment gravel. The bay shoreline, consisting of wetlands, deltas, sand and shell beaches, and almost vertical cliffs, is approximately 235 miles long.

Three general physiographic elements characterize the study area. These are: (1) Matagorda Peninsula and Matagorda Island; (2) the Pleistocene uplands; and (3) rivers and small streams that dissect the uplands. Matagorda Peninsula ranges in width from 0.75 to 1.0 mile, and has an average elevation of about 7 feet. Dunes are rare on the peninsula, but some isolated dunes attain heights of 25 feet. Only the eastern 7.5 miles of Matagorda Island occurs in the study area. The island ranges in width from 1.25 to 1.5 miles. Fore-island dunes up to 30 feet high (Wilkinson, 1973) are well developed on Matagorda Island.

Pleistocene uplands, which are underlain by fluvial-deltaic and strandplain deposits (fig. 2), are relatively flat. Maximum elevation is about 50 feet in the northwest corner of the area. The slope of the upland surface is shown on figure 3. Areas of lowest slope are near Caney Creek and Port O'Connor. Small drainage systems are, in part, affected by the degree and direction of the slope of the land surface.

Several rivers and creeks discharge water and sediment into the Matagorda Bay system. The larger streams, such as the Colorado and Lavaca Rivers and Garcitas Creek have constructed bayhead deltas along the bay margins. The largest of these deltas, the Colorado, has prograded completely across Matagorda Bay.

Climate of the Matagorda Bay area is humid subtropical (U. S. Department of Commerce, 1958-1969). Rainfall and temperature data (fig. 4) are almost identical for four weather stations in the vicinity of Matagorda Bay (fig. 5). Rainfall distribution graphs show two peaks, one in June and the other in September, which coincide with thunderstorm and hurricane occurrences, respectively.

Wind data from the Victoria Weather Station records indicate that surface winds are chiefly onshore (fig. 6). Prevailing winds for the period 1951-1960 were from the south-southeast, whereas strongest winds during the same period were from the northwest.

Hurricanes and tropical storms are naturally occurring phenomena of the Atlantic, Caribbean,

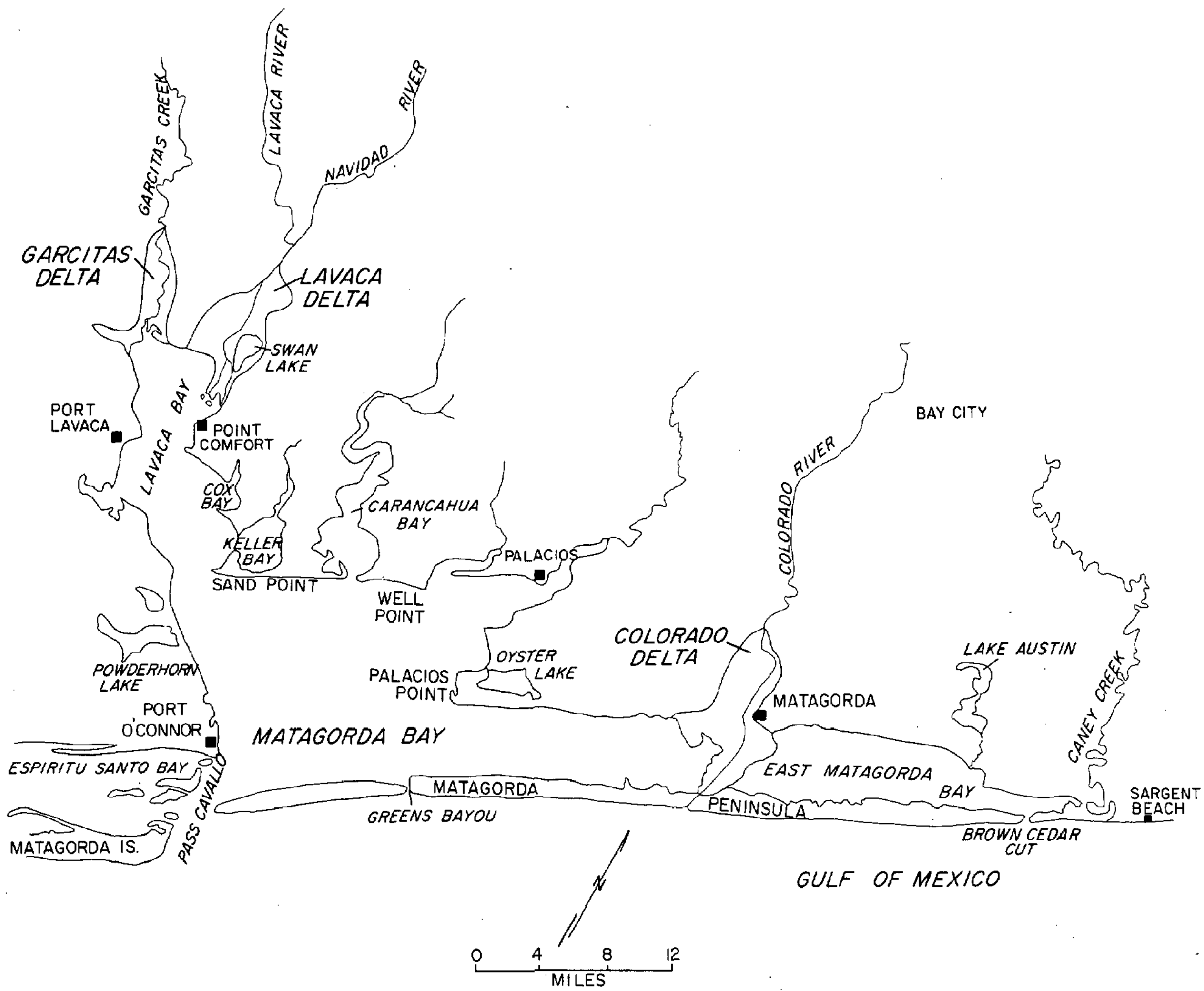
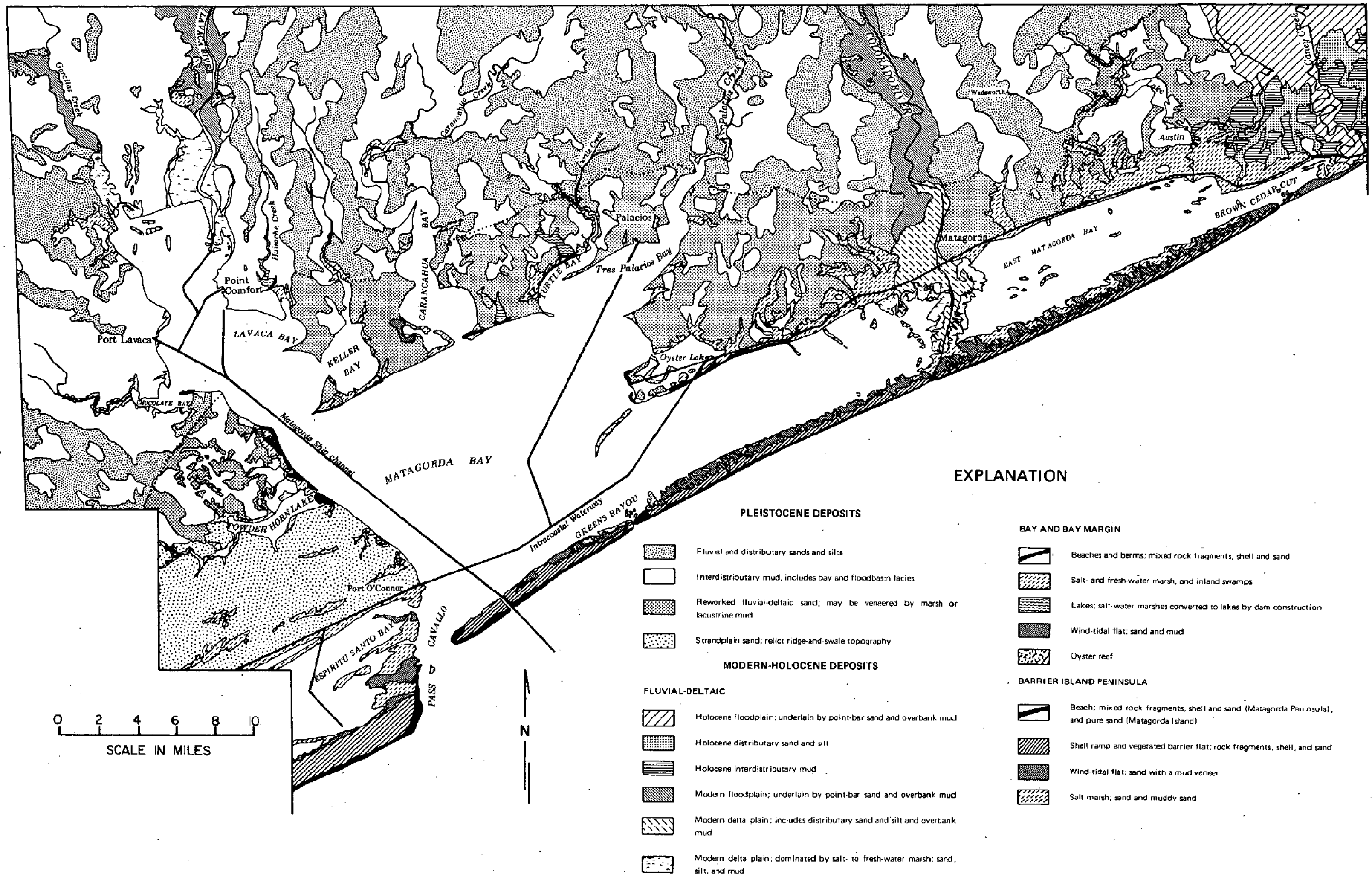


Figure 1. Locality map of the Matagorda Bay area.

and Gulf Coast areas. Hurricanes are storms of tropical origin with cyclonic circulation of 74 mph or higher (Dunn and Miller, 1960). During the period 1900-1963, the Texas Coast was struck by 42 tropical cyclones, a frequency of one storm every 1.5 years (Hayes, 1965, 1967). Hurricanes occur most commonly during the months August and September. The effects of hurricanes on the Coastal Zone are: (1) shoreline erosion; (2) breaching of barrier islands and peninsulas; (3) salt-water flooding by storm surge; (4) damage to man-made structures by flooding and wind; and (5) flooding resulting from aftermath rains.

Tides in the northern Gulf of Mexico are chiefly diurnal (one high and one low water level each tidal day). Tidal range is low. The mean diurnal range at Freeport Harbor is 1.7 feet and 1.4 feet at Pass Cavallo (U. S. Department of Commerce, 1973). Tidal currents are an important sand-transporting mechanism in tidal pass areas; elsewhere waves and longshore currents are the principal sediment-transporting mechanisms.

The Texas Coast is a wave-dominated coast (Hayes, 1965). Since prevailing wind in the Matagorda Bay area is from the southeast quadrant, most waves approach the shoreline from that direction, strike the shoreline at an angle, and set up longshore currents that move sediment to the southwest.



GEOLOGIC MAP, MATAGORDA BAY AREA

Figure 2. Geologic map, Matagorda Bay area.

GEOLOGIC HISTORY OF THE MATAGORDA BAY AREA

Pleistocene, Holocene, and Modern deposits constitute the uplands, bay margins, and Gulf shoreline features (fig. 2). Water bodies, including bays, estuaries, and their associated fluvial systems, are Holocene and Modern features. Uplands are underlain by deltaic sediments which were deposited during the Sangamon Interglacial Stage and a strandplain sand that accumulated during a Wisconsin Interstadial Stage. Shorelines of the Matagorda Bay area began developing their present configuration at sea-level stillstand, about 3,000 to 2,500 years B.P. (before present). The term stillstand implies a halt in the rise of sea level. The dates given for stillstand are those reported by Curray (1960), Nelson and Bray (1970), and Frazier (1974).

Depositional and erosional features of the Texas Gulf Coast were created, indirectly, by alternate growth and reduction in size of continental glaciers. Glaciation began to affect the North American continent approximately three million years B.P. (Cooke, 1973, table 3, p. 215). The sequence of Pleistocene glacial events is shown in table 1 and figure 7.

Table 1. Pleistocene glacial and interglacial episodes (after Kummel, 1961).

Glacial (Low Sea-Level Stand)	Interglacial (High Sea-Level Stand)
	Holocene
Wisconsinan	
	Sangamon
Illinoian	
	Yarmouth
Kansan	
	Aftonian
Nebraskan	

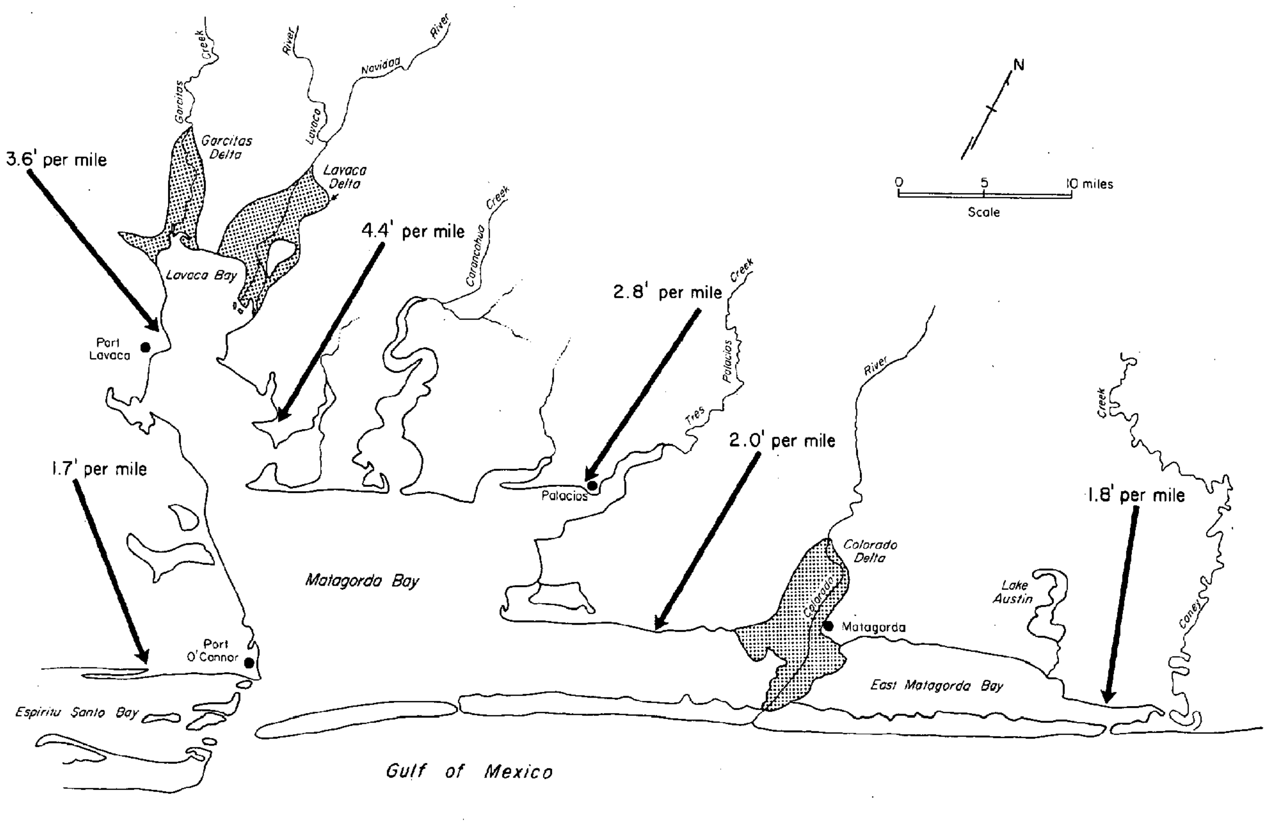


Figure 3. Slope of the lower 20 miles of coastal plain. Slope gradient and direction are shown for six areas along the Sangamon delta plain and Wisconsin strandplain. Slope directions converge along the axis of Lavaca Bay.

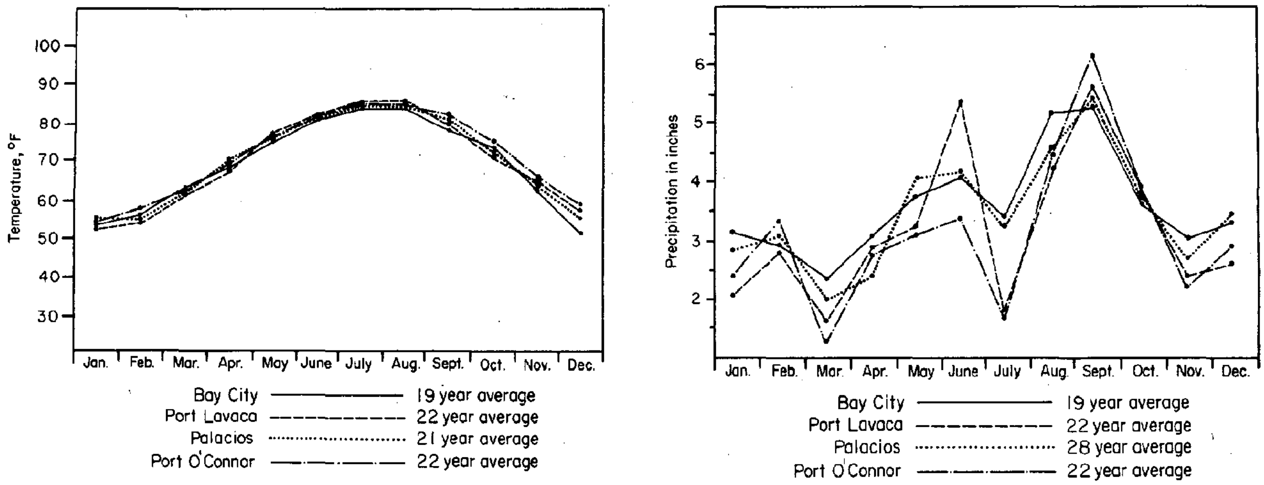


Figure 4. Temperature and rainfall distribution for Bay City, Port Lavaca, Palacios, and Port O'Connor. (A) Mean monthly temperature. (B) Mean monthly precipitation. Data from U. S. Dept. Commerce, Climatological summary, Bay City, 1943-1961, and from Env. Sci. Serv. Adm., U. S. Dept. Commerce, Palacios 1941-1968, Port Lavaca 1947-1968, and Port O'Connor, 1948-1969.

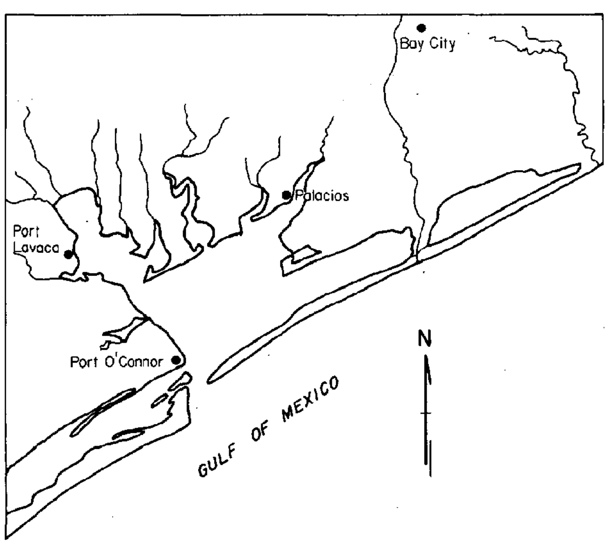


Figure 5. Location of weather stations in the Matagorda Bay area.

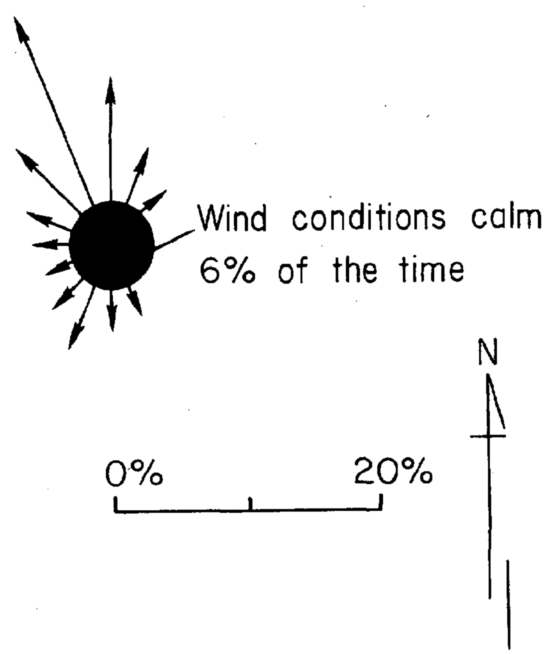


Figure 6. Percentage frequency of surface wind direction (annual). Data from Victoria weather station (U. S. Department of Commerce, Local Climatological Data, Victoria, Texas, 1958-1969).

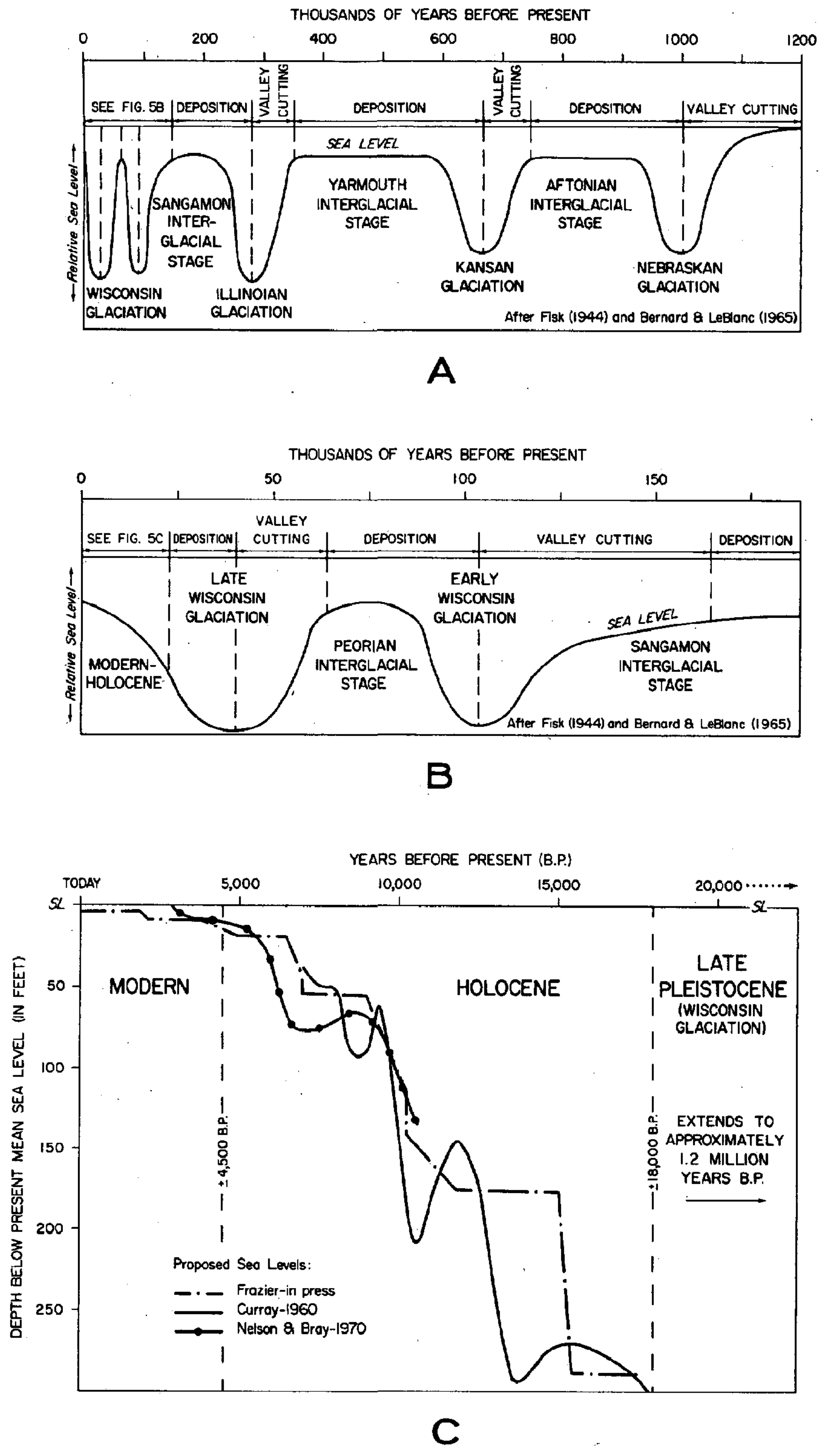


Figure 7. Sea-level changes related to glacial and interglacial stages. (A) Generalized Pleistocene sea-level variations and associated erosional and depositional episodes. (B) Generalized sea-level changes during Late Wisconsin glaciation. (C) Proposed sea-level changes during the last 20,000 years (after Fisher and others, 1973).

Pleistocene History

Alternate deposition and erosion occurred along the coastal plain in response to waxing and waning of continental glaciers (fig. 7). With the growth of glaciers, there was a lowering of sea level, and streams were entrenched across the coastal plain and continental shelf. Melting glaciers returned water to the sea creating a rise in sea level and renewed sedimentation in the area of the present outer coastal plain (outer coastal plain is the general area extending inland from the Gulf of Mexico a distance of 50 miles). The sediments exposed within the outer coastal plain were deposited during one Pleistocene interglacial stage and one interstadial stage, probably during the Sangamon Interglacial Stage and a Wisconsin Interstadial Stage.

During the Sangamon high stand of sea level, most of the outer coastal plain, extending from the bay shore inland, was constructed by sediment delivered to the area by the ancestral Brazos-Colorado and San Antonio-Guadalupe Rivers. The coastal plain was built seaward into the Gulf of Mexico by prograding deltas. The Pleistocene delta lying to the east of the Modern Lavaca River was constructed by the ancestral Brazos-Colorado Rivers, and the delta to the west is the Pleistocene San Antonio-Guadalupe delta. The slope of the coastal plain surface (fig. 3) reflects the overlap of these two major deltaic systems.

Sangamon deposits consist of fluvial and distributary gravel and sand, interdistributary and overbank mud, and bay-estuarine mud and shell. In some outcrops along the shores of the Matagorda Bay system, red to brown bay mud containing oyster reefs is overlain by thin progradational deltaic sequences. Deltaic muds and sands are chiefly red or brown. Commonly, both mud and sand have been extensively calichified. Distributary channel fill is coarse-grained silt and very fine-grained sand. Channel-fill fluvial sand and gravel were recognized in only one bay-shore outcrop. It consists of a lower granule to small pebble gravel unit (containing abundant vertebrate remains) which grades upward into fine-grained sand. Sedimentary structures are well preserved in the fluvial deposit, but structures have been obliterated in adjacent Pleistocene units by caliche replacement.

The Wisconsin Glacial Stage which began about 130,000 years B.P. (Cooke, 1973) was characterized by several advances and retreats of the continental ice sheet and fluctuations in sea level. During one of the advances and associated lowering of sea level, a soil was developed on the Sangamon delta plain. The following rise in sea level flooded part of the area covered by this soil. During subsequent stillstand, sand delivered to the Gulf of Mexico by several local streams constructed a strandplain in the area of Port O'Connor (McGowen and others, 1972; Wilkinson, 1974; Wilkinson and others, in press). Where observed in outcrop and by subsurface methods, the strandplain sand rests on the soil horizon.

During the late Wisconsin, sea level was lowered approximately 390 feet (Curray, 1960) to 450 feet (LeBlanc and Hodgson, 1959). According to Curray, shoreline position at that time was at or near the edge of the continental shelf. Streams entrenched their courses across the coastal plain and continental shelf in response to a changing base level.

Holocene History

Sea level began to rise approximately 18,000 years B.P. (fig. 7). This rise marks the beginning of the Holocene Epoch. Several temporary stillstands during Holocene sea-level rise produced barrier islands and lagoons on the continental shelf similar to Modern barriers and lagoons of the Texas Coast (Frazier, 1974). The sea reworked these deposits as it resumed its landward migration with rising sea level. River valleys were filled with sediment during this Holocene transgression across the continental shelf.

Erosion associated with Wisconsin low stand of sea level produced numerous valleys in the Matagorda Bay area. The largest of these valleys was scoured by the Lavaca-Navidad fluvial system. Smaller systems, such as Tres Palacios and Carancahua Creeks, were probably tributary to the Lavaca-Navidad Rivers. Data from subbottom profiling and coring indicate that the depth of the Lavaca-Navidad valley ranged from about 100 feet near the head of the Modern Lavaca Bay to at least 125 feet in the vicinity of Port O'Connor. Water from the Gulf of Mexico first invaded the Lavaca-Navidad estuary 11,000 to 10,500 years B.P. These dates were derived from Frazier's (1974) sea-level data.

A relict shoreline at 45 to 60 feet below sea level was reported by Frazier (1974) to have developed between 10,000 and 7,500 years B.P. During this time interval, water from the Gulf of Mexico probably exerted an influence on the Lavaca-Navidad estuary as far north as the present head of Lavaca Bay.

Transgression was resumed at about 7,500 years B.P. Sea level reached its present position between 3,000 and 2,500 years B.P. (Curray, 1960; Nelson and Bray, 1970; Frazier, 1974). During the latter phases of Holocene transgression, estuaries were being filled by a sequence of fluvial and estuarine sediments, and parts of the Pleistocene strandplain sand were being reworked and transported landward to form nuclei for Matagorda Island (Wilkinson, 1973).

Modern History

Modern history of the Matagorda Bay area dates from stillstand, 3,000 to 2,500 years B.P., to the present. Development of the Modern shoreline may be divided into prehistoric and historic categories. Prehistoric development is based chiefly on interpretation of field data, and documentation of historic development is from both published records and field observations.

Prehistoric Development

Following stillstand, rivers began to fill their estuaries by progradation of bayhead deltas. Sediment derived from several major fluvial systems directly influenced the development of shoreline features in the Matagorda Bay area. Among these are the Brazos, Colorado, and Lavaca-Navidad Rivers, and Garcitas Creek.

At stillstand, the Brazos and Colorado Rivers were discharging into a common estuary which had an estimated average depth of 25 feet, a width of 30 miles, and a length (measured from the Gulf shoreline to bayhead) of 22 miles. With the use of sediment volume data for the Brazos and Colorado Rivers published in the Nineteenth Report of Texas Board of Water Engineers (1950, p. 161), it is apparent that the Brazos and Colorado Rivers could have filled their estuary in 1,200 years. While these rivers were filling their estuary, and before Matagorda Peninsula was constructed, much of the suspension load delivered to the Gulf of Mexico by these streams was transported into Matagorda and Lavaca Bays. Upon reaching the Gulf of Mexico, bed-load material from the Brazos and Colorado Rivers was put into the longshore drift system; at this time Matagorda Peninsula began to develop. The Brazos and Colorado bayhead deltas were characterized by distributary sands and interdistributary muds, but deltas constructed by these same rivers in the open Gulf of Mexico were similar to the present Brazos delta; they were high-destructional, wave-dominated deltas (Scott and Fisher, 1969, p. 11-29).

While the Brazos and Colorado Rivers were filling their estuary, the north and west shores of Matagorda Bay were probably open to the Gulf of Mexico. At this time, mudflats and marshes were developing in the area of Lake Austin and shell beaches were being constructed along most of the remaining shoreline. West of Pass Cavallo, incipient islands had coalesced to form Matagorda Island.

Subsequent to the filling of the Brazos-Colorado estuary, sand was transported toward the southwest by persistent longshore drift. Matagorda Peninsula was constructed by spit accretion across the bay and estuarine muds. Growth of the peninsula eventually separated Matagorda Bay from the Gulf of Mexico. Since Matagorda Peninsula has been erosional throughout much of its history, it does not display its original accretionary grain.

Approximately 1,000 years ago, the lower part of the Colorado River, known today as Caney Creek, was captured in the area between Wharton and Columbus by a headward-eroding stream. After its capture, the Colorado began discharging into Matagorda Bay in the vicinity of the small town of Matagorda.

Historic Development

Configuration of Gulf and mainland shorelines has not changed significantly since the first reliable coastal charts were produced in 1856-1859. Some local changes have resulted from man's activities. Accretion of the north shore of Matagorda Bay (between Lake Austin and Oyster Lake) and the north shore of Espiritu Santo Bay resulted from dredging the Intracoastal Canal. Construction of Matagorda Ship Channel jetties has produced changes along the Gulf shoreline. Sand that is transported to the southwest by longshore currents is trapped along the north jetty, thereby accreting the shoreline. Since most of the sand is trapped by the north jetty, the Gulf shoreline lying between the south jetty and Pass Cavallo consequently is eroding.

Perhaps the most obvious change in the Matagorda Bay area was the growth of the Colorado delta, during 1929-1935, from a small 45-acre delta to a complex delta of almost 5,000 acres. Rapid deltation resulted from removal of a log jam from the river in 1929 (Wadsworth, 1941, 1966). The log jam extended inland 46 miles from the town of Matagorda. A large volume of sediment had accumulated in the river because of the greatly reduced flow. Upon release of the log jam, sediment was rapidly transported to the bay creating a delta that prograded completely across Matagorda Bay. In 1936, a channel was dredged through Matagorda Peninsula, and the Colorado River began to discharge into the Gulf of Mexico. Tiger Island Channel was dredged from the river to west Matagorda Bay in the early 1950's. Since then a small delta lobe has developed in Matagorda Bay.

HISTORICAL SHORELINE MONITORING

GENERAL METHODS AND PROCEDURES USED BY THE BUREAU OF ECONOMIC GEOLOGY

Definition

Historical Shoreline Monitoring is the documentation of direction and magnitude of shoreline change through specific time periods using accurate vintage charts, maps, and aerial photographs.

Sources of Data

Basic data used to determine changes in shoreline position are near-vertical aerial photographs and mosaics and topographic charts. Accurate topographic charts dating from 1850, available through the Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), were mapped by the U. S. Coast Survey using plane table procedures. Reproductions of originals are used to establish shoreline position (mean high water) prior to the early 1930's. Aerial photography supplemented and later replaced regional topographic surveys in the early 1930's; therefore, subsequent shoreline positions are mapped on individual stereographic photographs and aerial photographic mosaics representing a diversity of scales and vintages. These photographs show shoreline position based on the sediment-water interface at the time the photographs were taken.

Procedure

The key to comparison of various data needed to monitor shoreline variations is agreement in scale and adjustment of the data to the projection of the selected map base; U. S. Geological Survey 7.5-minute quadrangle topographic maps (1:24,000 or 1 inch = 2,000 feet) are used for this purpose. Topographic charts and aerial photographs are either enlarged or reduced to the precise scale of the topographic maps. Shorelines shown on topographic charts and sediment-water interface mapped directly on sequential aerial photographs are transferred from the topographic charts and aerial photographs onto the common base map mechanically with a reducing pantograph or optically with a Saltzman projector. Lines transferred to the common base map are compared directly and measurements are made to quantify any changes in position with time.

Factors Affecting Accuracy of Data

Documentation of long-term changes from available records, referred to in this report as *historical monitoring*, involves repetitive sequential mapping of shoreline position using coastal charts (topographic surveys) and aerial photographs. This is in contrast to short-term monitoring which employs beach profile measurements and/or the mapping of shoreline position on recent aerial photographs only. There are advantages and disadvantages inherent in both techniques.

Long-term historical monitoring reveals trends which provide the basis for projection of future changes, but the incorporation of coastal charts dating from the 1850's introduces some uncertainty as to the precision of the data. In contrast, short-term monitoring can be extremely precise. However, the inability to recognize and differentiate long-term trends from short-term changes is a decided disadvantage. Short-term monitoring also requires a network of stationary, permanent markers which are periodically reoccupied because they serve as a common point from which future beach profiles are made. Such a network of permanent markers and measurements has not been established along the Texas Coast and even if a network was established, it would take considerable time (20 to 30 years) before sufficient data were available for determination of long-term trends.

Because the purpose of shoreline monitoring is to document past changes in shoreline position and to provide basis for the projection of future changes, the method of long-term historical monitoring is preferred.

Original Data

Topographic surveys.—Some inherent error probably exists in the original topographic surveys conducted by the U. S. Coast Survey [U. S. Coast and Geodetic Survey, now called National Ocean Survey]. Shalowitz (1964, p. 81) states "... the degree of accuracy of the early surveys depends on many factors, among which are the purpose of the survey, the scale and date of the survey, the standards for survey work then in use, the relative importance of the area surveyed, and the ability and care which the individual surveyor brought to his task." Although it is neither possible nor practical to comment on all of these factors, much less attempt to quantify the error they represent, in general the accuracy of a particular survey is related to its date; recent surveys are more accurate than older surveys. Error can also be introduced by physical changes in material on which the original data appear. Distortions, such as scale changes from expansion and contraction of the base material, caused by reproduction and changes in atmospheric conditions, can be corrected by cartographic techniques. Location of mean high water is also subject to error. Shalowitz (1964, p. 175) states "... location of the high-water line on the early surveys is within a maximum error of 10 meters and may possibly be much more accurate than this."

Aerial photographs.—Error introduced by use of aerial photographs is related to variation in scale and resolution, and to optical aberrations.

Use of aerial photographs of various scales introduces variations in resolution with concomitant variations in mapping precision. The sediment-water interface can be mapped with greater precision on larger scale photographs, whereas the same boundary can be delineated with less precision on smaller scale photographs. Stated another way, the line delineating the sediment-water interface represents less horizontal distance on larger scale photographs than a line of equal width delineating the same boundary on smaller scale photographs. Aerial photographs of a scale less than that of the topographic base map used for compilation create an added problem of imprecision because the mapped line increases in width when a photograph is enlarged optically to match the scale of the base map. In contrast, the mapped line decreases in width when a photograph is reduced optically to match the scale of the base map. Furthermore, shorelines mechanically adjusted by pantograph methods to match the scale of the base map do not change in width. Fortunately, photographs with a scale equal to or larger than the topographic map base can generally be utilized.

Optical aberration causes the margins of photographs to be somewhat distorted and shorelines mapped on photographic margins may be a source of error in determining shoreline position. However, only the central portion of the photographs are used for mapping purposes, and distances between fixed points are adjusted to the 7.5-minute topographic base.

Meteorological conditions prior to and at the time of photography also have a bearing on the accuracy of the documented shoreline changes. For example, deviations from normal astronomical tides caused by barometric pressure, wind velocity and direction, and attendant wave activity may introduce errors, the significance of which depends on the magnitude of the measured change. Most photographic flights are executed during calm weather conditions, thus eliminating most of the effect of abnormal meteorological conditions.

Interpretation of Photographs

Another factor that may contribute to error in determining rates of shoreline change is the ability of the scientist to interpret correctly what he sees on the photographs. The most qualified aerial photograph mappers are those who have made the most observations on the ground. Some older aerial photographs may be of poor quality, especially along the shorelines. On a few photographs, both the beach and swash zone are bright white (albedo effect) and cannot be precisely differentiated; the shoreline is projected through these areas, and therefore, some error may be introduced. In general, these difficulties are resolved through an understanding of coastal processes and a thorough knowledge of factors that may affect the appearance of shorelines on photographs.

Use of mean high-water line on topographic charts and the sediment-water interface on aerial photographs to define the same boundary is inconsistent because normally the sediment-water interface falls somewhere between high and low tide. Horizontal displacement of the shoreline mapped using the sediment-water interface is almost always seaward of the mean high-water line. This displacement is dependent on the tide cycle, slope of the beach, and wind direction when the photograph was taken. The combination of factors on the Gulf shoreline which yield the greatest horizontal displacement of the sediment-water interface from mean high water are low tide conditions, low beach profile, and strong northerly winds. Field measurements indicate that along the Texas Gulf Coast, maximum horizontal displacement of a photographed shoreline from mean high-water level is approximately 125 feet under these same conditions. Because the displacement of the photographed shoreline is almost always seaward of mean high water, shoreline changes determined from comparison of mean high-water line and sediment-water interface will slightly *underestimate rates of erosion* or slightly overestimate rates of accretion.

Cartographic Procedure

Topographic charts.—The topographic charts are replete with a 1-minute-interval grid; transfer of the shoreline position from topographic charts to the base map is accomplished by construction of a 1-minute-interval grid on the 7.5-minute topographic base map and projection of the chart onto the base map. Routine adjustments are made across the map with the aid of the 1-minute-interval latitude and longitude cells. This is necessary because: (1) chart scale is larger than base map scale; (2) distortions (expansion and contraction) in the medium (paper or cloth) of the original survey and reproduced chart, previously discussed, require adjustment; and (3) paucity of culture along the shore provides limited horizontal control.

Aerial photographs.—Accuracy of aerial photograph mosaics is similar to topographic charts in that quality is related to vintage; more recent mosaics are more accurate. Photograph negative quality, optical resolution, and techniques of compiling controlled mosaics have improved with time; thus, more adjustments are necessary when working with older photographs.

Cartographic procedures may introduce minor errors associated with the transfer of shoreline position from aerial photographs and topographic charts to the base map. Cartographic procedures do not increase the accuracy of mapping; however, they tend to correct the photogrammetric errors inherent in the original materials such as distortions and optical aberrations.

Measurements and Calculated Rates

Actual measurements of linear distances on maps can be made to one-hundredth of an inch which corresponds to 20 feet on maps with a scale of 1 inch = 2,000 feet (1:24,000). This is more precise than the significance of the data warrants. However, problems do arise when rates of change are calculated because: (1) time intervals between photographic coverage are not equal; (2) erosion or accretion is assumed constant over the entire time period; and (3) multiple rates ($\frac{n^2 - n}{2}$, where n represents the number of mapped shorelines) can be obtained at any given point using various combinations of lines.

The beach area is dynamic and changes of varying magnitude occur continuously. Each photograph represents a sample in the continuum of shoreline changes and it follows that measurements of shoreline changes taken over short time intervals would more closely approximate the continuum of changes because the procedure would approach continuous monitoring. Thus, the problems listed above are interrelated, and solutions require the averaging of rates of change for discrete intervals. Numerical ranges and graphic displays are used to present the calculated rates of shoreline change.

Where possible, dates when individual photographs actually were taken are used to determine the time interval needed to calculate rates, rather than the general date printed on the mosaic. Particular attention is also paid to the month, as well as year of photography; this eliminates an apparent age difference of one year between photographs taken in December and January of the following year.

Justification of Method and Limitations

The methods used in long-term historical monitoring carry a degree of imprecision, and trends and rates of shoreline changes determined from these techniques have limitations. Rates of change are to some degree subordinate in accuracy to trends or direction of change; however, there is no doubt about the significance of the trends of shoreline change documented over more than 100 years. An important factor in evaluating shoreline changes is the total length of time represented by observational data. Observations over a short period of time may produce erroneous conclusions about the long-term change in coastal morphology. For example, it is well established that landward retreat of the shoreline during a storm is accompanied by sediment removal; the sediment is eroded, transported, and temporarily stored offshore. Shortly after storm passage, the normal beach processes again become operative and some of the sediment is returned to the beach. If the shoreline is monitored during this recovery period, data would indicate beach accretion; however, if the beach does not accrete to its prestorm position, then net effect of the storm is beach erosion. Therefore, long-term trends are superior to short-term observations. Establishment of long-term trends based on changes in shoreline position necessitates the use of older and less precise topographic surveys. The applicability of topographic surveys for these purposes is discussed by Shalowitz (1964, p. 79) who stated:

> "There is probably little doubt but that the earliest records of changes in our coastline that are on a large enough scale and in sufficient detail to justify their use for quantitative study are those made by the Coast Survey. These surveys were executed by competent and careful engineers and were practically all based on a geodetic network which minimized the possibility of large errors being introduced. They therefore represent the best evidence available of the condition of our coastline a hundred or more years ago, and the courts have repeatedly recognized their competency in this respect . . . ."

Because of the importance of documenting changes over a long time interval, topographic charts and aerial photographs have been used to study beach erosion in other areas. For example, Morgan and Larimore (1957), Harris and Jones (1964), El-Ashry and Wanless (1968), Bryant and McCann (1973), and Stapor (1973) have successfully used techniques similar to those employed herein. Previous articles describing determinations of beach changes from aerial photographs were reviewed by Stafford (1971) and Stafford and others (1973).

Simply stated, the method of using topographic charts and aerial photographs, though not absolutely precise, represents the best method available for investigating long-term trends in shoreline changes.

Limitations of the method require that emphasis be placed first on *trend* of shoreline changes with rates of change being secondary. Although rates of change from map measurements can be calculated to a precision well beyond the limits of accuracy of the procedure, they are most important as *relative* values; that is, do the data indicate that erosion is occurring at a few feet per year or at significantly higher rates. Because sequential shoreline positions are seldom exactly parallel, in some instances it is best to provide a range of values such as 10 to 15 feet per year. As long as users realize and understand the limitations of the method of historical monitoring, results of sequential shoreline mapping are significant and useful in coastal zone planning and development.

VINTAGE MATERIALS USED IN THE MATAGORDA BAY AREA STUDY

Two types of data were collected to document direction and rates of shoreline change: (1) historical data from charts, maps, and aerial photographs; and (2) field data. Historical monitoring was accomplished for the years 1856-1859, 1934-1937, 1946-1947, 1952-1953, and 1956-1957, specifically to document long-term changes. Field observations and measurements were made to document changes that occurred between 1957 and 1971-72.

Baseline data for this study are U. S. Coast Survey charts for the years 1856-59. These charts were reproduced photographically to a scale of approximately 1:24,000. Other data used were U. S. Geological Survey topographic maps (1946-1947) and two vintages of Tobin aerial photomosaics (1934-1937 and 1956-1957), also at a scale of 1:24,000. A set of U. S. Department of Agriculture stereophotographic pairs (1952-1953), at a scale of 1:10,000, completes the list of vintage materials used for compiling the Matagorda Bay shoreline change map. All charts, maps, and photos, with exception of the stereophotos, were at approximately the same scale. The base on which the vintage data were compiled was at a scale of 1:24,000.

PRESENTATION OF DATA IN MAP FORM

Each of the five vintages of Gulf and mainland shorelines is color coded and presented on a series of accurate base maps. Measurements of distances between the oldest and youngest shorelines are adequate to show long-term shoreline trends. Intermediate shorelines may not all show the same trend (erosion or accretion). To aid in reading the shoreline map, graphs were prepared at selected intervals along the shoreline. The 1856-1859 shoreline serves as the base line for these graphs. Although a shoreline segment may have an overall erosional trend, it may display short-term accretionary trends; these trends will be depicted by the graphs.

Long-term erosional and accretionary shorelines are highlighted on the maps by color, red for erosion and green for accretion. Width of the color bands are indicative of the amount of erosion or accretion experienced by a particular shoreline segment. The 100-year shoreline change can be determined by measuring distances between the color-coded, vintage shorelines.

EFFECT OF ASTRONOMICAL TIDE ON POSITION OF WATERLINES ON VINTAGE AERIAL PHOTOGRAPHS

In general, differences in position of mean high-water line, as shown on topographic charts, and waterline, as mapped on aerial photographs, were discussed in the section on Interpretation of Photographs. Slopes of Gulf and mainland beaches were measured in the Matagorda Bay area for the purpose of showing the effect of tides on historical monitoring.

Slopes of Gulf and mainland beaches were measured and the horizontal distance between flood and ebb tide was determined. Gulf beaches consist of sand and shell with slopes of 1.5 to 6.0 degrees (fig. 8A). Sand beaches average 2.75 degrees and shell beaches 3.9 degrees. Slopes of Gulf beaches are roughly bimodal with 44 percent occurring in the 2- to 3-degree range and 47 percent in the 4- to 5-degree range. There are three types of mainland beaches: (1) terrigenous sand; (2) shell gravel; and (3) caliche and shell gravel veneer over Pleistocene mud. Slopes of mainland beaches range from less than 1 degree to 11 degrees (fig. 8B). Sand beaches average 5.25 degrees, shell beaches 6.3 degrees, and caliche and shell gravel beaches have average slopes of 5.4 degrees. Mainland beaches are steeper than Gulf beaches; 37 percent of the mainland beaches occur in the 3- to 5-degree range and 50 percent range from 6 to 7.5 degrees.

Assuming a 2-foot mean tidal range along the Gulf shoreline, the horizontal distance between flood and ebb tide along the 2- to 3-degree beaches would be 60 and 40 feet, respectively, and the horizontal distance along the 4- to 5-degree beaches would be 30 and 23 feet, respectively. Accuracy of measurement at the 1:24,000 scale used in the historical monitoring program is on the order of ±40 feet. The difference between ebb and flood tide would have an effect on waterline position, indicated on aerial photos, where beaches slope 2 degrees or less, but the difference probably would not be detected on beaches with higher slopes.

Range of astronomical tide in Matagorda Bay is on the order of 0.5 to 0.7 foot. A 1-foot tidal range was used for determination of the horizontal distances between ebb and flood tide along mainland beaches. Two dominant beach classes, their slopes, and associated horizontal distances between ebb and flood tide positions are 3- to 5-degree beaches and 6- to 7.5-degree beaches. Horizontal distance between ebb and flood tide is 8 and 7 feet, respectively. These differences would not be detected on aerial photographs.

Parts of the mainland shoreline are almost vertical cliffs. Here the horizontal difference between flood and ebb tide is insignificant. Low-lying areas, such as marshes, are inundated by astronomical and wind tides. Extent of inundation may not be discernible on conventional black-and-white aerial photographs because marsh plants tend to obscure the tidal waters. Regardless of whether the tidal cycle is ebb or flood, however, the bay margin of the salt marsh is commonly defined by *Spartina alterniflora*. Height of *S. alterniflora* is greater than the tidal range and is not inundated by the flood tide.

GULF AND MAINLAND SHORELINE CHANGES, 1856-1957

The purpose of this section on historical monitoring is to document the direction and rate of long-term shoreline change and to present some of the probable causes of change. Elaboration on the interaction of coastal processes and shoreline stability is deferred, however, until short-term shoreline changes are considered.

Long-term trends of Gulf and mainland shorelines are presented on eight maps, each at a scale of 1:24,000 (in pocket). Four of the maps display only the mainland shoreline. These are—Lavaca Bay South, Lavaca Bay North, Carancahua Bay, and Tres Palacios Bay areas (fig. 9). Both Gulf and mainland shorelines occur on the remaining maps—Brown Cedar Cut, Colorado River, Shell Island Reef, and Pass Cavallo areas. In the following discussion, shoreline trends are presented for each map area.

Brown Cedar Cut Area

Salient features of this area are: (1) Matagorda Peninsula, which is tied at its east end to a deltaic headland; (2) an inactive tidal delta (near station 13); (3) an active tidal delta (Brown Cedar Cut); and (4) east Matagorda Bay.

Gulf Shoreline

The Gulf shoreline has been chiefly erosional since 1856. Minor accretion occurred between 1946 and 1956, and between 1952 and 1956 (see fluctuation graphs for stations 1 through 6). Maximum erosion (1856-1956) of 1,580 feet was recorded at station 3. Least amount of erosion was 880 feet at station 6. Yearly erosional average was about 11 feet, with total land loss for this 100-year period being about 1,575 acres. This is the most rapidly eroding shoreline segment in the study area. Several factors contribute to rapid shoreline retreat. These are: (1) Matagorda Peninsula is a thin sand body; (2) there is a sand deficit; (3) waves approach the shoreline at a high angle; (4) eustatic rise of sea level has increased over the past 50 years (K. O. Emery, personal communication); (5) the low peninsula is frequently washed over during storms; and (6) there is compactional subsidence of underlying deltaic muds.

Bay Shoreline of Matagorda Peninsula

With the exception of the two tidal pass areas, the bay shoreline has been chiefly erosional. Land area accreted to this shoreline amounts to about

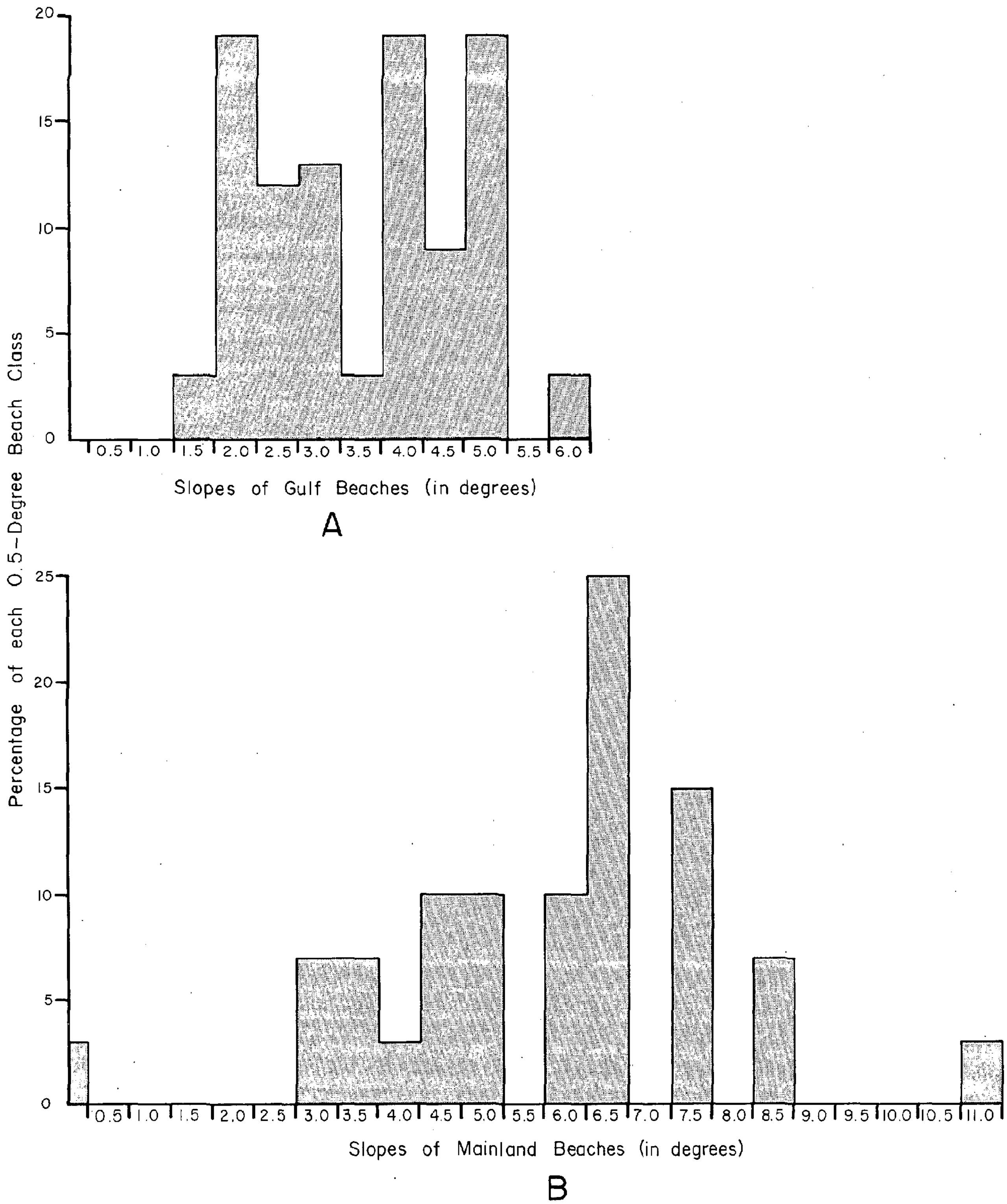


Figure 8. Slopes of Gulf and mainland beaches. Measurements are representative of slopes lying between the lower berm and the toe of the forebeach.

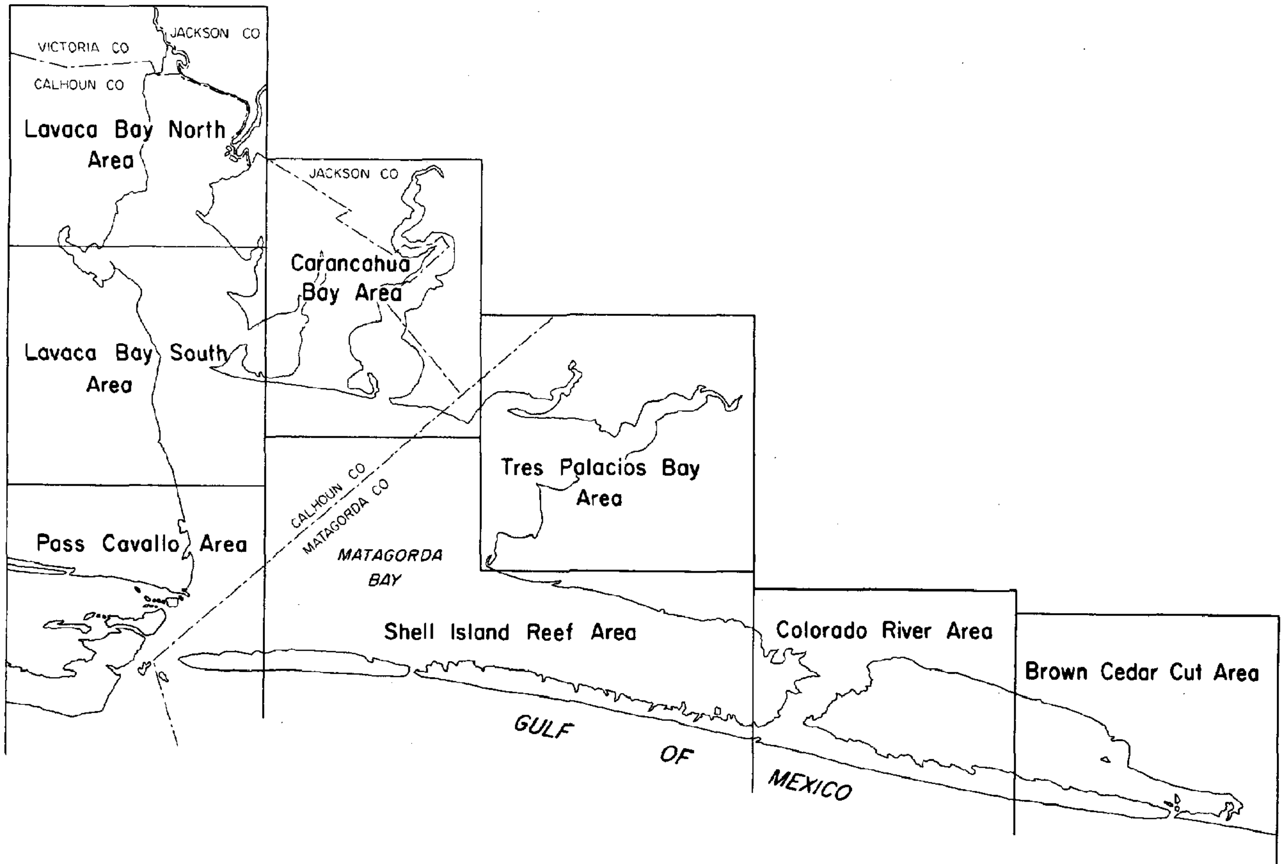


Figure 9. Index of shoreline change and marsh distribution maps.

424 acres, whereas land loss was about 298 acres. Most of the accretion, 337 acres, occurred in the tidal pass areas. West of Brown Cedar Cut, approximately 210 acres of land were lost through erosion. Maximum erosion of 600 feet was recorded at station 8, and least erosion, 240 feet, occurred in the area of station 12.

Erosion of Matagorda Peninsula bay shore results from waves generated by north winds.

Mainland Shoreline

Mainland shoreline, the area between stations 14 and 22, was primarily erosional during the interval 1856-1957. Shoreline fluctuation graphs indicate short-term accretionary periods since 1934. Accretion resulted from spoil outwash. Stations 14, 18, and 21 all display an accretionary trend since 1934. Accretion ranged from a maximum of 400 feet at station 14 to a minimum of 80 feet at station 21. Maximum erosion of 760 feet was measured at station 19, and least erosion was recorded at station 22. In 1856, Dressing Point was tied to the mainland. Net land loss of about 501 acres occurred along the mainland shoreline.

Colorado River Area

Gulf and bay shorelines of Matagorda Peninsula have been chiefly erosional since 1856. Mainland shoreline was mostly erosional until a log jam was removed from the Colorado River and the Intracoastal Canal was dredged. Following the removal of the log jam in 1929, a delta rapidly prograded across Matagorda Bay. To the east of the delta, the mainland shoreline accreted by spoil outwash.

Gulf Shoreline

Gulf shoreline erosion decreases westward. This shoreline segment experienced short-term accretion (sections 2-6). Station 1 has shown overall net accretion for the 100-year period. Maximum shoreline retreat of 300 feet was recorded at station 4, and the minimum of 80 feet was recorded at station 2. Net land loss of 245 acres was recorded for this shoreline segment.

The westward decrease in erosion and slight accretion between Spring Bayou and the mouth of the Colorado River result in part from low, continuous, fore-island dunes that prevent sand transport across the peninsula into Matagorda Bay.

Bay Shoreline of Matagorda Peninsula

The bay shoreline was erosional during the historical monitoring period. Three stations (9, 10, and 11) show insignificant short-term accretion. Accretion near Tiger Island and Greek Island is related to Colorado River deltation. Maximum erosion of about 560 feet was recorded at station 7 and a minimum of 120 feet at station 11.

Minor accretion was shown as small beaches in embayed areas and as spits downcurrent from erosional segments. Net land loss was about 532 acres.

Mainland Shoreline

With the exception of the area of station 16, the mainland shoreline is accretionary. The shoreline segment bounded by stations 13 and 16 is regarded as mainland shoreline; the large accretionary area to the west is the Colorado delta. All of the mainland shoreline, except the station 16 area, is accretionary.

Most of the accretion occurred after 1934. Accretion values range from 1,050 feet at station 15 to 1,680 feet at station 13. Spoil outwash is the cause of accretion.

Net land gain was about 675 acres. Part of the sediment which accreted this shoreline was derived from the Colorado River.

Deltaic Shoreline

In 1957, the subaerial Colorado delta, which was chiefly marsh, covered an area of 8,000 acres (12.5 square miles). Except for the Tiger Island Channel area, the delta is depositionally inactive.

Shell Island Reef Area

Both Matagorda Bay and Matagorda Peninsula widen somewhat to the west. Long oyster reefs extend at right angles from the mainland shoreline into west Matagorda Bay. Matagorda Peninsula is divided into two sections on this map; these are treated as a single unit in the following discussion.

Gulf Shoreline

During the period 1856-1957, the shoreline east of Greens Bayou was mostly erosional, whereas to the west of Greens Bayou, the shoreline was accretionary. Maximum accretion of 260 feet was recorded at station 4, and minimum accretion of 40 feet occurred at station 3. Maximum erosion of 500 feet occurred at station 11, and the minimum of 150 feet was recorded at station 13. Net land gain of 121 acres occurred to the west of Greens Bayou, and land loss of about 652 acres was calculated for the shoreline between stations 3 and 11.

Bay Shoreline of Matagorda Peninsula

Erosion exceeded accretion along the bay shoreline during the 100-year period. Land loss was approximately 1,807 acres.

The bay shoreline between stations 8 and 21 is highly irregular. The serrated bay shoreline results from the scouring of storm channels. Storm breaching is common east of Greens Bayou, but is uncommon west of Greens Bayou because of the continuous fore-island dunes.

Bay-shore accretion occurs during hurricanes. Sediment is transported across the peninsula through storm channels; it accumulates in the bay as small islands (station 21). Extreme erosion takes place during storms, at which time the peninsula may be segmented. At station 20, about 2,520 feet of the peninsula was eroded by storms. Minimum erosion of 120 feet (1856-1957) was recorded at station 6.

Mainland Shoreline

The mainland shoreline has been accreting since 1934. West of station 27, the shoreline, consisting chiefly of shell beaches and berms, was erosional. Shell beaches and berms also form the shoreline east of station 27. Prior to removal of the Colorado River log jam and dredging of the Intracoastal Canal, shell beaches also existed west of station 27. Now the shoreline west of station 27 is composed of spoil outwash.

Accretion began after 1934 (fluctuation graphs 22, 23, 24, and 25); rates of accretion increase from west to east. Land gain from spoil outwash was about 1,079 acres. Land loss of about 80 acres occurred in the area of stations 26 and 28. A net gain of about 1,000 acres was experienced by the mainland shoreline during the interval 1886-1957.

Approximately 2,200 feet of accretion was recorded at station 22, and minimum accretion of 150 feet occurred at station 25. Maximum erosion of 330 feet occurred in the area of station 26; the minimum was 160 feet at station 28.

Oyster Lake

Only the southern accretionary shore of Oyster Lake is shown on this map. Here, spoil outwash has created about 97 acres of new land.

Pass Cavallo Area

Pass Cavallo, a major tidal pass, separates the erosional Matagorda Peninsula from Matagorda Island. This is the only major pass on the Texas Coast that has not been physically altered by man. A ship channel was dredged through Matagorda Peninsula in 1965, and since then Pass Cavallo has begun to shoal. The vintage shorelines displayed on the Pass Cavallo area map all predate dredging of the ship channel.

Gulf Shoreline

The Gulf shoreline is defined by the areas lying between station 23 and Decros Point, and Saluria Bayou and station 1. Erosion exceeded accretion during the period of historical monitoring, and local changes in shoreline stability were effected by the Matagorda Ship Channel jetties.

The Gulf shoreline of Matagorda Peninsula at station 23 was in equilibrium from 1856 to 1957. Shoreline retreat of approximately 1,460 feet was recorded at station 25. Net land loss was calculated to be about 289 acres.

Matagorda Island was erosional between stations 2 and 6, and accretionary west of station 2. Maximum erosion of 2,200 feet was recorded at station 3, and maximum accretion of 620 feet at station 1. Net land loss between stations 2 and 6 was about 816 acres, and net land gain in the area of station 1 was about 47 acres.

Bay Shoreline—Matagorda Peninsula and Matagorda Island

The bay shoreline of Matagorda Peninsula begins at Decros Point and extends to the east map limit, and the bay shoreline for Matagorda Island lies between the south bank of Saluria Bayou and the west map limit.

There are a few local accretion areas along the bay shore of Matagorda Peninsula, but principal direction of change has been erosional. Net land loss was about 501 acres.

Areas of erosion alternate with accretion along the bay shore of Matagorda Island with erosion occurring in the area of stations 12 and 13, and accretion occurring between Lighthouse Cove and Saluria Bayou. The tidal delta was the principal site of sedimentation. Net land gain was about 123 acres.

Mainland Shoreline

There are two mainland shoreline segments on this map. One is situated along the west shore of Matagorda Bay between Saluria Bayou and the northwest map limit. The other is along the north shore of Espiritu Santo Bay between Port O'Connor and the west map boundary.

The west shoreline of Matagorda Bay was dominated by erosion. Maximum erosion of 1,200 feet and a minimum of 370 feet were measured at stations 7 and 10, respectively. Net land loss was about 770 acres. Rapid erosion was documented between Port O'Connor and the north map boundary. Here, relatively nonresistant Pleistocene sand is subjected to wave erosion. Erosion of the shoreline south of Port O'Connor has also been rapid. Here, almost pure sand beaches are attacked by unimpeded waves which approach the area from the northeast and southeast.

The north shoreline of Espiritu Santo Bay is erosional along Dewberry and Blackberry Islands; net land loss was 113 acres. Shoreline accretion ranging from 140 to 190 feet was measured adjacent to the Intracoastal Canal; net land gain was approximately 633 acres.

Marsh Islands

Farwell, Grass, and Bayucos Islands are emergent parts of Pass Cavallo tidal delta. The islands which are bounded by Big Bayou and Barroom Bay are also part of the tidal delta. Most of the islands are vegetated with salt-tolerant plants. Land loss in the areas of Bayucos, Grass, and Farwell Islands amounted to about 188 acres. Net land gain in the Big Bayou—Barroom Bay area was about 81 acres.

Lavaca Bay South Area

The amount of physical energy (waves, tidal and longshore currents) expended along the bay shoreline varies from place to place depending upon (1) shoreline orientation, (2) width of the bay, and (3) the extent of bay segmentation resulting from spoil islands adjacent to dredged channels. Wave energy appears to be more intense along the north and west shores of Matagorda Bay and the west shore of Lavaca Bay. Smaller waves attack the shores of small, enclosed water bodies such as Powderhorn Lake, Chocolate Bay, and Keller Bay.

For convenience of discussion, the shoreline has been divided into five segments: (1) west Matagorda Bay; (2) west Lavaca Bay; (3) Cox Bay; (4) Sand Point area; and (5) Powderhorn Lake.

West Matagorda Bay

This part of the bay shoreline lies between station 1 and Indian Point; it is predominantly erosional. The shoreline at stations 2 and 10 accreted between 1856 and 1934. An equilibrium shoreline existed in the area of station 10. Approximately 580 feet of shoreline retreat occurred at station 1. Net land loss was approximately 162 acres.

West Lavaca Bay

From Indian Point to the north map limit, the bay shore is diversified. It is made up of shell beaches and berms, almost vertical bluffs, shell spits, and marshes. This shoreline segment has not experienced the dramatic changes that characterize some of the previously described areas.

The overall direction of change has been erosional. Indian Point (station 12) exhibited the maximum accretion of 360 feet, whereas 200 feet of shoreline recession was measured at station 17. Net land loss for this area was about 49 acres.

Cox Bay

The bay shore between stations 18 and 22 is chiefly low-relief vertical cliffs with a few marsh areas such as the head of Huisache Cove. In this area, accretion (58 acres) and erosion (59 acres) were virtually equal. Between 1856 and 1957, the trend in shoreline change was to erode promontories and deposit sediment in the small reentrants.

This shoreline segment lies in the lee of the prevailing southeast wind. North wind, however, generates waves that break on the south shore of Cox Bay.

Sand Point Area

Erosion dominates this shoreline segment. Maximum land loss (116 acres) occurred between Sand Point and the northeast map limit. Accretion was measured in marsh areas along the south shore of Keller Bay.

A maximum of 500 and a minimum of 20 feet of shoreline retreat were recorded at stations 25 and 23, respectively. Net land loss was approximately 130 acres.

Powderhorn Lake

Powderhorn Lake is a water body with its longest dimension oriented transverse to the prevailing southeast wind. Because of its orientation, small waves from the southeast do not significantly erode the north shore; sedimentation exceeds erosion. The opposite is true for the south shore. High-velocity, short-duration north winds generate waves that erode the south shoreline. Net land loss was approximately 49 acres.

Lavaca Bay North Area

The north bay shore receives sediment from Garcitas Creek and Lavaca River. At Port Lavaca and in the Mitchell Point area, some shoreline changes have resulted from man's activities. Many of the man-made changes are directly related to dredging activities. For this discussion, the shoreline was divided into four sections based on shoreline orientation: (1) west shoreline of Lavaca Bay from the map boundary northward to Placedo Creek; (2) north shoreline of Lavaca Bay from Placedo Creek eastward to station 8; (3) east shoreline of Lavaca Bay from station 8 to Mitchell Point; and (4) Cox Bay shoreline from Mitchell Point to the southeast map boundary.

West Shoreline, Lavaca Bay

Erosion exceeded sedimentation, and net land loss was approximately 162 acres. Noble Point and station 13 experienced the most erosion, 1,200 and 600 feet, respectively. Noble Point was a large marsh area; loss of wetland area was about 128 acres.

The principal areas of accretion were stations 14 and 16. Spoil dredged from boat basins, in the vicinity of station 16, created about 24 acres of new land. At least two factors contributed to sedimentation near station 14. These are: (1) a concave shoreline; and (2) sediment discharged into the bay through drainage ditches.

North Shoreline, Lavaca Bay

There was a net land gain of about 34 acres along the north shore. Shoreline accretion is attributed to sediment delivered to the bay by Placedo Creek, Garcitas Creek, and the Lavaca River. Erosion is restricted to cliffed shorelines in the stations 10-12 area. The amount of shoreline retreat was 720 and 580 feet at stations 12 and 10, respectively.

Land loss in these two areas amounts to approximately 138 acres. Approximately 137 acres of new marsh in Garcitas Cove resulted from sedimentation at the mouth of Garcitas Creek.

East Shoreline, Lavaca Bay

The Lavaca River strongly influences shoreline stability north of State Highway 35. South of the highway, man dominates shoreline activities. There has been a net gain of about 103 acres along the east shore. Sediment for shoreline accretion was derived from the Lavaca River and from material dredged from the bay bottom for a turning basin.

Deltation at the mouth of the Lavaca River created approximately 96 acres of new land. Calculations made for the shoreline segment south of State Highway 35 indicate that at least 95 acres of bay bottom were covered with spoil.

Cox Bay

Historical shoreline data for the period 1856-1957 document a net land gain of about 39 acres. Field observations made in the winter of 1971 and spring of 1972, however, revealed that the shoreline was in an erosional state. Net gain and loss of land for the period 1856-1972 were approximately equal.

Carancahua Bay Area

Within this map area there are: (1) large water bodies characterized by large waves generated by prevailing southeast winds; (2) enclosed bays that are elongate transverse to the prevailing wind; and (3) small, shallow, enclosed water bodies characterized by small waves.

For convenience of discussion, the shoreline was divided into four segments. Grouping of shoreline segments was made on the basis of relative wave intensity, shoreline orientation, and degree of enclosure. The segments are (1) the north shore of Matagorda Bay, including part of Turtle Bay, (2) Carancahua Bay, (3) Keller Bay, and (4) Salt Lake and Redfish Lake.

North Shore, Matagorda Bay

The shoreline was erosional during 1856-1957, except for two small accretionary areas—a shell spit at Well Point, and a salt marsh between station 2 and Carancahua Pass.

The banks of Carancahua Pass were highly erosional. At station 3, shoreline retreat was about 1,540 feet and about 1,480 feet at station 15. Beaches and berms in the Carancahua Pass area are composed of 80 to 90 percent shell, and erosion is attributed to a decrease in shell production within the bay.

This part of the bay shore is fronted by a wide bay and is, therefore, subjected to the forces of breaking waves generated by southeast winds. Land loss resulting largely from wave activity was about 342 acres.

Carancahua Bay Shoreline

The east shore is in the lee of the southeast wind, but is open to waves approaching from the north. The opposite is true for the west shoreline.

Erosion has dominated the east shore since 1856. Maximum erosion of 280 feet was recorded at station 6; at station 11, directly across the bay, 420 feet of shoreline retreat was measured during the same period. Small areas of spit and marsh accretion occur between sections 5 and 6. Net land loss amounts to about 83 acres.

The west shore has undergone almost equal amounts of accretion and erosion; there was a net land loss of about 29 acres. Accretion occurs downdrift from erosional cliffs (see section 8) and along concave shoreline segments (between sections 9 and 11 and 11 and 12). Shoreline configuration is continually changing in the area between sections 12 and 14. Here, shell spits accrete across entrances to Salt Lake and Redfish Lake; spits are breached during storms.

Keller Bay Shoreline

Both the east and west shores of Keller Bay, which are modified by processes identical to those operating in Carancahua Bay, are chiefly erosional.

Net land loss along the east shore was about 47 acres. Up to 260 feet of shoreline retreat was recorded at station 20, which is near the bayhead. Bluffs that front the bay are up to 10 feet high and slumping is probably the dominant cause of shoreline retreat. Sedimentation occurred along two concave shoreline segments at stations 17 and 19.

Approximately 61 acres of land were eroded from the west shore of Keller Bay. In the area of station 22, where maximum erosion of 370 feet was recorded, there is evidence that erosion was prevalent prior to 1856.

Salt Lake and Redfish Lake

Salt and Redfish Lakes were initially parts of Carancahua Bay. They were cut off from the main body of water by the accretion of spits. The shoreline of Salt Lake accreted approximately 8 acres since 1856, but there was a loss of about 28 acres along the Redfish Lake shore. The long-term trend has been for the lakes to fill with sediment derived from Pleistocene uplands and from Carancahua Bay.

Tres Palacios Bay Area

Most of the Tres Palacios Bay shore is relatively protected from waves approaching from the southeast. The orientation of spits, which occur between Palacios Point and Oliver Point, indicates that southeast waves generate longshore currents which transport sediment northward. Depositional grain preserved as beach ridges along the same point suggests that net longshore drift was to the south in 1856.

The shoreline was divided into the following segments based upon shoreline orientation and degree of enclosure of water bodies: (1) Palacios Point to Oliver Point; (2) Oliver Point to the mouth of Tres Palacios Creek; (3) mouth of Tres Palacios Creek to Turtle Point; (4) Turtle Point to the mouth of Turtle Creek; (5) mouth of Turtle Creek to Sartwelle Lakes; and (6) Oyster Lake.

Palacios Point-Oliver Point

Between Palacios Point and Oliver Point, the shoreline trend was erosional. All shoreline changes were natural except for the area just north of the dredged channel. Sediment accumulated as spits downcurrent from erosional headlands. Successive changes in size, shape, and orientation of spits are illustrated at Palacios Point and at stations 2 and 3. In the winter of 1972, the spit at Palacios Point was attached to the headland at both its upcurrent and downcurrent ends.

Approximately 1,040 feet of erosion was recorded at station 2. Material eroded from station 2 was moved downcurrent and was deposited at station 3, accreting the shoreline about 520 feet. Although the shoreline between Palacios Bayou and Oliver Point is concave, it was also eroded. The shoreline was erosional because waves approaching from the north struck the area at a high angle. Net land loss was about 199 acres.

Oliver Point-Tres Palacios Creek

This segment of the bay shore lies in the lee of the prevailing southeast wind and, therefore, it is not significantly affected by waves generated by the southeast winds. However, waves approaching from the north do erode the shoreline.

Several accretionary pockets are present along this predominantly erosional bay shore, e.g., the southeast shore of Coon Island Bay and a small area lying between stations 11 and 12. Accretionary areas are protected by oyster reefs (Coon Island) and shell spits.

Approximately 350 to 440 feet of shoreline retreat were recorded at stations 12 and 13, respectively. Each of these areas is a promontory, upon which wave energy is focused. Net land loss was approximately 73 acres.

Tres Palacios Creek-Turtle Point

Shoreline accretion prevailed between the mouth of Tres Palacios Creek and Grassy Point, whereas erosion dominates the shoreline between Grassy Point and Turtle Point. Sediment is supplied to the north shore by river flooding and by wind tides produced by the southeast wind. Erosion in the Grassy Point-Turtle Point areas results from a paucity of sand-size sediment supplied to the area and from relatively large waves from the southeast. Net land gain for the shoreline segment between the mouth of Tres Palacios Creek and Grassy Point was about 78 acres.

Only one significant accretionary area occurs between Grassy Point and Turtle Point. This is a spoil area created by dredging boat harbors at Palacios; accretion amounts to about 9 acres. Net land loss for the Grassy Point-Turtle Point shoreline was about 91 acres.

Turtle Point-Turtle Creek

Waves that approach from the north affect this shoreline segment more than waves produced by southeast wind. This is demonstrated by the fact that erosion exceeds accretion, and that the rate of erosion increases as Turtle Bay widens westward. Shoreline retreat of 320 feet was recorded at station 20. Net land loss was about 45 acres.

Turtle Creek-Sartwelle Lakes

Depositional and erosional shoreline segments alternate in this area. Waves from the southeast are the dominant process along this part of the bay shore. Deposition was recorded in local reentrants and to the west of Buttermilk Slough where shell beaches and berms are common.

Deposition and erosion were approximately the same between 1856 and 1957. There was a net land loss of approximately 23 acres.

Oyster Lake

Oyster Lake is a small, shallow, tidally influenced water body that is connected to Matagorda Bay through Palacios Bayou and the Intracoastal Canal.

Most of the south shore is accretionary. Erosion dominates the other shoreline segments. Erosion amounting to 150 feet was recorded at station 7. Spoil outwash has accreted the south shore 1,040 to 1,480 feet at stations 5 and 4, respectively. There was a net land gain of about 220 acres.

Summary

Most of the Gulf and mainland shorelines of the Matagorda Bay area were in an erosional phase from 1856 through 1957. The erosional shoreline trend was established prior to any major activities of man which could have caused a change in shoreline stability.

Man's activities tend to accelerate Gulf shore erosion by depleting the sand supply. Sedimentation has been localized by jetties that trap sand on their upcurrent sides. Erosion is initiated or accelerated on the downcurrent sides of jetties. The principal effect of man's activities in the bay area was shoreline accretion.

Natural accretion of the Gulf shoreline was to the southwest of Greens Bayou and Pass Cavallo. Accretion to bay shores occurred at the heads of bays as bayhead deltas, at the terminus of tidal channels as flood deltas, and on the back side of Matagorda Peninsula as washover deposits.

Appendix A summarizes the shoreline changes (1856-1957) of the Matagorda Bay area in terms of acres of land accreted or eroded.

MARSH DISTRIBUTION, 1856-1957

Marshes were mapped on the same charts, maps, and aerial photographs that were utilized for shoreline mapping. Five vintages of marsh distribution could not be displayed on a single set of maps, and, therefore, long-term changes in marsh area were determined by comparing the oldest coastal charts and the youngest aerial photographs.

The 1956-1957 marsh distribution was mapped on Tobin photomosaics (scale 1:24,000). Field work (winter 1971 through spring 1972) verified the photo interpretation and also documented the fact that certain marsh areas had been filled or dammed by man in the interim period of 1957-1972. Wetlands were mapped by the U. S. Coast Survey in 1856-1859. The distinction was not made, however, between salt marsh and fresh-water marsh. The 1856-1859 marsh boundaries were determined by comparing the 1934-1937, 1952-1953, and 1956-1957 photomapping with the U. S. Coast Survey charts.

A set of eight maps at a scale of 1:48,000 shows the distribution of marshes during 1856-1859 and 1956-1957. Marshes are color coded. The 1856-1859 marsh is represented by diagonal red lines and the 1956-1957 marsh is shown in solid green. An overlap of colors depicts the persistence of the marsh for at least 100 years. Extinct marshes are shown in red only, and a single green color indicates areas of marsh expansion.

Marsh maps have the same designation as shoreline change maps—Brown Cedar Cut, Colorado River, Shell Island Reef, Pass Cavallo, Lavaca Bay South, Lavaca Bay North, Carancahua Bay, and Palacios Bay areas (fig. 9).

General Wetland Trends

Many of the marshes in the Matagorda Bay area decreased in size from 1856 to 1957. Some of the 1856-1859 maps, however, did not extend far enough up some of the bays and their associated creeks and rivers for a valid comparison to be made between the oldest and youngest marshes.

Significant marsh changes occurred on Matagorda Peninsula, in the Lake Austin area, and on the Colorado delta. Changes in marsh area result from both natural processes and man's activities. Natural causes are shoreline erosion, sedimentation, and relative sea-level change. River diversion and impoundment, construction of dams across tidal creeks, dredging of channels, and creation of spoil mounds are some of man's activities that produce change in marsh area.

Marsh Change Resulting From Natural Processes

A decrease in marsh area was recorded along the bay shore of Matagorda Peninsula. The 1856-1859 marsh was widely distributed, whereas the 1956-1957 marsh was more restricted in area. Between 1856 and 1957, the marsh area decreased through erosion and deposition. The Gulf shoreline was eroded and marsh deposits were locally exposed in the swash zone. Burial of marsh by washover deposits and erosion along the bay shore further reduces marsh area.

Erosion and deposition have decreased the marsh area of the Pass Cavallo flood delta. Marsh has been destroyed by erosion as Pass Cavallo migrates westward, and burial of marsh by washover deposits has also reduced marsh area.

Much of the bay shore is composed of marsh. Marsh is commonly eroded by waves approaching from the south or north. Construction of beaches and berms at the bay margin is coincident with marsh erosion.

Small, enclosed water bodies, such as Powderhorn Lake, Chocolate Bay, Salt Lake, and Redfish Lake, are less affected by wave erosion than are the larger water bodies. Marshes associated with the small enclosed water bodies, however, also decreased in size. Sediment was washed into the marsh from adjacent slopes.

Marsh area increased where streams discharge directly into the bays, for example: (1) at the head of Lavaca Bay (Placedo Creek, Garcitas Creek, and Lavaca River); (2) at the head of Carancahua Bay (Carancahua Creek); and (3) at the head of Tres Palacios Bay (Tres Palacios Creek). Marshes associated with the Holocene Brazos-Colorado delta (Lake Austin area) increased in size during 1856-1957. A probable cause of marsh expansion was compactional subsidence of formerly surficial deltaic deposits.

Three areas on the bayside of Matagorda Peninsula exhibited an increase in marsh area. These are marsh islands associated with active and inactive tidal channels. Two of these tidal channels occur on the Brown Cedar Cut area map. The western channel, Brown Cedar Cut, is active; the other channel, now closed, lies at the east end of east Matagorda Bay. A third tidal pass area, Greens Bayou, is also closed (Shell Island Reef area map).

Marsh Change Resulting From Man's Activities

Man's activities may either destroy or create conditions that promote marsh growth. Some marshes were buried by spoil along the bay margin; see the mainland shoreline on the Brown Cedar Cut, Colorado River, Shell Island Reef, and Pass Cavallo maps. Spoil outwash has created conditions favorable for marsh growth in the vicinity of McNabb Lake (Colorado River area) and Fresh-water Lake (Shell Island Reef area).

Several dams have been constructed across tidal creeks and between the bays and relatively large marsh areas. This kind of activity converts marshes into fresh-water lakes. Examples of marshes that were dammed are: (1) Blind Bayou area (Lavaca Bay South area); (2) Huisache Cove (Lavaca Bay North area); (3) Piper Lakes and a marsh along the north shore of Carancahua Bay near the Jackson-Calhoun County line (Carancahua Bay area); and (4) Buttermilk Slough (Palacios Bay area).

A large marsh has developed on the Colorado delta. Within the next few years, the course of the Colorado River will be diverted, and it will discharge into Matagorda Bay between Culver Cut and Middle Channel (Colorado River area map). A new delta will be constructed in this area and there should be an increase in salt marsh in that area.

Expansion and/or decrease in marsh area is summarized in appendix B. Net loss or gain for the period 1856-1859 through 1956-1957 is expressed as acres.

COASTAL PROCESSES AND SHORT-TERM SHORELINE CHANGES

Observations of coastal processes operating on Gulf shorelines of Matagorda Peninsula and Matagorda Island began in the winter of 1970 and continued through the fall of 1973. Similar observations were made along the mainland shoreline during the winter of 1971 and spring of 1972. Short-term shoreline changes were measured in the field, and an attempt was made to correlate these changes with coastal processes.

Coastal Processes

Processes that constructed and that are presently modifying shorelines in the Matagorda Bay area are astronomical and wind tides, longshore currents, normal wind and waves, hurricanes, river flooding, and slump along cliffed shorelines.

In the Gulf Coast region, astronomical tides are low, ranging from a maximum of about 2 feet along the Gulf shoreline to about 0.5 foot in the bays. Wind regime greatly influences coastal processes by raising or lowering water level along both Gulf and mainland shorelines, and by generating waves and longshore currents (Price, 1954; Hayes, 1965; Watson, 1968; Watson and Behrens, 1970).

Gulf and mainland shorelines may be drastically altered during the approach, landfall, and inland passage of hurricanes (Hayes, 1967; Scott and others, 1969; Shepard, 1973). Storm-surge flood and attendant breaking waves erode Gulf shorelines a few tens to a few hundreds of feet. Washovers along barriers and peninsulas are common, and salt-water flooding may be extensive along mainland shorelines.

Rivers and small streams normally flood in the spring and early fall. Flooding corresponds with spring thunderstorm activity and the hurricane season. Rivers may flood as a result of regional rainfall, but the smaller streams may be activated only by local thunderstorms. Effects of river flooding are: (1) overbanking into floodbasins and onto delta plains; (2) progradation of bayhead and oceanic deltas; and (3) flushing of bays and estuaries.

Short-Term Shoreline Changes, 1957-1972

The direction and rate of shoreline change for the period 1856-1957 were determined by using vintage charts, maps, and aerial photographs. A field study was conducted from October 1971 through May 1972, for the purpose of documenting shoreline changes which occurred after 1957. Profiles were measured with alidade and stadia rod along Gulf and mainland shorelines.

Beach profiles were measured in 1971-72 from the waterline to a known geographic point, which distance could be compared to the distance between the 1957 waterline and the same geographic point. At each profiling station, physiographic setting and sediment composition were described. Normally, the profiles were extended into the bays and Gulf of Mexico to water depths from 1 to 3 feet. Sediment characteristics, fauna and/or flora were determined for the shallow, nearshore parts of the profiles. Also, marsh and upland flora were described wherever a profile crossed these communities. Observations of coastal processes were made at each profiling station; observations were also made at selected intervals between profile stations.

Within the Matagorda Bay area, there are two broad classes of shorelines: (1) open Gulf shoreline which extends from the vicinity of Caney Creek on the northeast to about 4.5 miles west of Pass Cavallo (fig. 1); and (2) mainland shoreline. A wide range of variation in sediment types and physiographic features was encountered within the Matagorda Bay region. These variations reflect past geologic history of the area, coastal processes currently operating on the shoreline, sediment availability, and, to a certain degree, man's activities.

Characteristics of Gulf and mainland shorelines, based upon field observations, are presented in the following sections on "Open Gulf Shorelines" and "Bay Shorelines."

Open Gulf Shorelines

In general, Matagorda Peninsula beaches are characterized by a mixture of terrigenous sand, shell, and rock fragments. Matagorda Island, on the other hand, has beaches composed of terrigenous sand (Wilkinson, 1973). Composition of beach sediment is a good indication of sand availability and stability of a particular shoreline segment (McGowen and Garner, 1972; McGowen and others, 1972). Most of Matagorda Peninsula has been in an erosional condition for at least 118 years, whereas Matagorda Island has just recently shifted from an equilibrium to an erosional phase.

Beaches composed of shell and rock fragments characterize the rapidly eroding shorelines. Shell and rock fragments are derived primarily from Pleistocene and Holocene deposits which are being eroded from the shoreface and inner continental shelf. These materials are direct evidence that the volume of terrigenous sand is low. The relative abundance of shells of shelf and bay species indicate that relict paralic deposits are the chief sources of coarse sediment that compose beaches and ramps of Matagorda Peninsula.

Beaches between Caney Creek and Pass Cavallo have a high shell and rock fragment content (fig. 10). Shell material consists of both bay and Gulf species, with bay species being more abundant. East of the mouth of the Colorado River, *Crassostrea virginica* and *Rangia* sp. are the most common species. Radiocarbon ages for *Crassostrea virginica* shell collected from this beach segment range from 860 to 37,000 years B.P., indicating that offshore Pleistocene and Holocene deposits are sources of oyster shell. West of the mouth of the Colorado River, three bay species (*Crassostrea virginica*, *Mercenaria campechiensis texana*, and *Rangia cuneata*) are more common than Gulf species. Locally, one of these bay species may be more abundant than the other two, but throughout this segment of beach, *Rangia cuneata* is the dominant species. Rock fragments are common between Caney Creek and Pass Cavallo; they occur most frequently between Caney Creek and the Colorado River. Rock fragments range in size from granule-size gravel to boulders up to 2-foot-maximum diameter. Small rock fragments are compact, and large fragments are platy to bladed (clast morphology, after Sneed and Folk, 1958). Pleistocene distributary sand, beach rock, reef flank sediments, and carbonate lacustrine deposits are the sources of rock fragments.

Profiles of the Gulf beaches (figs. 10, 11, and pl. I) show that shell beaches are narrower and steeper than sand beaches. Evidence that most shell beaches are erosional is the common occurrence of marsh deposits in the swash zone. An exception to the erosional nature of shell beaches is shown at profiles 10, 11, and 12 (fig. 11). Terrigenous sand content of these shell beaches is higher than those to the east. This segment of Matagorda Peninsula is slightly convex seaward; it lies along the axis of a buried Pleistocene fluvial sand body (fig. 2). The shoreline convexity, short-term accretionary trend, and increase in terrigenous sand are probably

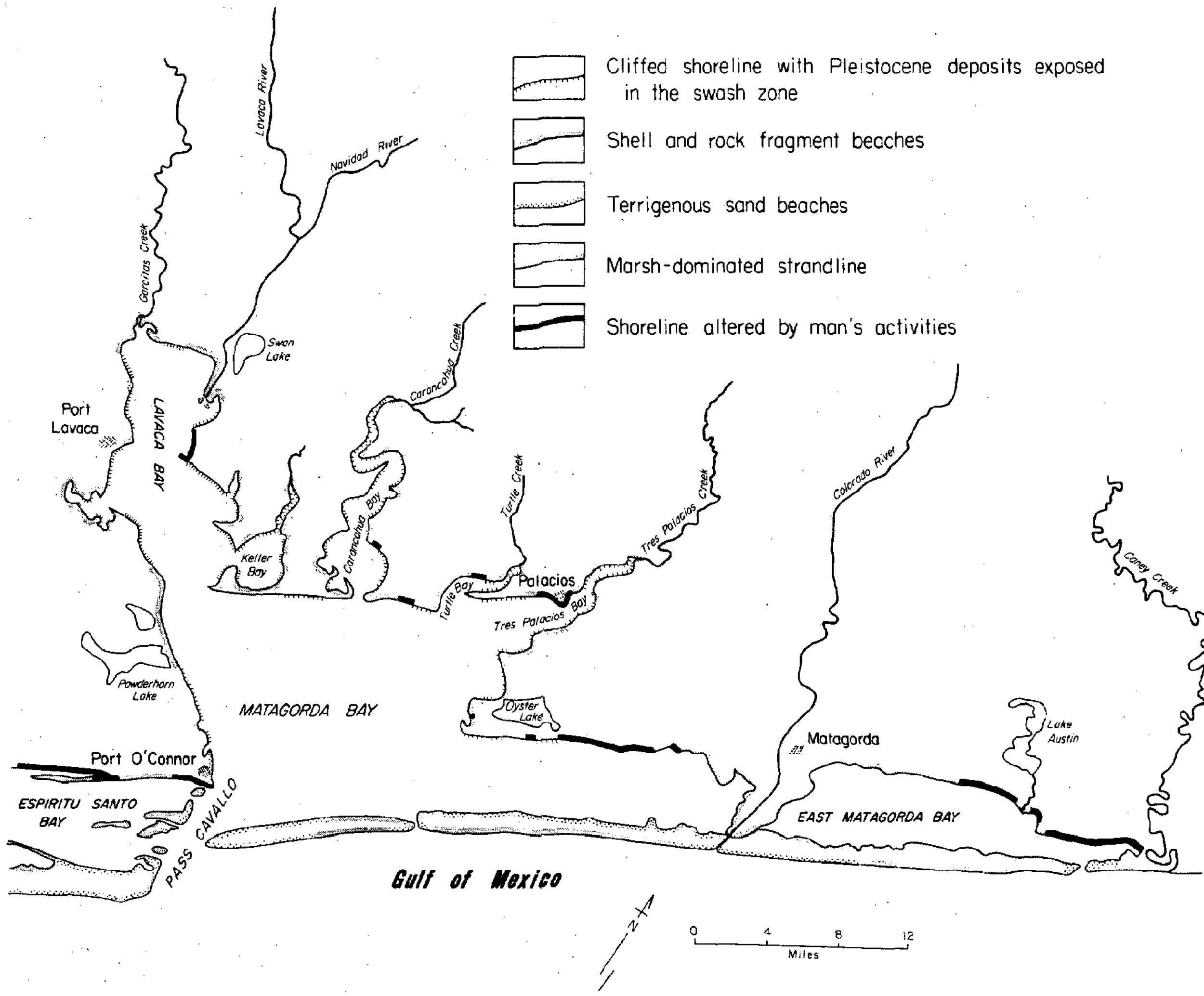


Figure 10. Shoreline types of the Matagorda Bay area.

related to the Pleistocene sand source which underlies the shoreface in the vicinity of profiles 10, 11, and 12.

The distribution of sand and shell beaches is shown on figure 10, erosional and accretionary rates are shown on figure 11, and beach profiles are shown on plate I. Profiles of sand beaches on plate I are represented by numbers 4, 5, 13, 14, 15, 16, 28, 30, 31, and 32 (appendix C, profiles 23 and 30). The occurrences of fore-island dunes and beaches consisting of shell and rock fragments are mutually exclusive. Coppice mounds and low, discontinuous sand dunes are associated with shell beaches. Fore-island dunes, ranging in height from 9 to 25 feet, occur along segments of Matagorda Peninsula that have broad sandy beaches.

Some of the principal questions about Gulf shorelines in the area involve the location of sand and shell beaches and the factors which cause shoreline erosion. Sand and shell beaches are the products of sediment availability and coastal processes that are operating in the area. Sediment sources are the Brazos and Colorado Rivers, the Holocene Brazos-Colorado delta, and the inner continental shelf and shoreface. The principal coastal processes responsible for sediment transport and deposition are wind, waves and attendant longshore drift, and hurricane storm surge.

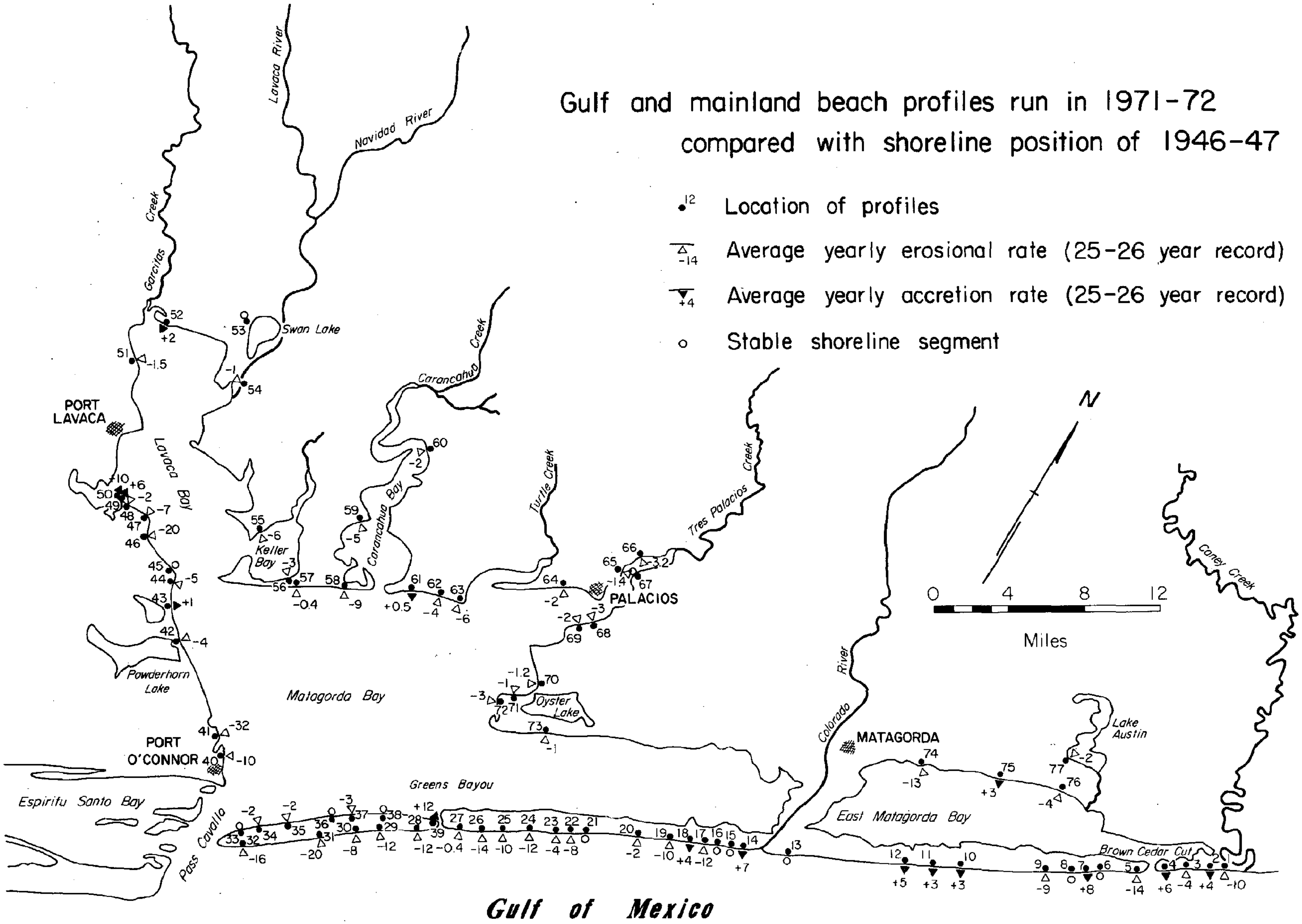


Figure 11. Short-term erosional and accretionary shorelines of the Matagorda Bay area. At each profile, which was run in 1971-72, the distance was measured from the waterline to a known geographic point. These distances were then compared with the 1956-57 distances from the waterline to the same point.

Modern rivers are not providing a significant volume of sand to the longshore drift system. The Brazos River discharges its sediment load about 17 miles east of the study area. The Brazos transports a large volume of sand and mud to the Gulf, but beaches only five miles west of the river mouth are retreating at rates of 25 to 40 feet per year. The Brazos carries a large suspension load, approximately 993 x 10^6 cubic feet per year. The morphology of the present Brazos delta (constructed since 1929, Nienaber, 1963) and the direction of wave approach and wave refraction limit the volume of sand that will be contributed to the beaches of Matagorda Peninsula.

Promontories, such as the Brazos delta, cause waves to refract. Sometimes wave refraction creates currents that flow counter to the dominant direction of southwest longshore drift. Hayes and others (1970), in their discussion of offset inlets, explain the mechanism of countercurrent generation by wave refraction. The Brazos delta, by causing wave refraction, creates a local drift system that is directed eastward along its western periphery. This countercurrent system is possibly one of the mechanisms that retards westward sand transport along Matagorda Peninsula.

The Colorado River contributes about 250 x 10^6 cubic feet of suspension load to Matagorda Bay and the Gulf of Mexico annually. Annual sand contribution is estimated to be about 20 x 10^6 cubic feet. Sediment and water discharge is divided between west Matagorda Bay and the Gulf of Mexico; the sediment volume delivered to each has not been determined. Sand delivered to the Gulf by the Colorado River, however, causes accretion of the shoreline for a distance of about 1 mile west of the river mouth. Beyond that point, the shoreline is mostly erosional.

In 1957, Matagorda Peninsula had a well-developed beach, shell ramp, and wind-tidal flat (fig. 12). Hurricane *Carla* (1961) breached the peninsula in many places (fig. 12). Field measurements made in the spring of 1971 (fig. 12, and pl. I, profiles 19 and 23) indicate that during Hurricane *Carla* the shoreline was eroded 450 to 600 feet. Shepard (1973) reported that as much as 800 feet of shoreline erosion occurred west of the Colorado River. In addition to eroding the beach area, hurricanes and tropical storms transport sediment onto the back side of barrier islands and into the adjacent bay. Through these brief but high energy events, the entire peninsula migrates bayward. Major hurricanes scour storm channels through the peninsula and build lobate sand bodies that project into the bay. At this time, coarse shell and rock fragments accumulate in the interchannel areas as shell ramps. Storms that raise the water level less than 5 feet activate a few storm channels, and sand is transported through these channels toward the bay area, building small washover fans. Most of the present beach of Matagorda Peninsula west of the mouth of the Colorado River postdates Hurricane *Carla*.

Under normal wind and tide conditions, sediment is moved onshore and alongshore to the southwest. Erosion is not as severe under normal sea conditions as during storms, but steep, short-period waves are especially erosive in the area of the Holocene deltaic headland. There is selective sorting of terrigenous sand, shell, and rock fragments. Turbulence of breaking waves tends to keep the fine- to very fine-grained terrigenous sand in suspension, making it readily available for longshore transport. The large, heavy shell and rock fragments travel at a slower rate than sand, thereby forming a lag in the upcurrent areas; terrigenous sand tends to be concentrated in the downdrift direction (figs. 11 and 13).

Two other factors are involved in sand and shell distribution. First, the Pleistocene and Holocene sedimentary sources have a high mud/sand ratio. Secondly, tidal passes are areas in which sand is concentrated. In the areas where Pleistocene and Holocene deposits are being eroded, the longshore current system is sand deficient; erosion occurs because the longshore current has the capacity to transport a greater sediment load. Since the shoreline is eroded throughout most of its length from Caney Creek to Pass Cavallo and because drift is to the west, sand load tends to increase in the direction of longshore drift. This, in part, explains local development of sand beaches. The volume of sand within the longshore drift system also increases in areas underlain by Pleistocene fluvial sand.

Sand is stored in the bays within flood deltas. Sand also accumulates on the barrier islands immediately downdrift from tidal inlets; this downdrift accumulation of sand produces a Gulfward offset of barrier islands adjacent to tidal channels. Downdrift offset is another indication of a sand deficient system (Seelig and Sorensen,

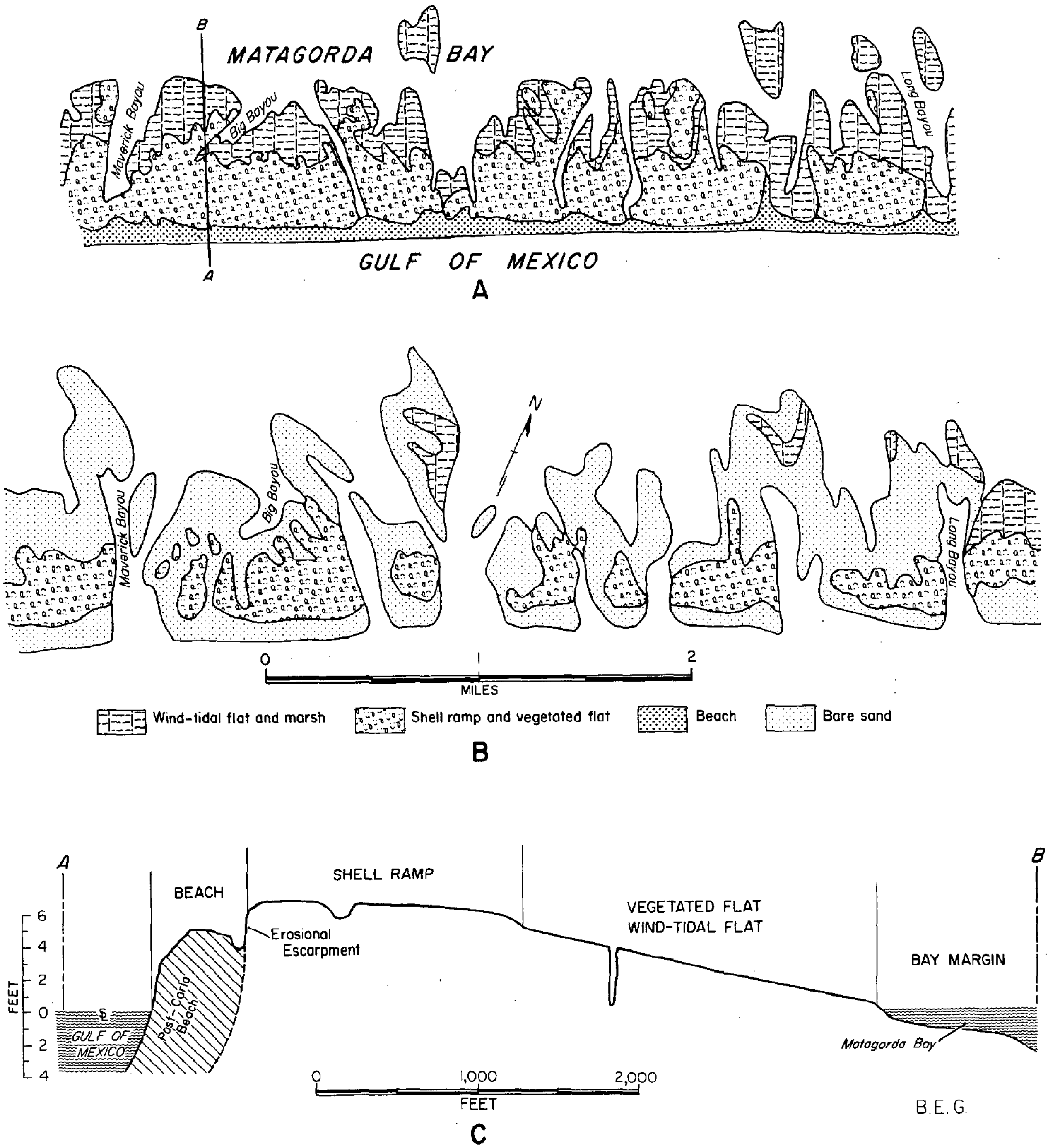


Figure 12. Effects of Hurricane *Carla*, 1961, on a segment of Matagorda Peninsula beginning about 1.5 miles west of the Colorado River. (A) Matagorda Peninsula as it appeared in 1957. (B) Matagorda Peninsula shortly after the passage of Hurricane *Carla*. This shoreline segment was eroded as much as 800 feet. (C) Profile across Matagorda Peninsula (May 1971); parts of the shoreline had accreted 500 feet.

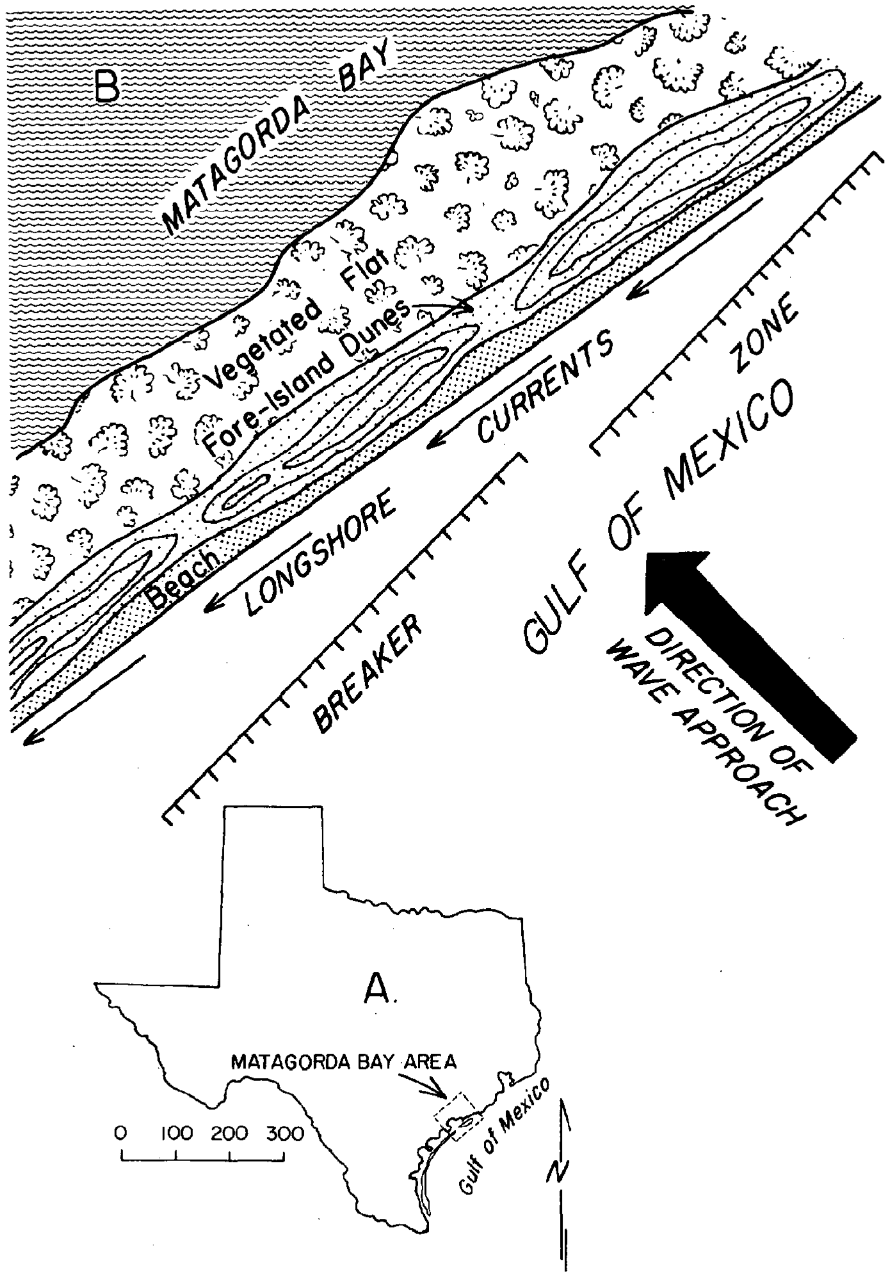


Figure 13. Relationship between direction of wave approach and longshore drift. Waves generated by prevailing southeast wind strike the shoreline at an angle. The northeast segment of the wave begins to feel bottom before the southwest segment, thereby generating currents that move alongshore toward the southwest.

1973). Tidal channels along Matagorda Peninsula have opened and closed several times. For example, Greens Bayou was opened by hurricanes in 1943, 1961, and 1967, and closed shortly after passage of the storms. Pass Cavallo was closed at least once. With the closing of a tidal pass, the shoreline is straightened when sediment is eroded from the downcurrent island (fig. 14). Sediment eroded from Matagorda Island moved to the southwest by longshore currents where it accumulated causing accretion of a shoreline segment without any significant increase in the overall sand budget.

Bay Shorelines

There are a variety of overlapping bay shoreline types (fig. 10) in Matagorda Bay. Most of the bay shoreline is eroding; rates of erosion (for the interval 1957-1972) range from 1 foot to 25 feet per year. Equilibrium and accretionary shorelines are rare; accretionary rates range from 0.5 foot to 3.0 feet per year.

Five types of shorelines characterize the Matagorda Bay system. Shorelines are classified on the basis of elevation and gradient, composition and caliber of materials constituting beaches, dominance of vegetation, and degree of alteration by man's activities. The shoreline types are: (1) cliffed shorelines; (2) shorelines characterized by shell beaches and berms; (3) river-influenced shorelines; (4) shoreline segments dominated by salt marsh; and (5) shorelines dominated by spoil outwash.

Cliffed shorelines.—The distribution of cliffed shorelines is shown on figure 10. Cliffed shoreline profiles are shown on figure 11. A comparison of these profiles (pl. I, profiles 37, 41, 46, 47, 51, 55, 59, 62, 63, 65, 66, 71; appendix C, profiles 37, 41, 47, 51, 55, 59, and 62) with figure 11 indicates that cliffed shorelines are erosional. Cliffed shorelines increase in height toward the heads of Lavaca, Keller, Carancahua, and Tres Palacios Bays (fig. 1). Commonly, as cliff heights increase, erosional rates decrease.

Field measurements and historical monitoring both indicate that cliffed shorelines have been erosional for at least the past 116 years (from 1856 to 1972). A comparison of erosional rates for the interval 1856-1957 with field measurements (1957-1972) indicates that there has been an increase in erosional rates for most of these shoreline segments (table 2).

The height of cliffed shorelines in Matagorda Bay generally increases northward; erosional rates consequently decrease northward. Lowest cliffs are

Table 2. Comparison of erosional rates of cliffed shorelines determined from field measurements (1957-1972) and from historical monitoring (1856-1957).

Field Measurements (1957-1972)		Historical Monitoring (1856-1957)	
Station	Erosional Rate (yearly av.)	Station	Erosional Rate (yearly av.)
41	- 32 feet	41	- 7 feet
46	- 20	46	-1.4
47	- 7	47	-0.6
51	-1.5	51	-5.2 †
57	-0.4	57	-2.5 *
58	-9.0	58	-3.8 *
62	-4.0	62	-1.7 *
63	-6.0	63	-1.5 *

†This segment is near the head of Lavaca Bay. A decrease in erosional rate may result from increased sediment delivery through Lavaca-Navidad Rivers and Garcitas Creek as a result of increase in area of cultivation.

*This area is adjacent to that part of Matagorda Bay that is being dredged for oyster shell. Increased erosional rates may result from destruction of marine grassflats and decrease in number of *Crassostrea virginica* clumps (personal communication, Mr. H. C. Smith, Dec. 20, 1971).

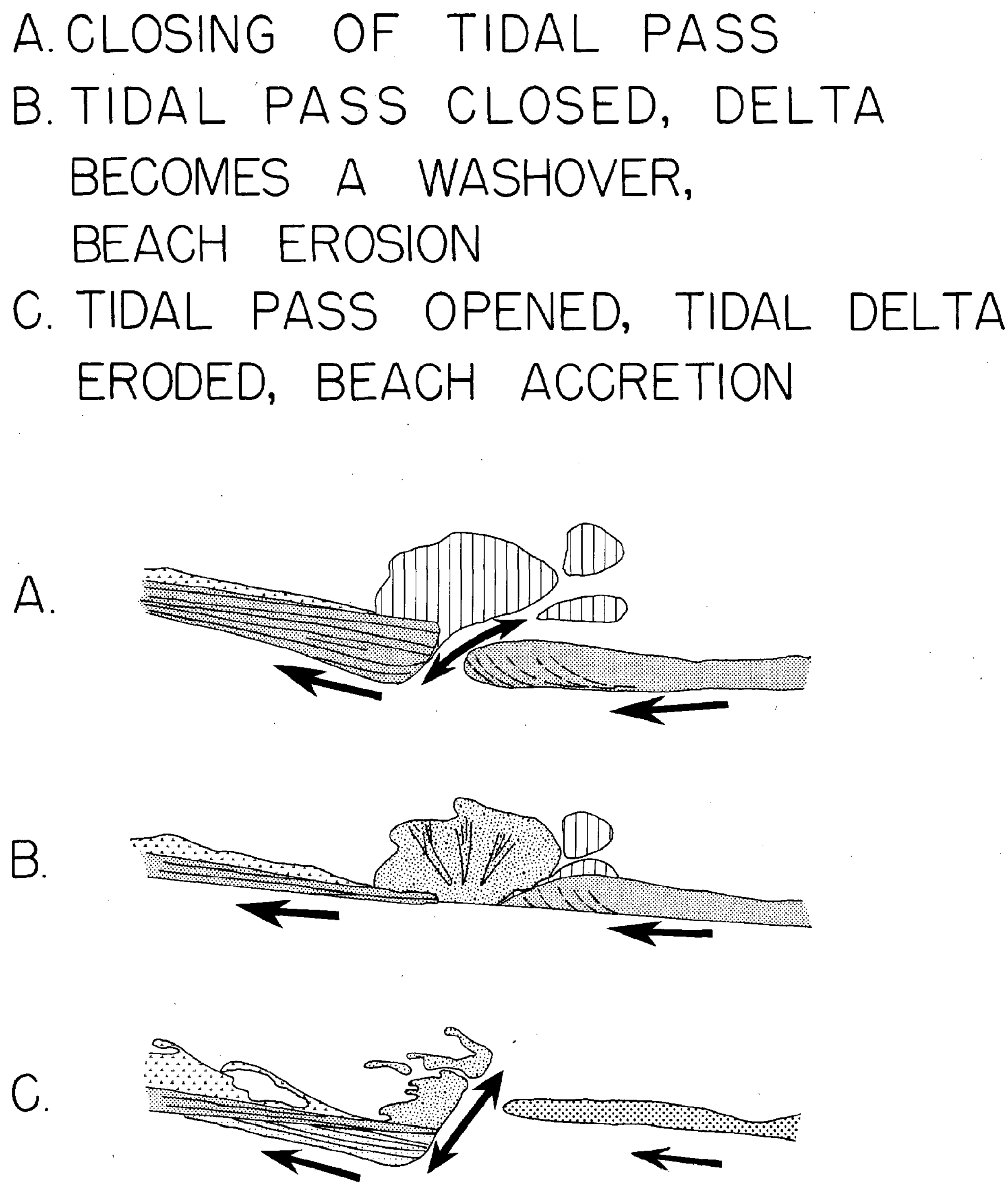


Figure 14. Postulated sequence of events leading to the development of an erosional unconformity on Matagorda Island. Sequence C is the present configuration of Matagorda Peninsula and Matagorda Island in the vicinity of Pass Cavallo.

about 4 to 5 feet, and the highest cliffs stand about 20 feet above bay level. The most rapid erosional rates occur along shoreline segments that face into the southeast wind (pl. I, profiles 41, 46, 55, 59, 62, and 63; appendix C, profiles 41, 55, 59, and 62). Each of these shoreline segments, except the area of profile 41, is eroded into Pleistocene deltaic deposits (distributary sand, interdistributary mud). The cliffed shoreline at profile 41 is eroded into a lower, muddy, deltaic sand, and an upper, clean, incoherent strandplain sand. Since this shoreline segment is situated near Pass Cavallo, it is affected by both tidal currents and waves. The bay margin in the vicinity of profile 41 is characterized by a broad sandflat with marine grass and oyster clumps.

The shoreline in the area of profiles 55 and 59 faces into the southeast wind. Cliffs have been eroded into Pleistocene muds that accumulated along the distal end of abandoned Sangamon deltas. Erosional rates here are less than those along the western shoreline of Matagorda and Lavaca Bays because fetch is relatively short across Keller and Carancahua Bays and Pleistocene muds offer more resistance to wave erosion than sandy deposits. The bay bottom immediately offshore from profiles 55 and 59 consists of Pleistocene mud. Beaches are virtually nonexistent in these areas, but there is generally a veneer of caliche and shell gravel over the eroded Pleistocene surface. Most of the shell is derived from *Crassostrea virginica*. During exceptionally high wave conditions, gravel composed of caliche and oyster shell is deposited upon these erosional escarpments forming a thin berm.

Erosional rates along the north shore of Matagorda Bay (profiles 62 and 63) are intermediate between those of the west shore of Matagorda and Lavaca Bays and the northeast shore of Keller and Carancahua Bays. Cliffs are cut into Pleistocene muds, and, like the shorelines of Keller and Carancahua Bays, beaches are rare; there are shell beaches to the east and west of this area (Carancahua Pass and Well Point). To the south of the Carancahua Pass-Well Point area, there is a relatively broad shoal up to 0.25 mile wide developed on eroded Pleistocene sediments. A sand veneer overlies the Pleistocene for a distance of about 200 feet from the cliff; this 200-foot zone is characterized by bare Pleistocene mud with some caliche clasts, burrows, and oyster clumps. Oysters and caliche fragments are transported from this area to the swash zone where they form beaches along small reentrants, or a gravel veneer over the Pleistocene.

Shorelines at Gallinipper Point (appendix C, profile 47), north of Port Lavaca (appendix C, profile 51) and along the south shore of smaller bays (pl. I, profiles 65, 66, 71) erode less rapidly than other cliffed shorelines because they are either in the lee of southeast winds or they are near the heads of bays where rivers discharge their sediment load. Profile 47 (appendix C) is typical of Pleistocene deposits exposed along Alamo Beach-Gallinipper Point. This shoreline segment erodes more rapidly in the winter when winds are from the north. Cliffs are 17 to 20 feet high in the area of profile 51. Pleistocene distributary sands and interdistributary muds are exposed in cliff faces. Shoreline recession results from wave erosion and slumping (profile 51, appendix C). In the immediate area of this shoreline segment, the bay is floored by Pleistocene mud.

Parts of the Matagorda Peninsula bay shoreline are characterized by low cliffs. Erosional escarpments have been cut into barrier-flat sands and marsh deposits consisting of muddy sand. Escarpments are about 1 to 4 feet high, and erosional rates are 2 to 3 feet per year. Erosion is greatest during the winter when winds are from the north.

Cliffed shorelines have developed primarily from lateral cutting of Pleistocene deposits by wind-generated waves. They are developed, to a lesser degree, on the bayside of barriers and peninsulas. Shorelines of bays having a large fetch erode rapidly, particularly in areas where cliff height is low and where cliffs consist of incoherent sand. Along most of these shorelines, the only coarse sediment (sand size or greater) available to the wave and longshore drift system is derived from the cliffs and from molluscs living in the adjacent, shallow, bay-margin areas. Where oyster clumps are abundant, they provide coarse material that may be deposited at the base of cliffs, thereby retarding wave erosion.

Shorelines characterized by shell beaches and berms.—Parts of Matagorda Bay and Lavaca Bay shorelines are characterized by shell beaches (fig. 10). Prominent shell beaches occur along the north and west shores of Matagorda Bay and the west and south shores of Lavaca Bay. Prior to excavation of the Intracoastal Canal, shell beaches were continuous between the West Branch of the Colorado River and Palacios Point. This shoreline segment was cuspate, and oyster reefs were offshore from each salient. Shell Island Reef and Mad Island Reef appear to be bayward extensions of these salients (fig. 15).

Numerous shell beach segments were profiled (fig. 11, profiles 42, 43, 44, 45, 48, 49, 50, 56, 57, 58, 68, 70, 72, and 73; pl. I). Generally, salt marshes lie between shell beaches and Pleistocene uplands. A few shell deposits are spits that are tied to Pleistocene headlands; others have accumulated upon gently sloping, eroded, Pleistocene deposits. Heights of shell beaches and berms range from 1.0 foot to 9.5 feet and widths from 80 to 900 feet. Thicknesses of shell beaches and berms were determined at Dog Island, Shell Lakes, Carancahua Pass, Indianola, and Magnolia Beach (figs. 10 and 16); thicknesses range from 1 foot to 8 feet. Only two trenches completely penetrated the shell deposits; both were in the Indianola-Magnolia Beach area.

Composition of shell beaches is variable. At Dog Island, whole and fragmented oyster shell makes up most of the deposit. In the Shell Lakes area, the ridges consist almost entirely of fragmented shell ranging in size from coarse sand to pebbles. Oyster shell is the most abundant constituent; however, shelf species are common. One of the highest shell ridges lies just to the east of Carancahua Pass. The ridge is fronted by 1,250-1,300 feet of salt marsh, which is underlain by shell, suggesting that the shell ridge has remained virtually unchanged since it was deposited. The ridge at Carancahua Pass consists of shell debris, with oyster shell being the most abundant type. Caliche fragments constitute about 5 percent of the deposit. Bay species, other than oysters, and Gulf species were present; among Gulf species identified was the "surf clam," *Donax*.

In the Magnolia Beach-Indianola area (fig. 17), there are two prominent beach ridges and several older shell berms that were deposited upon escarpments cut into the Pleistocene. Thickness of these deposits is 3 to 8 feet. There is a wide range

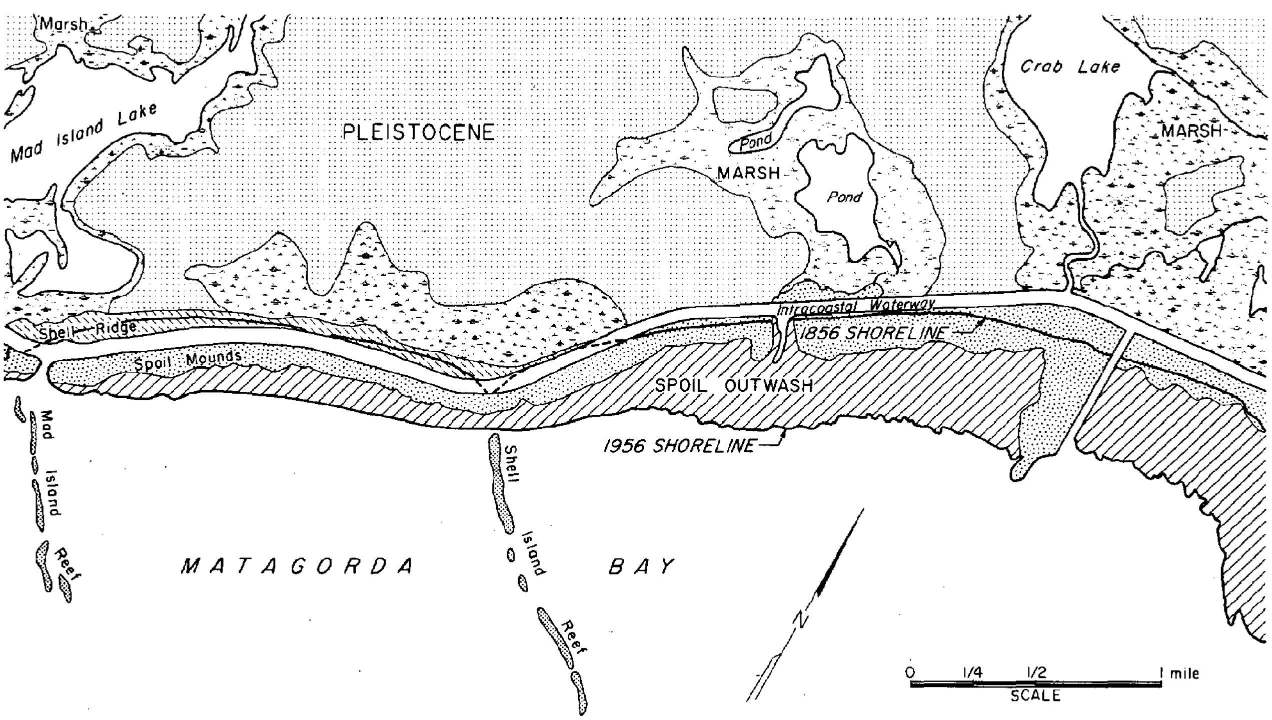


Figure 15. Cuspate shell beaches, oyster reefs, and spoil outwash along the north shore of Matagorda Bay, west of the Colorado delta. The shell beach marks the position of the 1856 shoreline. Mad Island and Shell Island reefs appear to have been attached to cusps of the shell beach. The 1956 shoreline lies some 1,100 to 2,500 feet bayward of the shell beach. The shoreline accreted from spoil outwash.

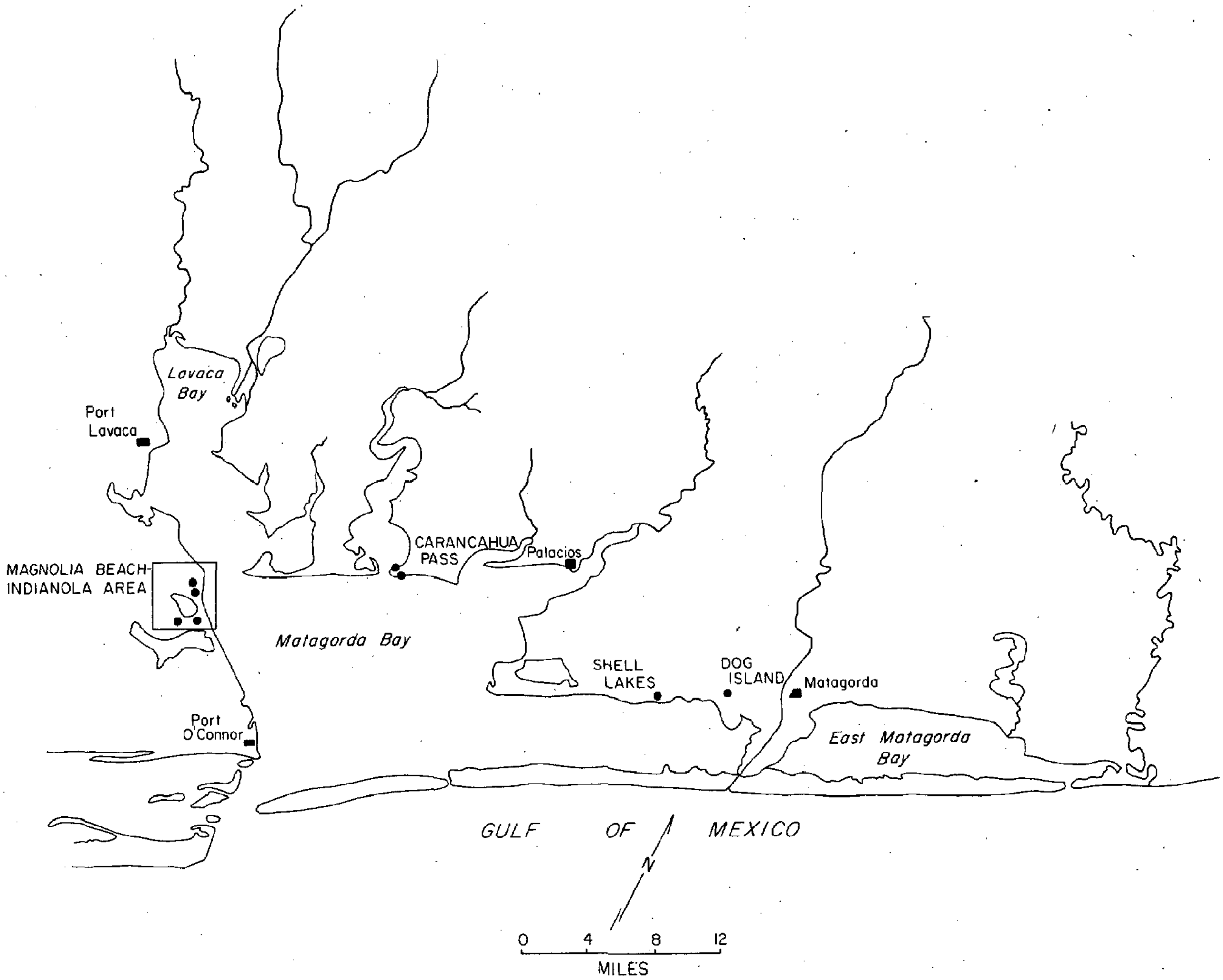


Figure 16. Locations of trenches dug into shell beaches, berms, and spits.

in texture and composition of materials composing the shell ridges. Some deposits, e.g. in the area of the 3-foot trench, consist mostly of oyster shell with a few rock fragments. Others, such as in the area of the 4-foot trench south of Blind Bayou, consist almost entirely of shell debris from coarse sand to pebble size. Shell was derived from both bay and Gulf species.

A large shell ridge extending from Blind Bayou to Old Town Lake (fig. 17) is up to 8 feet thick; it is separated from the Pleistocene uplands and Modern beach by salt marsh. This ridge has been mined for road metal. Faces of some of the shell pits display graded bedding, channel fill characterized by steep foresets that dip in the direction of channel migration, horizontal bedding, and a few poorly developed soil zones. Oyster shell is the most abundant component; however, there are many shelf- and inlet-related species in this deposit (Parker, 1960; Andrews, 1971), such as *Macrocallista nimbosa*, *Eonitia ponderosa*, *Trachycardium muricatum*, *Polinices duplicatas*, *Busycon contrarium*, and *B. spiratum plagosus*. This shell deposit accumulated as a northward migrating spit across a tributary of Matagorda Bay. A second spit is represented by the present beach-berm system (fig. 17). With the exception of shell removed for road material, the older spit has remained virtually intact since it was deposited.

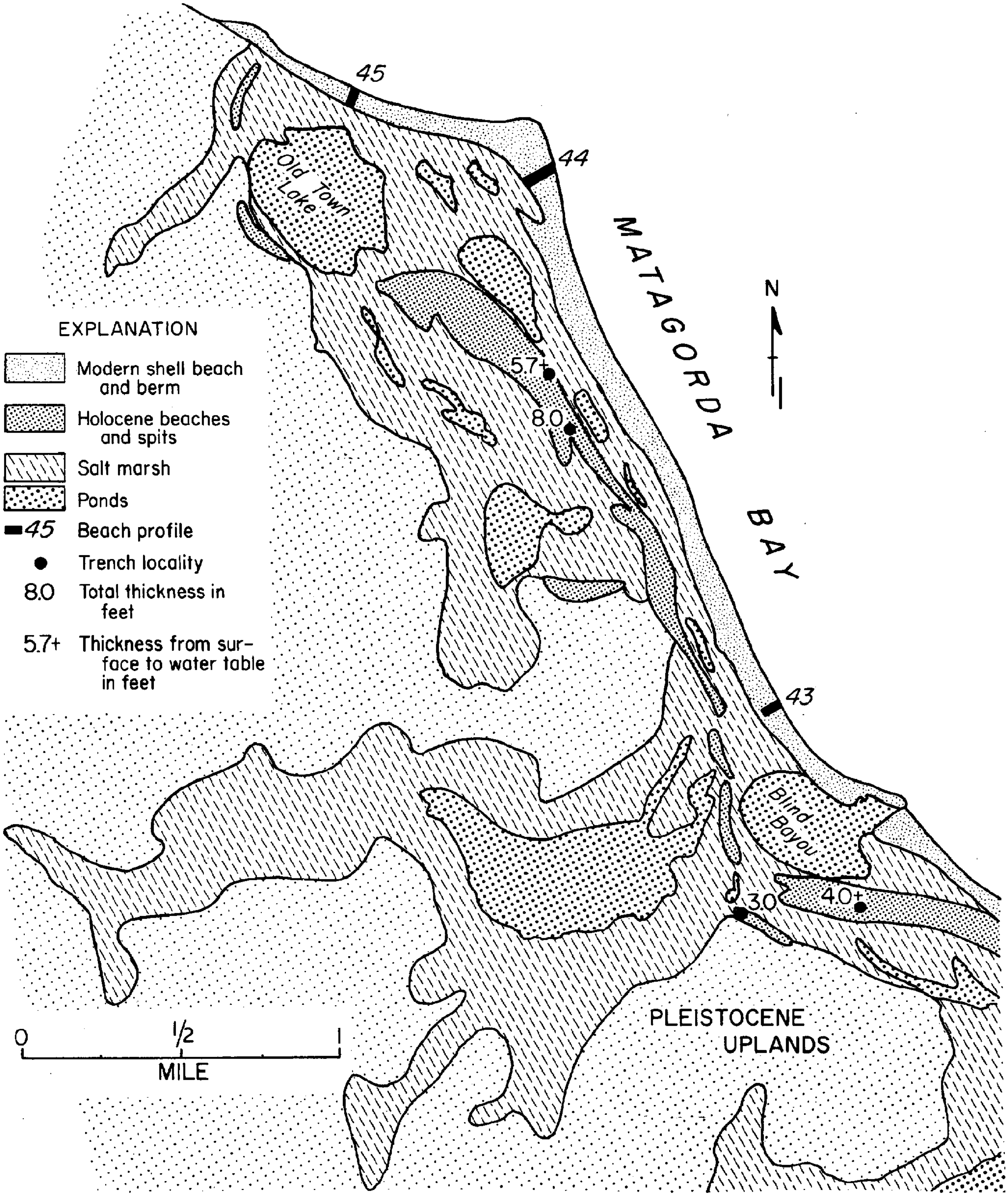


Figure 17. Distribution of shell beaches, berms, and spits in the Magnolia Beach-Indianola area. See figure 16 for location.

A comparison of field measurements and historical monitoring (table 3) indicates that most of the shell beaches were erosional during the period 1856-1972. Three segments, defined by profiles 42-45, profile 48, and profiles 56-58, experienced an overall increase in rate of erosion for the period 1957-1972. Each of these shoreline segments is fronted by relatively wide bays on which large waves are generated by southeast or north winds. Remaining shell beach areas display a decrease in rate of erosion. With exception of profile 73, each of these beaches is associated with somewhat less expansive water bodies. Shell beaches have an average yearly erosional rate that is significantly less than cliffed shorelines (shell beaches, 2.6 feet; cliffed shorelines, 10 feet).

Based on direction of prevailing wind alone, the north and west shorelines should erode the most rapidly. Profiles 42-45 are along the west shoreline. Two of these areas (42 and 44) are erosional; one is accretionary (43) and one is in equilibrium (45). Shoreline configuration in this area probably localizes erosion or accretion. Profile 45 is typical of the Modern shell beach, berm, and marshes of the Magnolia Beach area (appendix C).

Most of the shell beaches along the north shore of Matagorda Bay are erosional. At profiles 57 (appendix C) and 73, erosional rates are 0.4 and 1.0 foot per year, whereas at profile 58, the erosional rate is 9 feet per year. Shell berms and beaches in the areas of profiles 57 and 73 are backed by Pleistocene and older Holocene deposits; during storms these deposits build upward. In the area of profile 58, the low shell beach is backed by wind-tidal flat, marsh, and a water body. During storms, shell from the beach washes into the marsh and lake. Erosional rates in these three areas are controlled by height of the beach-berm system and the physiography of the adjacent area.

Shell beaches that form parts of southern bay shorelines are depicted by profiles 48, 56, and 68 (pl. I and appendix C). These shoreline segments erode at rates of 2 to 3 feet per year. Waves, generated by northers, are the chief erosional agents. The beach and berm in the vicinity of profile 48 is 9 to 10 feet high. It consists chiefly of oyster shell; live *Crassostrea virginica* were found offshore in water about 3 feet deep. North of profile 48, fetch is greater than in the other areas. It is unlikely, however, that winter storms ever generate waves sufficiently large to construct a 10-foot-high berm. Large waves, associated with hurricane storm-surge ebb, probably constructed this beach and berm couple. Parts of this berm have been removed for road material. The shell berm in the area of profile 56 is about 2.5 feet high; it consists of subequal amounts of caliche gravel and oyster shell. Live oyster clumps were found along the shallow bay margin in water 1 to 2 feet deep. A relatively wide salt marsh lies behind

Table 3. Comparison of changes along bay-shore shell beaches, field measurements (1957-1972) and historical monitoring (1856-1957).

Field Measurements (1957-1972)		Historical Monitoring (1856-1957)	
Station	Erosion or Accretion Rate (yearly av.)	Station	Erosion or Accretion Rate (yearly av.)
42	- 4.0 feet	42	- 4.5 feet
43	+ 1.0	43	0.0
44	- 5.0	44	- 2.8
45	0.0	45	+ 3.6
48	- 2.0	48	0.0
49	+ 6.0	49	——
50	+10.0	50	——
56	- 3.0	56	+ 0.8
57	- 0.4	57	- 2.5
58	- 9.0	58	- 3.5
68	- 3.0	68	- 0.4
70	- 1.2	70	- 6.4
72	- 3.0	72	-10.3
73	- 1.0	73	- 1.5

the berm, and marsh deposits were exposed in the swash zone. Winter storms are responsible for development of this berm.

Profiles 70 and 72 (fig. 11 and appendix C) are typical of shell beaches that occur along east bay shores. Erosional rates at profiles 70 and 72 are 1.2 and 3 feet per year, respectively. The shell beach in the area of profile 70 is backed by a wide salt marsh. Oyster reefs which lie offshore from profiles 70 and 72 are effective in damping waves and reducing erosional rates.

Shell beaches erode less rapidly than other bay shoreline types because shell material remains in the swash zone, whereas, very fine-grained sand and silt are kept in suspension in the swash and breaker zones, and subsequently come to rest in water 1 to 2 feet deep. The most rapidly eroding shell beaches are those which face into the southeast wind and those that are backed by marsh or shallow water bodies. Configuration of shorelines determines, in part, whether a particular segment will be erosional or accretionary. Waves are normally focused on promontories (fig. 18), thereby accelerating erosion. Orthogonals diverge along concave shorelines, waves decrease in height, physical energy decreases, and sediment accumulates.

River-influenced shorelines.—Where a river discharges into a bay, its velocity decreases and its sediment load is deposited forming a bayhead delta. The Trinity, Colorado, and Guadalupe bayhead deltas have been studied extensively (Wadsworth, 1941, 1966; McEwen, 1963; Kanes, 1965, 1970; Bouma and Bryant, 1969; Donaldson and others, 1970; Manka and Steinmetz, 1971). To date, there are no data on the Lavaca and Garcitas bayhead deltas which are building into Lavaca Bay (fig. 1). The Garcitas delta has not prograded significantly beyond the head of Lavaca Bay, whereas the Lavaca delta has prograded about 2.7 miles into the bay. For the most part, deltas are accretionary features. However, because of the lateral shifts in sites of sediment input, one deltaic segment may be accretionary, whereas another segment may be undergoing erosion. The two deltas at the head of Lavaca Bay are experiencing growth primarily in the immediate vicinity of the river mouths. The Colorado River built its delta across Matagorda Bay, a distance of about 4 miles, between 1929 and 1935 (Wadsworth, 1966). Figures 19 and 20 show the growth of the delta; by 1941, the delta had almost completed its growth.

In the area of Tiger Island Channel, the Colorado delta is prograding about 28 feet per year; elsewhere it is in a destructive phase. A delta

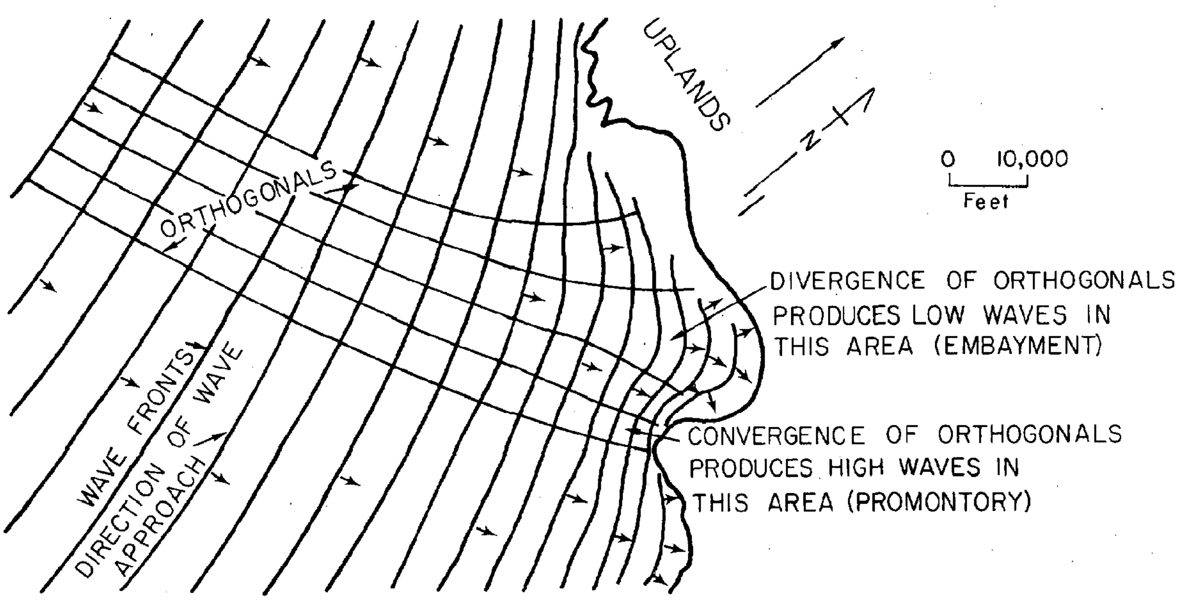


Figure 18. Wave refraction at Arena Cove, California (after Wiegel, 1964; reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, New Jersey).

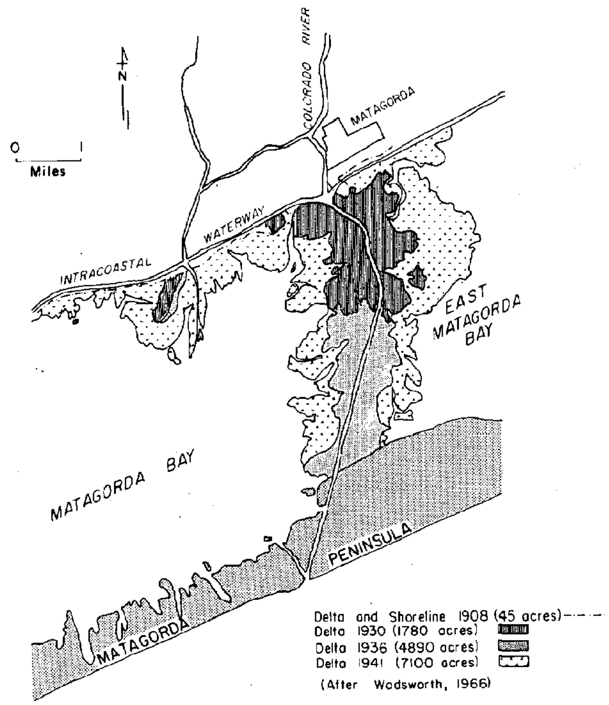


Figure 19. Map of the growth of the Colorado delta during the period 1908-1941 (after Wadsworth, 1966; reprinted by permission of the author).

is destroyed by erosion and compactional subsidence (Scruton, 1960). Compactional subsidence is rapid where prodelta mud is thick, where sedimentation rates were rapid prior to abandonment, and where deposits are young. The Colorado delta prograded rapidly as a consequence of a large sediment volume and a shallow receiving basin; maximum depth of the basin was about 6 feet (Kanes, 1970). Total thickness of the delta is 8 to 10 feet, and maximum thickness of the prodelta is 4 to 5 feet (Manka and Steinmetz, 1971). The thin prodelta mud precludes excessive compactional subsidence. Bay muds that are 10 to 14 feet thick and estuarine deposits up to 80 feet thick underlie the delta.

The Colorado delta is eroding 6 to 8 feet per year along its eastern margin, but the western delta margin has remained relatively stable during the interval 1957-1972. Subsequent to diverting river discharge into the Gulf of Mexico, oysters had begun to colonize the offshore area of east Matagorda Bay. Shell berms and beaches now accentuate parts of the deltaic shoreline of east Matagorda Bay.

Garcitas Creek delta is protected by Pleistocene headlands from waves approaching from the southeast. Within the estuary, the deltaic shoreline is relatively stable. Some sediment has accreted to marsh islands at the mouth of Garcitas Creek. Sedimentation rates, thickness of deltaic deposits, the ratio of mud to sand, and rates of compactional subsidence are not known.

The Lavaca delta is undergoing erosion along most of its perimeter. The area between the Lavaca River and Venado Lakes was once the site of deltation. This shoreline segment, which is now straight, was cut back by wave and current activity. Since 1934, parts of this shoreline have eroded from 1 to 5 feet per year, whereas other parts show no change. While the abandoned delta was undergoing erosion, the active delta prograded about 2.7 miles into Lavaca Bay. Shoreline accretion is now limited to the immediate area of the mouth of the Lavaca River. Accretion rates near the river mouth were about 4 feet per year for the interval from 1957-1972. The western margin of the delta was in equilibrium over the same time period. Thickness of the delta, sand and mud ratio, frequency of overbank flooding, and compactional subsidence are not known for Lavaca delta.

The largest marsh areas in the Matagorda Bay system are associated with deltas. These include the active Colorado, Lavaca, and Garcitas deltas and the inactive Holocene Brazos-Colorado delta. Delta plains of the active deltas are covered with salt marsh, brackish marsh, and fresh-water marsh. The Holocene Brazos-Colorado delta (most of this delta lies to the east of the Matagorda Bay area) is characterized by marshes that are broken by tidal channels, lakes, and ponds. Expansion of lakes and ponds indicates that the area is subsiding (Kolb and Van Lopik, 1966).

In order for marshes to propagate, there must be a rather constant relationship between the delta plain and sea level. If there is excessive vertical accretion, marsh vegetation is replaced by grasses, shrubs, and trees. If, on the other hand, the marsh surface subsides rapidly, the plants drown, and waves and currents erode the area.

At the present, marsh surface-water level relationships of Garcitas, Lavaca, and Colorado deltas are stable. Apparently subsidence and sedimentation rates are balanced. Delta-plain and marsh deposits are derived from rivers and bays.

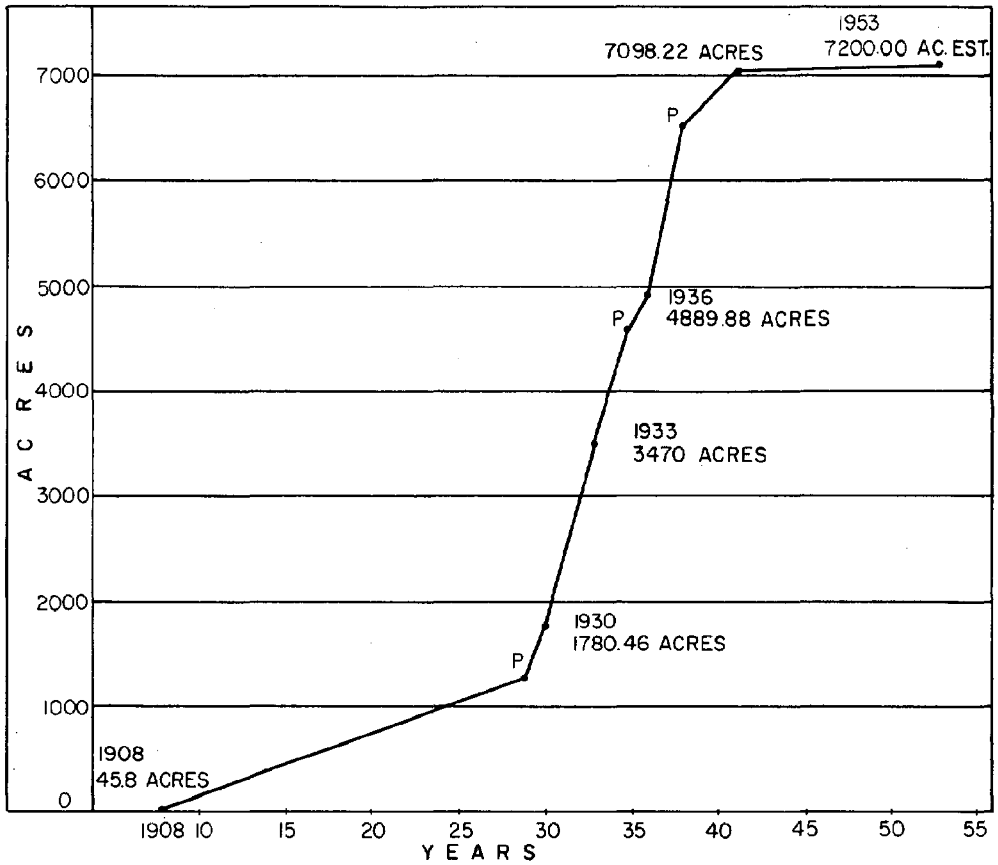


Figure 20. Area increase of the Colorado delta, in acres, for the period 1908-1953 (after Wadsworth, 1966; reprinted by permission of the author).

When the streams overflow their banks, fine sediment is added to the delta plain. Southeast winds create wind tides that inundate parts of the bayhead deltas. These wind-driven waters transport fine sediment onto the delta plain.

The normal succession of marsh types from bayward inland is salt marsh, brackish marsh, and fresh-water marsh. Some marsh areas on the Lavaca delta do not exhibit the normal floral succession (figs. 10 and 11; appendix C, profile 54).

Shoreline segments dominated by salt marsh.—The most extensive marshes are associated with deltas (figs. 1 and 2). Salt marsh is also associated with barrier islands and peninsulas; salt marsh of this type is situated between Brown Cedar Cut and the Colorado delta. Other marshes occur on the flood-tidal delta at Pass Cavallo, along minor reentrants and mouths of lesser streams, along the back sides of shell berms that tie Pleistocene headlands together (the south shore of Keller Bay), at bay margins of spoil outwash, and along the mainland shoreline between the Colorado River and Oyster Lake.

Most of the marsh areas are undergoing erosion. Table 4 shows the erosion or accretion rate for the marsh areas measured in the field and their associated physiographic features.

Several profiles were measured across marshes that face into the southeast wind. Cliffs occur landward of three of the marsh areas (fig. 10; pl. I, profiles 52, 61, 64; appendix C, profiles 52 and 61). Two of the marshes are accretionary; the other is erosional. The remaining two profiles are representative of marshes associated with spoil outwash (fig. 10; pl. I, profiles 74 and 75; appendix C, profile 75); one of these marshes is

Table 4. Erosional and accretionary rates (1957-1972) and physiographic units associated with marshes.

Station	Accretion	Erosion*	Nature of Associated Physiographic Unit
52	+2		Cliffed shoreline
56		-3	Shell berm
60		-2	Cliffed shoreline
61	+0.5		Cliffed shoreline
64		-2	Cliffed shoreline
67	0	0	Cliffed shoreline
68		-3	Shell berm
70		-1.2	Shell berm
74		-13	Spoil outwash
75	+3		Spoil outwash

*Erosion and accretion rates are yearly averages for the time interval 1957-1972.

erosional, the other accretionary. Accretionary marshes, which are backed by cliffs, lie downdrift from eroding headlands. Other marshes (e.g., profile 64) associated with cliffed shorelines occur in concave shoreline areas.

In east Matagorda Bay, marshes that front the southeast wind are developed upon spoil outwash. The marsh at profile 75 is accretionary and receives its sediment from the erosional shoreline to the east and from reworked spoil adjacent to the Intracoastal Canal. The spoil area that supplies sediment to the marsh at profile 75 has about 5 feet of relief and is 600 to 950 feet from the bay margin. The erosional marsh at profile 74 received sediment from a spoil area having about 7 feet of relief; the spoil was 1,200 to 1,450 feet from the bay margin. Marshes that face the southeast wind are flooded by wind tides which have a range of a few inches to approximately 2 feet.

Marshes mostly affected by waves that approach from the north were also profiled (figs. 10 and 11; pl. I, profiles 56, 67, 68; appendix C, profile 56). Two of the marshes (profiles 56 and 68) are eroding at rates of about 3 feet per year. The other marsh area (profile 67) has been in equilibrium since 1957.

The marsh at profile 56 is about 1,000 feet wide and is a rather uniform 0.75 foot above bay level; it increases to 1.5 feet above bay level where salt-marsh vegetation gives way to *Spartina spartinae* (sacahuista) and *Tamarix gallica* (salt cedar).

Marshes that are not associated with deltas receive sediment from the adjacent bay and from the erosion of headlands. Under normal wind and wave conditions, the marsh at profile 56 is supplied sediment from Keller Bay. Storm washovers from Matagorda Bay transport sand and shell into the marsh. The equilibrium marsh at profile 67 is affected by waves generated by both north and south winds. Measurements made along profile 67 during a norther indicated that water level was 1.5 feet below normal bay level. *Spartina alterniflora* marsh was completely emergent and the high salt marsh extended 3 feet above bay level. South or west winds inundate the marsh and a poorly defined, wind-tidal flat occurs at about 1.5 feet above mean high water.

Two profiles were measured across marshes that form parts of the eastern shorelines of Carancahua and Matagorda Bays (figs. 10 and 11; appendix C, profiles 60, 70). Both marshes were being eroded, but the rate was slightly less at profile 70 where oyster reefs lie offshore. Each marsh is rather broad, and under normal conditions, they are inundated by about 0.5 foot of water. Water levels were measured along profiles 60 and 70 during a norther. Water level at profile 60 was 0.75 foot below normal and 1.5 feet below normal at profile 70. A wind-tidal flat is developed 1.5 feet above normal bay level at profile 60, and at about the same elevation to the north of profile 70. Low and high marsh are well developed in the area of profile 60; *Distichlis spicata* dominates the high marsh. There is no low marsh at profile 70; the high marsh is characterized by three floral zones (appendix C, profile 70).

Shorelines dominated by spoil outwash.—Bay shorelines adjacent to the Intracoastal Waterway have been significantly altered. The areas that have been affected the most lie between Caney Creek and the town of Matagorda, between the Colorado delta and Oyster Lake, and to the west of Port O'Connor (figs. 1 and 10). Approximately 40 miles of canal were dredged through marshes and shell beaches which bordered Matagorda and Espiritu Santo Bays. The canal was initially 12 feet deep and 200 feet wide.

With the completion of the Intracoastal Waterway, approximately 500,544,000 cubic feet of spoil were placed adjacent to the bay margin. Depth measurements made in the Intracoastal Waterway in the spring of 1973 indicated that the canal had been deepened about 6 feet, thereby increasing the spoil volume to approximately 750,800,000 cubic feet.

Results of dredging and spoil disposal adjacent to bay margins are destruction of certain physiographic and environmental units, and filling of the bays through shoreline accretion (fig. 15). Accretion from spoil outwash is not a continuous process. Accretion occurs during dredging operations and during heavy rains when sheetwash transports sediment from spoil mounds into the bay. Bay shorelines that have accreted as a result of dredging operations also go through periods of erosion. Erosion occurs during extended dry periods, when the volume of spoil is low and when dense vegetation inhibits transport of sediment by sheetwash.

Profiles 75 and 76 (figs. 10 and 11; appendix C, profiles 75, 76) are characteristic of bay shorelines that have been affected by dredging and spoil outwash. The shoreline at profile 76 was experiencing erosion when this study was terminated. The shoreline was eroding because the volume of spoil was relatively low. At the same time, the shoreline at profile 75 was accreting. The volume of spoil was great, and the distal part of the spoil outwash was densely vegetated by marsh plants.

STABILITY OF SHORELINES

The term *stability* refers to the accretionary, equilibrium, or erosional condition of a particular shoreline segment. The specific condition may result from long-term, annual, or short-term processes (Wiegel, 1964). Short-term stability, as used in this report, refers to shoreline changes that occur during a time interval of months or a few years. Long-term stability reflects shoreline changes over a period of a few decades on up to a century or more. Shorelines that have a long-term erosional history may accrete under certain short-term wave conditions, and similarly shorelines with a long-term accretionary trend may be erosional under certain short-term wave conditions (Wiegel, 1964).

Over the short term, the beach may be erosional, accretionary, or in equilibrium, depending upon wave conditions at the time the observations were made. Steep waves that develop in deep water affect erosion or accretion at a moment in time. Steep waves tend to erode the beach, whereas flat waves have the opposite effect.

Long-term shoreline trends are controlled by sediment availability, subsidence, shoreline orientation, existence of promontories, and direction of sediment transport. In general, the long-term trend of Matagorda Peninsula has been erosional, and the trend of Matagorda Island has been accretionary or in equilibrium. Mainland shorelines have been chiefly erosional during the same time interval.

Sediment Availability

Sediment supplied to the mainland shore is derived from rivers, from erosion of Pleistocene uplands, and from molluscs that live along the bay margin. Sources of sediment for Matagorda Peninsula and Matagorda Island are the Brazos and Colorado Rivers, as well as erosion of Holocene Brazos-Colorado delta, and erosion of Pleistocene deposits exposed on the inner continental shelf.

Most of the shorelines associated with the Matagorda Bay system are eroding, a fact which indicates that the sediment volume supplied to Gulf and bay shorelines is insufficient to balance the amount of sediment removed by waves and longshore drift. The nature of beaches in the Matagorda Bay area is a good indicator of the condition of shoreline stability. There are very few pure sand beaches along the mainland shoreline. Sediments of mainland beaches are a mixture of sand, shell, and rock fragments; shell and rock fragments are the most common constituents. Beaches composed of shell and rock fragments indicate that virtually no sand is supplied currently to these beaches by fluvial systems. Accretionary mainland shorelines generally coincide with river mouths.

There are two contrasting areas along the Gulf shoreline: (1) the area from Pass Cavallo westward (Matagorda Island); and (2) the area from Pass Cavallo eastward to the boundary of the study area (Matagorda Peninsula). Composition of materials making up these two areas is different. Matagorda Island is composed chiefly of terrigenous sand, whereas shell and rock fragments compose a significant part of Matagorda Peninsula. The rate of delivery of terrigenous sand to Matagorda Peninsula is now, and probably was in the past, slower than the delivery rate to Matagorda Island. Among the more obvious lines of evidence are the following: (1) Matagorda Peninsula has a long erosional history, whereas Matagorda Island is just entering an erosional phase; (2) accretionary grain throughout Matagorda Island indicates rapid sand accumulation, whereas Matagorda Peninsula only exhibits accretion near Decros Point; (3) the two areas have contrasting widths, with a broad, barrier sand body indicating an excess of terrigenous sand and a narrow island suggesting the opposite; and (4) there is a contrasting sediment composition in the two areas.

Subsidence

In some areas of the Texas Coastal Zone, subsidence is a major cause of shoreline retreat. There has been some subsidence in the northeast part of the study area as a consequence of dewatering of Holocene Brazos-Colorado deltaic deposits. Transgression in the area from Caney Creek to about halfway to the mouth of the Colorado River probably resulted from a low sand supply and compactional subsidence. Subsidence changes the relative position of sea level and would by itself be sufficient to cause shoreline retreat.

Shoreline Orientation

Interaction between the direction of wave approach and shoreline orientation determines the direction of longshore drift (fig. 21). Prevailing wind and, hence, the direction of wave approach, is from the southeast. Near the shore, the shallow bottom begins to exert a drag (friction) on waves; it is in this shallow water zone that shoreline orientation begins to exert its influence on breaking waves and nearshore currents. The Texas Gulf shoreline is concave to the southeast. According to Watson (1968):

> "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 shore at the greatest angle. The current decreases in magnitude toward the center where it diminishes to zero because the waves approach parallel to the shoreline at the point where the wind direction is normal to the shoreline and no current is generated."

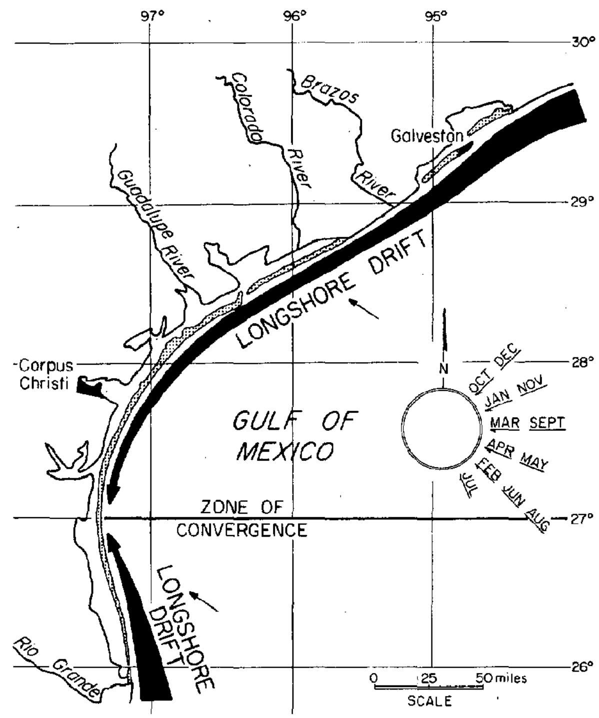


Figure 21. Net annual longshore drift (after Watson, 1968).

In the Matagorda Bay area, waves approaching from the east, east-southeast, and southeast generate southwestward-flowing longshore currents. Rate of longshore drift is greatest when wave approach is from the east, because the angle between wave approach and the shoreline is at a maximum. Waves approaching from the south and south-southeast create longshore drift and sediment transport to the northeast.

Direction of Sediment Transport

The dominant sediment transport direction, as indicated by natural tracers, is both onshore (from the inner shelf and shoreface) and alongshore to the southwest. Natural tracers are fragments of lacustrine limestone, calcite-cemented sandstone blocks, plates of beach rock, caliche nodules, and vertebrate and invertebrate fossils. During hurricanes, these materials are eroded from Pleistocene and Holocene deposits exposed on the shoreface and inner continental shelf and transported to barriers and peninsulas.

Morphological features of barrier islands and peninsulas indicate that dominant sediment transport is southwestward. Ridges and swales at Decros

Point indicate that Matagorda Peninsula grew to the southwest by spit accretion.

Rock fragments and shell, which are derived from bay species, occur on beaches throughout the extent of Matagorda Peninsula. The greatest concentration of shell and rock fragments is on the eastern two-thirds of the peninsula. The day-to-day process of breaking waves and longshore currents selectively transports terrigenous sand to the southwest where part of it accumulates on beaches. Coarse shell and rock fragments remain behind to be transported onshore by a storm surge.

Coarse materials are probably more abundant in relict sediment in the nearshore zone adjacent to eastern Matagorda Peninsula than to the west. Onshore winds contribute to the concentration of coarse materials by selectively removing sand-size particles from back-beach areas.

DISTINCTION BETWEEN NATURAL AND MAN-INDUCED SHORELINE CHANGES

Natural changes in the Coastal Zone are those changes that would occur even in the absence of man. Such natural changes result from the interplay among the various coastal processes and the interaction of these processes with sediments that are available for construction and maintenance of shoreline features. Man's role in producing shoreline changes generally has been to bring about a state of natural disequilibrium by interrupting the progression of natural coastal processes and by decreasing the sediment budget.

Natural Shoreline Changes

Historical monitoring and field studies have shown that most of the shoreline changes in the Matagorda Bay area are the result of natural processes. During the past 116 years, the dominant trend of Gulf and bay shorelines has been erosional.

The Gulf shoreline of the Matagorda Bay area is erosional because there is a deficit of sand-size sediment. Based upon calculations of volumes of sand eroded from the inner shelf and shoreface, sand volume delivered to the Gulf by the Brazos and Colorado Rivers, and the volume of sand trapped by the north jetty of the Matagorda Ship Channel, it is concluded that materials derived from shelf and shoreface erosion constitute over 60 percent of the current sand budget for this shoreline segment.

Bay shorelines are mostly erosional. Shoreline segments that face into the predominant southeast wind or face the north and that are adjacent to water bodies with significant fetch tend to erode rapidly. Erosion is retarded along shorelines adjacent to shallow bay margins which are inhabited by clumps of *Crassostrea virginica*.

Marsh areas, particularly those associated with the larger fluvial systems, are least likely to erode. Erosion is retarded by the ability of plant roots to trap and bind sediment particles. Some marshes are undergoing erosion; these are situated on abandoned delta lobes and along bay margins of barriers and peninsulas.

Bay shorelines also erode because of a sediment deficit. Maximum sediment input is localized at the mouths of Garcitas Creek, Lavaca and Colorado Rivers. The Matagorda Bay system constitutes a large water body which is conducive to generation of rather large waves. Waves strike much of the bay shoreline at an angle and are refracted, thereby setting up longshore drift. The north shoreline of Matagorda Bay is at the present a relatively straight segment, which results from wave erosion and longshore drift (the area between Well Point and Sand Point is an example). Waves erode the Pleistocene headlands, and longshore currents transport granular materials to the west where they accumulate in spits (Turtle Point, Sand Point, and Rhodes Point).

The natural trend is for the bay shorelines to retreat, thereby increasing the bay area. Matagorda Peninsula is also retreating; the peninsula will ultimately migrate across Matagorda Bay and attach itself to the bay-shore segment that lies between Chinquapin and Palacios Point.

Man-Induced Shoreline Changes

A few areas of shoreline change are definitely related to man's activities in the Coastal Zone.

Some of man's activities that affect shorelines, or that have the potential of affecting shorelines are: (1) construction of dams across major fluvial systems; (2) river diversion; (3) land use in major drainage basins; (4) construction of bulkheads, groins, and jetties; (5) mining beach materials; (6) shell dredging; (7) dredging canals; and (8) dune alteration. A few of these are ongoing activities in the Matagorda Bay area, and others have been conducted in the past.

Consequences of three of man's activities have been documented in the Matagorda Bay area. The rapid shoreline accretion which followed dredging of the Intracoastal Waterway, and progradation of the Colorado delta across Matagorda Bay are examples of shoreline changes produced by man's activities. Jetties cause changes in shoreline stability by trapping sand transported by longshore currents. There are two jetty systems in the Matagorda Bay area that are currently being used, one at Port O'Connor and the other on the Gulf side of Matagorda Peninsula.

Data on the jetties at Port O'Connor have been derived from 1934 and 1956 photomosaics, 1969 NASA photographs, and data supplied by the Galveston Office, U. S. Army Corps of Engineers. There are two sets of jetties at Port O'Connor. The oldest jetties (fig. 22, area 1), shown on 1934 photographs, have been abandoned; a second set of jetties (fig. 22, area 2) was constructed in 1939 and improved in 1965. Pleistocene strandplain sand in the Port O'Connor area yields sediment that is transported southward by tidal and longshore currents. Jetties at Port O'Connor prevent southward movement of this sand. These jetties are not the cause of downdrift erosion because the trend during 1856-1957 also had been erosional. The jetties trap sand that would normally move southward to an area already experiencing erosion. By 1969, sand had accreted to a point where it began to bypass the jetties and move into the Intracoastal Waterway (fig. 23). Sand dredged from the canal is placed south of the jetties where it is picked up by the current system and transported toward the Gulf of Mexico.

Matagorda Ship Channel (fig. 24) was completed in 1965. Initially, the north jetty extended approximately 5,000 feet beyond the shoreline into about 4 fathoms of water. Since 1964, the shoreline has accreted from 100 to 950 feet updrift from the north jetty (fig. 24). The nature of shoreline erosion and accretion adjacent to Matagorda Ship Channel jetties was determined from data (1964 through 1971) provided by the Galveston Office, U. S. Army Corps of Engineers. Twelve profiles (figs. 25 and 26) were constructed from the Corps data. The volume of sand that accumulated adjacent to the north jetty over the seven-year period was about 45,000,000 cubic feet (about 6,400,000 cubic feet per year). The shoreline adjacent to the south jetty has undergone erosion during the 1964-1971 interval (fig. 24); approximately 51,500,000 cubic feet of sand was removed from the beach and shoreface during the period 1964-1971 (fig. 26).

Activities of man in the drainage basins of major streams that discharge into bays and the Gulf of Mexico also affect shorelines. In most areas of the Texas Coastal Zone, the magnitude of shoreline changes resulting from altering major fluvial systems has not been determined. Increase in agricultural activity in drainage basins increases sediment yield, and dams constructed across major streams impound water and sediment. Suspension load volumes have been calculated for the major streams, but at this time the volume of bed load carried by these streams is not known. Other unknown factors are lag time between man's activities (increased sedimentation or reservoir construction) in the drainage basin and shoreline changes related to these activities. Examples of stream alteration are: (1) the diversion of the Brazos River in the Freeport area; and (2) removal of the log jam on the Colorado River. Diversion of the Brazos River has caused: (1) destruction of the old Brazos delta (Seelig and Sorensen, 1973); (2) construction of a new delta at the river mouth (Odem, 1953; Nienaber, 1963; Seelig and Sorensen, 1973); and (3) development of a trapping mechanism (local reversal of longshore currents) for most of the sand transported to the Gulf of Mexico by the Brazos River. Rivers have not been intensively studied with respect to the role they play in shoreline stability.

Bulkheads have been constructed to retard erosion of cliffed shorelines in several areas along the mainland shore. Such areas are: (1) Port O'Connor along the west shoreline of Matagorda Bay; (2) Olivia along the north shore of Keller Bay; (3) near the mouth of Keller Creek; and (4) along the east shore of Carancahua Bay west of the mouth of Fivemile Branch.

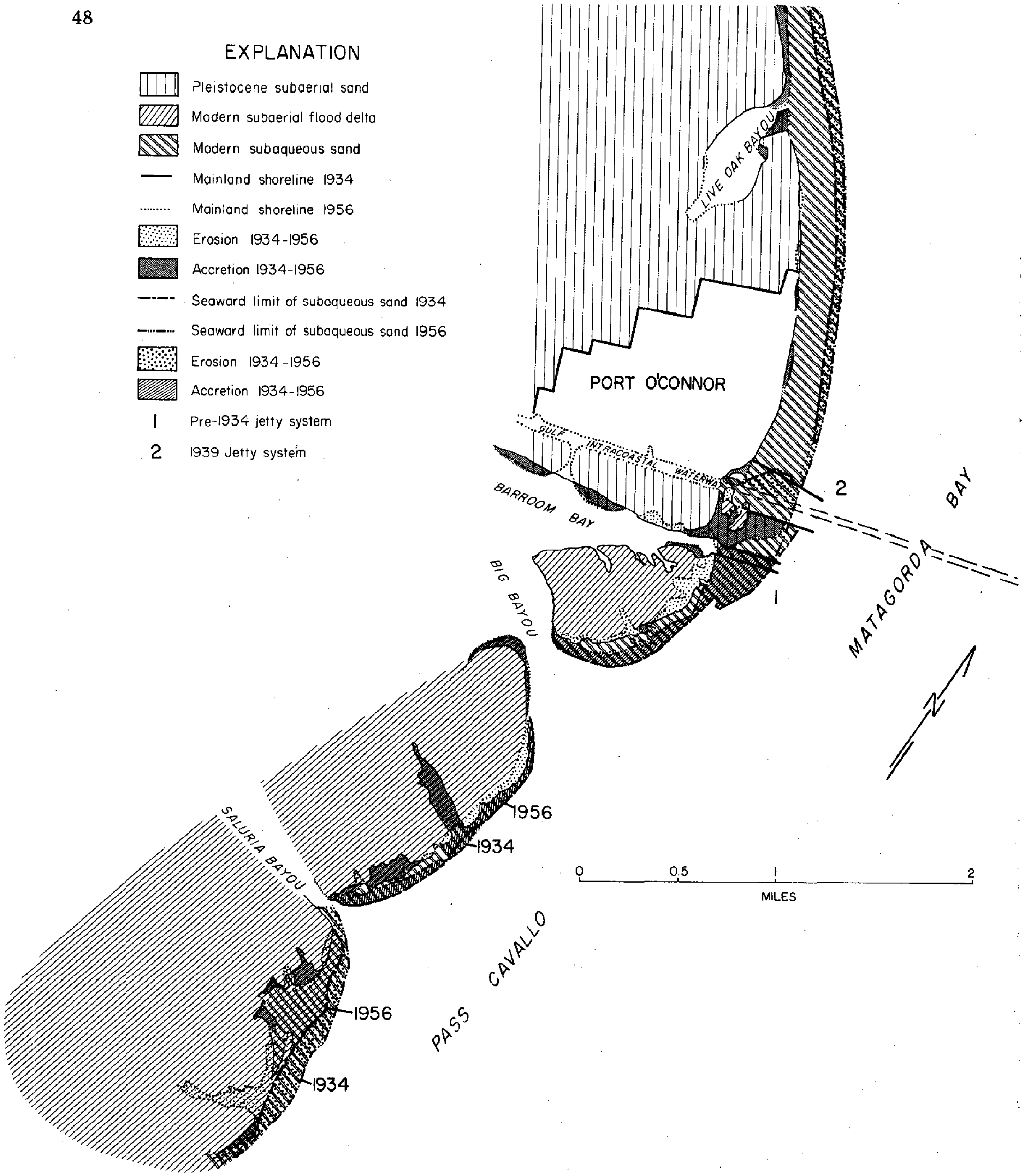


Figure 22. Locations of jetties in the Port O'Connor area, and changes in the shoreline and nearshore sand distribution during the interva 1934-1956.

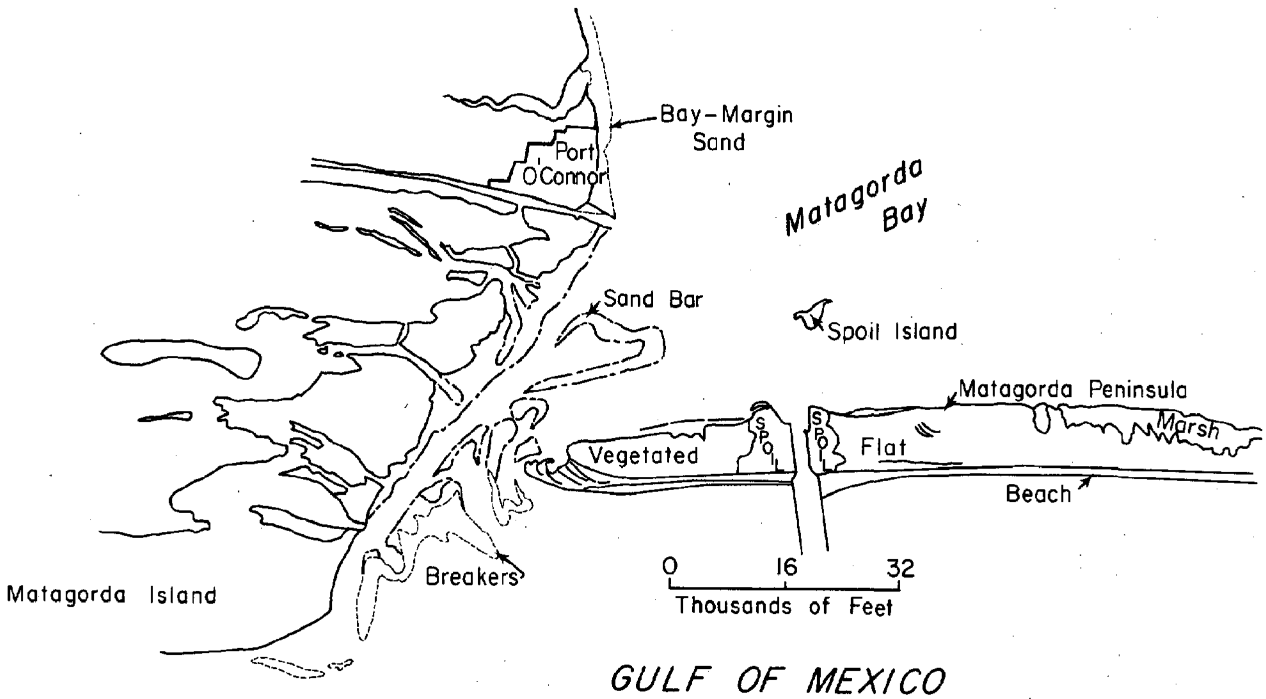


Figure 23. Distribution of bay-margin sand north of the jetties at Port O'Connor. The map was derived from 1969 NASA photography. Between 1956 and 1969, the bay-margin sand had accreted at least as far as the bayward extent of the north jetty.

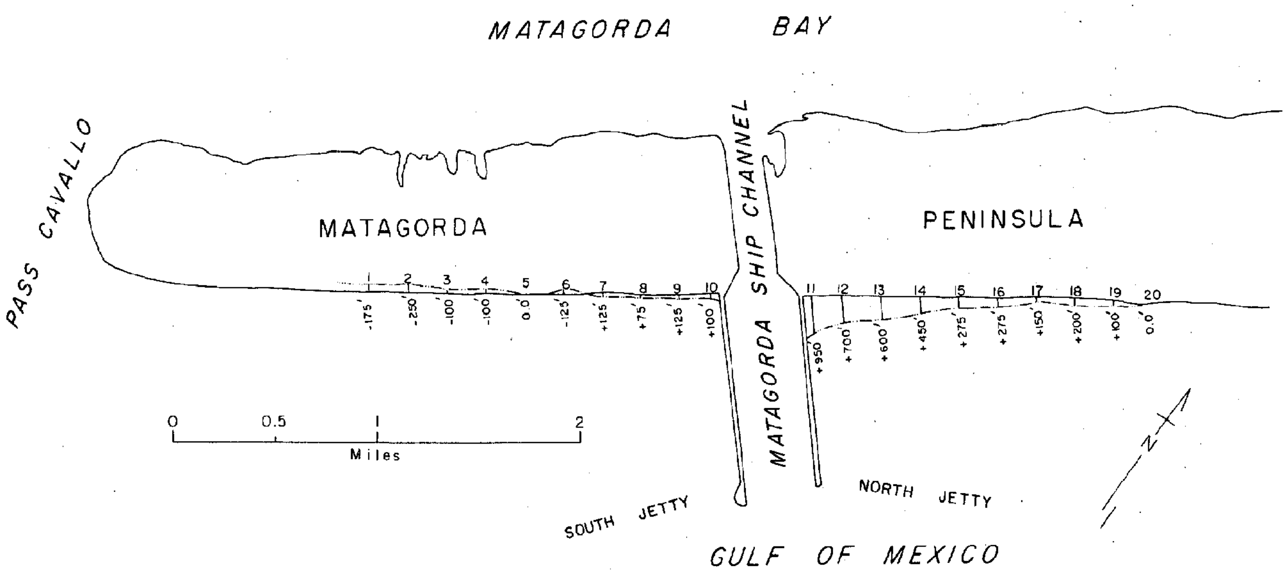


Figure 24. Accretion and erosion associated with Matagorda Ship Channel jetties. Accretion occurs adjacent to the upcurrent (north) jetty; erosion occurs downcurrent from the south jetty.

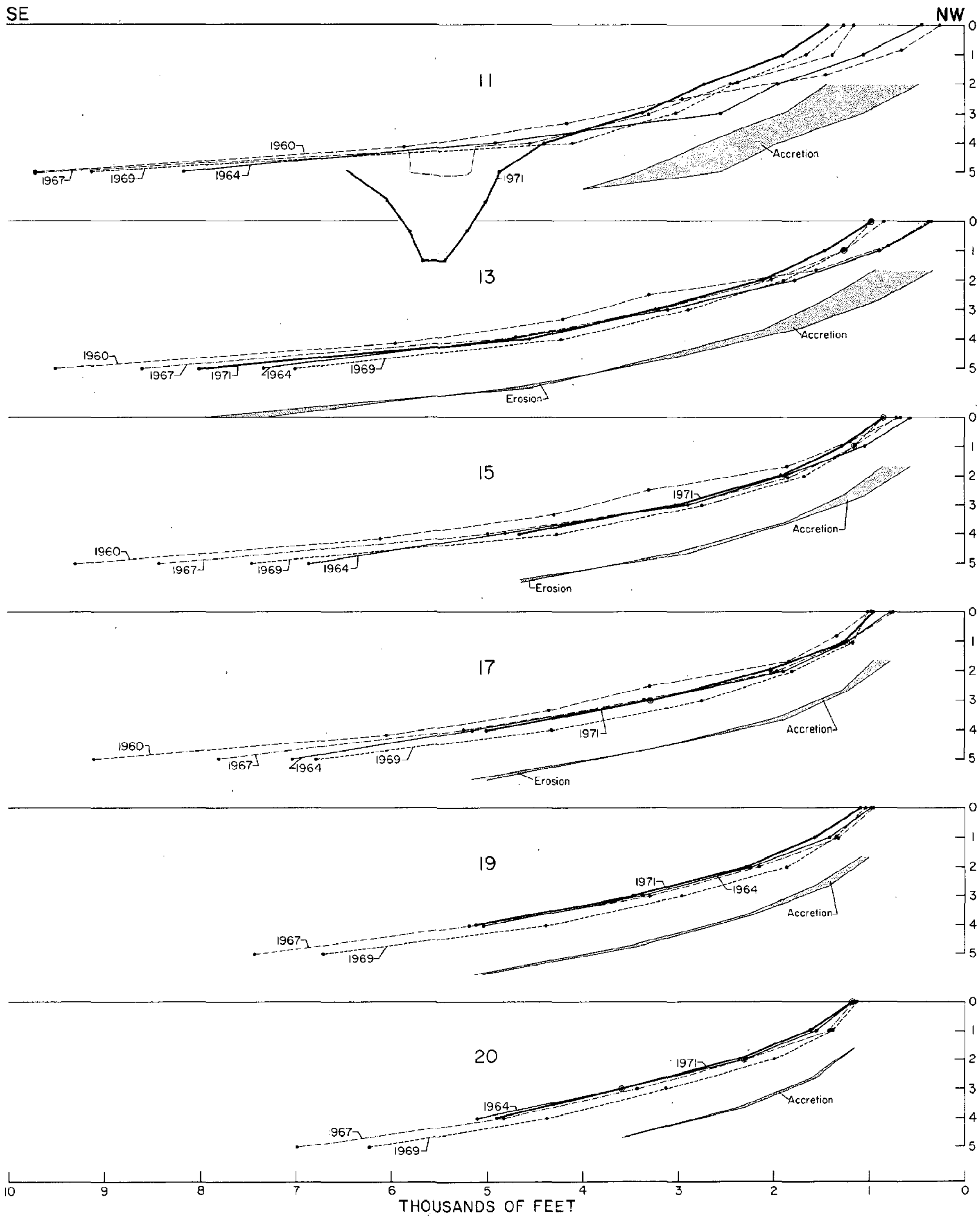


Figure 25. Shoreface profiles in the area of the north jetty, Matagorda Ship Channel. The upper set of profiles at each station includes profiles for 1960, 1964, 1967, 1969, and 1972. Accretion or erosion was determined for each profile by comparing the oldest and youngest data. See figure 24 for profile locations.

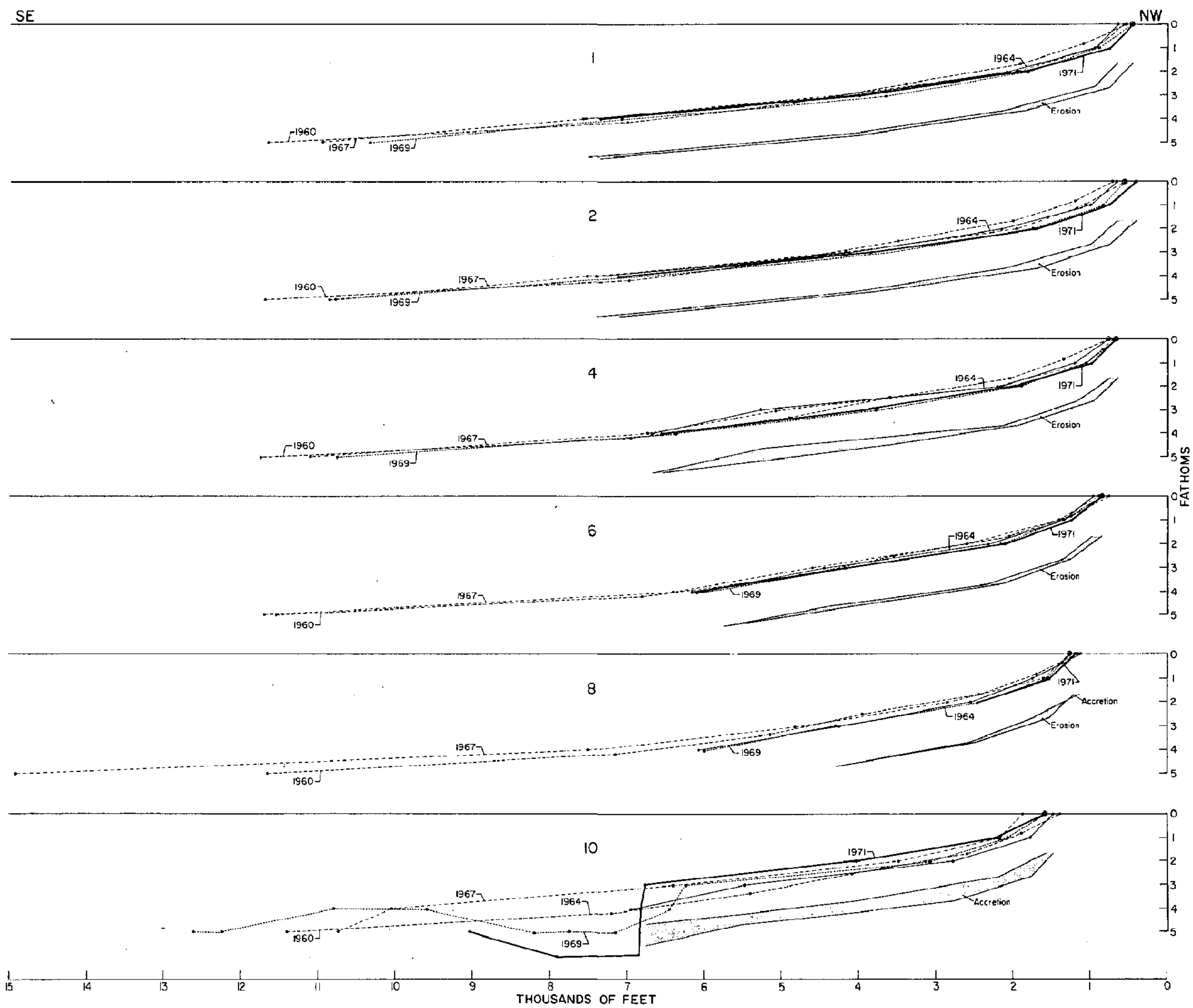


Figure 26. Shoreface profiles in the area of the south jetty, Matagorda Ship Channel. The upper set of profiles at each station includes profiles for 1960, 1964, 1967, 1969, and 1971. Accretion or erosion was determined for each profile by comparing the oldest and youngest data. See figure 24 for profile locations.

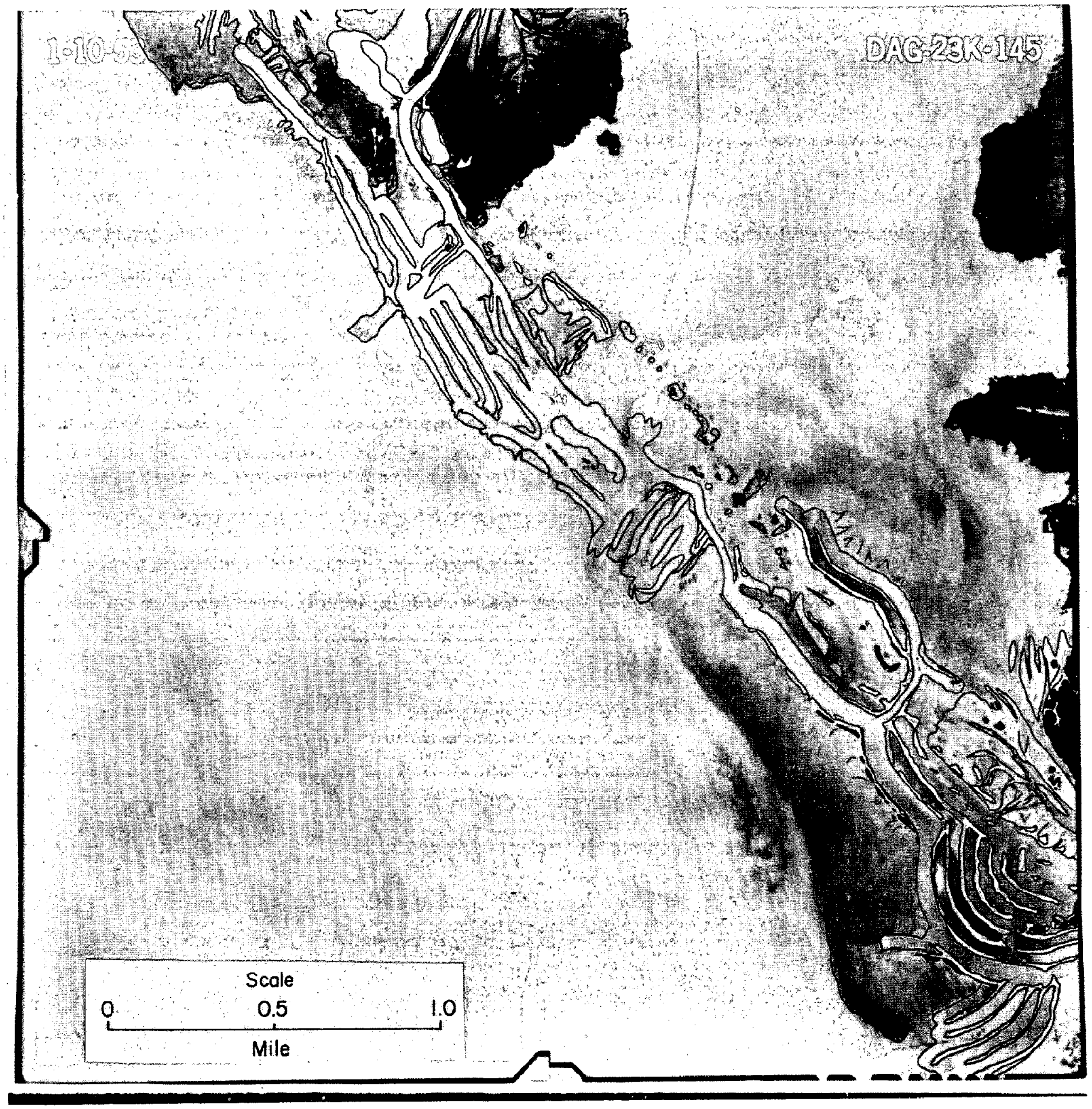


Figure 27. Dredging of Dog Island Reef for oyster shell (USDA photos, 1953). Dog Island Reef is situated west of the Colorado delta.

Shell dredging has in the past and is presently being conducted in the Matagorda Bay system. Dredging in the early 1950's destroyed Dog Island Reef (fig. 27). Dredging operations are proceeding near the north shore of Matagorda Bay in the general area between Carancahua Pass and Sand Point. The effects of shell dredging on shoreline stability are not definitely known.

In the past, Holocene and Modern beach and spit deposits were mined in the Indianola-Magnolia Beach area. Most of the mining operations were along the older Holocene deposits. A few shell pits were operated on the marsh side of Modern shell beaches. Holocene beach ridges, which are up to 10 feet high, provide protection for man-made structures during storms. Mining of shell from these ridges created gaps that can be easily breached during storms. Shell removed from Modern beaches has not destroyed these features, but continued mining could bring about serious erosional problems, particularly during hurricanes or tropical storms.

CONCLUSIONS

Historical shoreline monitoring (for the period 1856-1957) and field measurements (1971-1972) demonstrate that erosion is an important natural process along both Gulf and bay shorelines of the Matagorda Bay area. Erosion is a long-term trend. These trends were established at least 118 years ago prior to any significant modification of the coastal environment by man. Erosional shoreline trends will probably continue and may accelerate in the future as some of man's activities interrupt the normal movement of sand in the natural sediment dispersal system.

Shoreline Change

For the 100-year period of historical monitoring (1856-1957), approximately 8,450 acres of land were lost by natural erosion of Gulf and bay shorelines. During this same period, approximately 615 acres of land was gained through natural accretion. Natural accretion occurred at the mouths of Garcitas Creek and Lavaca River, along the Gulf shore of Matagorda Island near the west limit of the study area, and at ephemeral tidal passes such as Brown Cedar Cut and Greens Bayou. Since 1929, certain of man's activities have caused local accretion. Through man-induced accretion, a total of 9,600 acres has been gained at the mouth of the Colorado River, along segments of the north shore of Matagorda and Espiritu Santo Bays, and in the Port Lavaca-Point Comfort area.

Gulf shorelines have experienced the greatest amount of *erosion*. Matagorda Peninsula eroded at a rate of about 5 feet per year during the 100-year period; approximately 2,600 acres of land were lost. The shoreline along Pass Cavallo retreated at a rate of about 33 feet per year, and parts of Matagorda Island eroded at a rate of about 11 feet per year; combined land loss in these two areas was about 1,050 acres.

During the 100-year period, the bay shorelines of Matagorda Peninsula and Matagorda Island (including the bay margin of the tidal delta associated with Pass Cavallo) were in an erosional state, although there were areas of local accretion. Average rate of erosion along Matagorda Peninsula was approximately 4 feet per year; approximately 2,650 acres of land were lost. The bay shoreline of Matagorda Island retreated at an average rate of about 2.0 feet per year with a land loss of about 41 acres.

Most of the remaining shoreline segments of the Matagorda Bay system experienced erosion during the 100-year period. Shorelines of Powderhorn Lake and Carancahua Bay retreated at average rates of 0.2 and 0.7 foot per year, respectively. The west shorelines of Matagorda and Lavaca Bays eroded at about 2.6 feet per year, and the north shore of Matagorda Bay between Sand Point and Well Point eroded at an average rate of about 2.4 feet per year. Other shoreline segments retreated at rates between the maximum displayed by west Matagorda-Lavaca Bay and the minimum displayed by Powderhorn Lake and Carancahua Bay. Total land loss from these areas was approximately 2,200 acres.

Waves are the dominant erosive mechanism acting on both Gulf and bay shorelines. Prevailing southeast winds generate waves that erode south- and east-facing shoreline segments. Northers generate rather large waves which erode north- and west-facing shoreline segments. Huge waves generated by hurricanes erode both Gulf and bay shorelines. Erosion of several hundred feet of Gulf beaches, dunes, and shell ramps occurs when hurricanes such as *Carla*, 1961, make landfall in the Matagorda Bay area.

Natural *accretion* in the Matagorda Bay area was local and relatively insignificant when compared with the widespread erosion. Accretion occurred in a protected bay at the mouth of Garcitas Creek where over the 100-year period there were approximately 132 acres of land gain. Although Lavaca River is larger than Garcitas Creek, only 55 acres of new land was constructed during the same time interval; the Lavaca delta has prograded into Lavaca Bay and is subject to wave erosion.

Approximately 380 acres of land have accreted to the bayside of Matagorda Peninsula in the form of emergent segments of tidal deltas. These areas occur at the extreme eastern part of east Matagorda Bay, at Brown Cedar Cut, and at Greens Bayou. Each of these areas is representative of ephemeral tidal passes, each created when a hurricane scoured a channel through Matagorda Peninsula. Brown Cedar Cut is the only one of these passes that is presently active. Most of the sediment comprising these emergent tidal deltas was transported into the bay during hurricanes or tropical storms.

The westernmost part of the Gulf shoreline of Matagorda Island was accretionary during the 100-year period of historical monitoring; approximately 47 acres of land was added to this area. Sand that accreted this shoreline segment was derived from the erosional segments of Matagorda Peninsula, from along the west bank of Pass Cavallo, and from the northeast end of Matagorda Island; the sand was transported southwestward by longshore currents.

Large and small areas of shoreline accretion have resulted from man's activities. The largest single area, amounting to approximately 7,900 acres of new land, is the Colorado delta which prograded completely across Matagorda Bay between 1929 and 1936. The delta owes its existence to removal of a log jam which retarded water and sediment movement into Matagorda Bay. The log jam extended from the town of Matagorda up the Colorado River a distance of about 46 miles. With removal of the log jam, sediment that had been stored within the river was available for transport to the bay; rapid deltation ensued. Initial rates of shoreline accretion were about 1 mile per year.

Parts of the Gulf Intracoastal Waterway were dredged across coastal lands adjacent to the north shores of Matagorda and Espiritu Santo Bays. Sediment dredged from the canal was deposited as spoil banks upon marshes along the bay margins and within the bays. Spoil, deposited directly in the bays by the dredging process, or subsequently washed into the bays by sheetwash, has filled approximately 1,560 acres of the subaqueous bay margin. Spoil mounds and spoil outwash have created approximately 1,560 acres of new land by shoreline accretion.

Dredging of boat basins and turning basins in the Port Lavaca and Point Comfort areas created approximately 110 acres of new land.

Approximately 9,600 acres of new land accreted to bay shorelines as a result of man's activities. Or, stated differently, 9,600 acres of bay bottom have been filled by these activities.

Marsh Area Change

Marshes were historically monitored during the same time interval (1856-1957) as the monitoring of shoreline changes. Comparison of the distribution of marshes during the period from 1856-1957 indicates that there has been a decrease in wetland areas of approximately 5,000 acres (an average loss of 50 wetland acres per year). For the period 1856-59, there were approximately 46,000 acres of wetlands, and in 1956-57 there were about 41,000 acres.

Locally there was a natural increase in wetlands during the 100-year period; for example, wetlands formed at the mouths of Garcitas Creek and Lavaca River, in the Lake Austin area, and at active and inactive tidal passes through Matagorda Peninsula. Most of the wetlands experienced a loss in areal extent, and generally the magnitude of the loss increased from the heads of bays toward the barriers and peninsulas; maximum loss occurred along the bayside of Matagorda Peninsula.

Natural changes in wetland areas are brought about through shoreline erosion or accretion, and land-surface subsidence, and by burial beneath sediment and burial loss during droughts. Man-induced changes in wetland areas have occurred as a result of construction of earthen dams across marshes and tidal creeks, burial of wetlands beneath spoil or creation of new wetland areas by spoil outwash, and by changing a river regime so that there is an increase or decrease in the volume of fresh water and sediment delivered to bay-margin areas.

Approximately 5,800 acres of wetlands were lost along the bayside of Matagorda Peninsula between 1856 and 1957 (a rate of about 58 acres per year). During this time, approximately 2,650 acres of land were lost by erosion along the bayside of Matagorda Peninsula. Erosion accounts for almost half of the loss of marsh area; marsh area was reduced at a rate of about 26 acres per year through shoreline erosion. Burial beneath washover deposits, possibly in conjunction with the drought of the 1950's, accounts for about 3,150 acres of marsh reduction.

There was a decrease in marsh area from about 4,175 acres to about 2,250 acres on the Pass Cavallo tidal delta and along the bayside of Matagorda Island; this was a natural change of about 1,925 acres (19 acres per year). Approximately 475 acres of marsh were destroyed by erosion along Pass Cavallo, and approximately 1,450 acres were destroyed by burial beneath sediment and perhaps by drought conditions.

Marshes have expanded through natural processes in three general areas. There was an increase in wetland area of about 130 acres at the mouth of Garcitas Creek; this is an increase of about 1.3 acres per year. At the mouth of the Lavaca River, marsh area increased by 55 acres (about 0.5 acres per year); marshes expanded as new sediment was deposited at the river mouth. Flood-tidal deltas were constructed at the extreme east end of east Matagorda Bay, at Brown Cedar Cut, and at Greens Bayou. Emergent and intertidal segments of these deltas were the sites of marsh expansion; total marsh area related to these tidal deltas in 1957 was about 380 acres (an average increase of about 3.8 acres per year). The Lake Austin area has experienced an increase in wetland area of about 835 acres; rate of increase was about 8 acres per year. Within this area (bounded on the east by Caney Creek and extending to the northwest boundary of the Brown Cedar Cut Area map), there were some large patches of marsh which did not appear on the 1957 photomosaics; these areas were possibly destroyed by drought. Expansion of marsh in the Lake Austin area has resulted primarily from subsidence of the Brazos-Colorado delta. Subsidence in the vicinity of Lake Austin has been on the order of 0.2 to 1.0 foot during the past 3 or 4 decades (Brown and others, 1975).

Man has contributed directly to reduction of marsh area. Principal activities resulting in marsh loss were construction of dams across marshes and tidal creeks and piling of spoil in marshes adjacent to dredge channels and boat basins. A total of 1,307 acres of marsh was dammed between 1856 and 1972. These areas are (1) the Blind Bayou area between Indianola and Magnolia Beach (about 315 acres); (2) Huisache Creek (approximately 200 acres); (3) Piper Lakes (301 acres); (4) the marsh northwest of Piper Lakes (114 acres); and (5) Buttermilk Slough (379 acres). A total of 1,987 acres of marsh was destroyed when buried by dredge spoil. The three principal areas are (1) south of Oyster Lake along the north shore of Matagorda Bay (560 acres); (2) west of Port O'Connor along the north shore of Espiritu Santo Bay (1,323 acres); and (3) the Point Comfort area along the east shore of Lavaca Bay (104 acres).

Environments favorable for marsh development have also been created directly and indirectly by man's activities. The removal of some 46 miles of log jam along the lower Colorado River (between Matagorda and Wharton) changed the river regime and transported a large volume of sediment to Matagorda Bay. Rapid deltation resulted in creation of a delta plain covering an area of about 7,910 acres of which about 4,000 acres are inhabited by marsh plants. Outwash from spoil mounds created environments favorable for marsh plants. Two areas of spoil outwash along the north shore of Matagorda Bay are now inhabited by marsh plants. These areas are (1) east of the Colorado delta and south of McNabb Lake (about 316 acres); and (2) west of the Colorado delta and south of Freshwater Lake (about 267 acres).

Future Studies

The study of the Gulf and bay shorelines of the Matagorda Bay area has documented the rates and directions of shoreline changes and changes in marsh area. Field observations of coastal processes were made in the winter of 1971 and spring of 1972, and an attempt was made to explain shoreline changes in terms of these processes.

This study does not answer the question—Why are Texas Gulf and bay shorelines eroding? It does, nevertheless, suggest that a major cause is a deficit in the volume of sand being supplied to Gulf shorelines. It also suggests that, with the exception of a few local areas such as bayhead deltas, the bays have been increasing in area at least since stillstand (some 3,000 to 2,500 years before present). Bay area is increased, in part, by shoreline erosion.

Any future program intended to mitigate the effect of shoreline erosion and loss of wetlands along the Texas Gulf Coast will depend upon a thorough understanding of the sediment budget and sediment dispersal systems.

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APPENDIX A

CHANGES IN SHORELINE FOR THE PERIOD 1856-1957

Shoreline changes for the Matagorda Bay area are summarized in this appendix. Shorelines have been divided into three groups: (1) Gulf shoreline, (2) the bay shorelines of Matagorda Peninsula and Matagorda Island, and (3) mainland shoreline. Erosion or accretion associated with a particular shoreline group is shown for each map area. All three shoreline groups may occur in some map areas, whereas only one shoreline group may occur in other map areas.

Map areas are referred to by number in the following table: (1) Brown Cedar Cut Area, (2) Colorado River Area, (3) Shell Island Reef Area, (4) Pass Cavallo Area, (5) Lavaca Bay South Area, (6) Lavaca Bay North Area, (7) Carancahua Bay Area, and (8) Tres Palacios Bay Area.

Map Area	Gulf Shoreline			Bay Shoreline, Barriers, and Peninsulas			Mainland Shoreline		
	Erosion	Accretion	Net Loss or Gain	Erosion	Accretion	Net Loss or Gain	Erosion	Accretion	Net Loss or Gain
1	-1,574.87	——	-1,574.87	- 297.51	+424.29	+ 126.78	- 546.37	+ 44.99	- 501.38
2	- 256.19	+ 11.02	- 245.17	- 585.56	+ 53.53	- 532.03	- 21.11	+8,674.98	+8,653.87
3	- 651.98	+121.21	- 530.77	-1,998.99	+191.75	-1,807.24	- 83.55	+1,179.28	+1,095.73
4	-1,118.44	+ 59.68	-1,058.76	- 328.74	+294.76	- 33.98	- 1,056.93	+ 894.37	- 162.56
5							- 649.33	+ 261 7	- 387.63
6							- 498.66	+ 513.0	+ 14.34
7							- 777.29	+ 197.43	- 579.86
8							- 634.62	+ 363.65	- 270.97

For the period 1856-1957, there was a loss of 3,409.57 acres of land along the Gulf shoreline of Matagorda Peninsula and Matagorda Island.

For the period 1856-1957, there was a loss of 2,246.47 acres of land along the bay shore of Matagorda Peninsula and Matagorda Island.

When the Colorado delta is included in shoreline change, there has been 7,861.54 acres of land accreted to mainland shorelines. If the Colorado delta is excluded, then there has been a loss of 138.45 acres of land along the mainland shoreline.

APPENDIX B

CHANGES IN MARSH AREA FOR THE PERIOD 1856-1957

Areas of marsh expansion or diminution are summarized in this appendix. Marshes on the Brown Cedar Cut, Colorado River, Shell Island Reef, and Pass Cavallo area maps have been divided into two groups based upon (1) whether they occur on the bayside of Matagorda Peninsula and Matagorda Island, or (2) whether they are associated with the Pass Cavallo flood-tidal delta, or (3) whether they are situated along the mainland shoreline. Marsh associated with the Colorado delta developed since 1930 and is considered as a separate category.

BROWN CEDAR CUT AREA (1)

Matagorda Peninsula (Caney Creek to west limit of the map)
1856 marsh—2,031.74 acres
1957 marsh—1,404.83 acres
Marsh on Matagorda Peninsula was larger in 1856 than in 1957. Loss in area was 626.91 acres for the 100-year period. Loss in marsh area resulted from erosion along the bay margin, and burial of marsh by washover deposits. Marsh area along the mainland increased during 1856-1957 by about 835.12 acres. This area is representative of delta plain and mudflats associated with the Holocene Brazos-Colorado delta prior to construction of Matagorda Peninsula. Marsh area is expanding as the area is undergoing subsidence and is also experiencing a rise in sea level.

COLORADO RIVER AREA (2)

Matagorda Peninsula
1856 marsh—4,752.18 acres
1957 marsh—2,795.94 acres
Mainland (east boundary of the map to Colorado delta plain)
1856 marsh—5,193.76 acres
1957 marsh—2,951.52 acres
Colorado Delta Plain
Marsh in this area developed since 1930—3,628.77 acres
Causes of loss of marsh area on Matagorda Peninsula amounting to 1,956.24 acres are the same as for Map Area 1.

Between 1856-1957, there was a loss of marsh on the mainland of about 2,242.24 acres. Two natural processes and one man-made structure effected reduction in marsh area. Slopewash along some of the Pleistocene cliffs and transportation of this material to marshes reduced marsh area. Vertical accretion and progradation of the Colorado delta reduced marsh area, particularly to the west of the town of Matagorda. Dredging of the Intracoastal Waterway reduced marsh area by burial of marsh with spoil. Since 1930, 3,628.77 acres of new marsh developed on the Colorado delta plain. This marsh was indirectly created by man's activities (a log jam was removed in late 1929-early 1930).

SHELL ISLAND REEF AREA (3)

Matagorda Peninsula
1856 marsh—4,255.68 acres
1957 marsh—926.64 acres
Mainland
1856 marsh—2,738.74 acres
1957 marsh—2,100.38 acres

There was a decrease of 3,329.04 acres of marsh on Matagorda Peninsula for the period 1856-1957. Causes of decreases are the same as for Map Area 1. For the same period (1856-1957), there was a loss of 638.36 acres of marsh along the mainland shoreline. Change in area resulted from slopewash and dredging of the Intracoastal Waterway.

PASS CAVALLO AREA (4)

Matagorda Peninsula
Only 1856 marsh recorded—251.68 acres
Matagorda Island
1856 marsh—205.92 acres
1957 marsh—18.30 acres
Flood Tidal Delta
1856 marsh—4,173.31 acres
1957 marsh—2,244.53 acres
Mainland (includes Espiritu Santo and Matagorda Bay shorelines)
1856 marsh—1,671.38 acres
1957 marsh—800.8 acres

Matagorda Peninsula had virtually no marsh for the period 1957. There was a loss of 251.68 acres of marsh between 1856 and 1957. Matagorda Island (this includes the island proper, which is the area lying to the south of a line through Fish Pond and Lighthouse Cove). There has been a decrease in marsh area amounting to 187.62 acres for the 100-year period. Some of the loss is attributed to filling of swales on the island (this is fresh-water marsh) and part to erosion along the bay margin.

Flood-tidal delta (from the Fish Pond-Lighthouse Cove area northward to the Barroom Bay area). There was a loss of marsh for the period 1856-1957 of about 1,928.78 acres. Two factors, both natural, appear to be the cause of change in marsh area. First, erosion along the right bank of Pass Cavallo removed considerable marsh. Secondly, deposition on the marsh islands covered a large part of the marsh and raised the surface of the islands sufficiently to prevent inundation by tides.

Mainland marsh shows a decrease in area amounting to 870.58 acres for the 100-year period. Marsh has been lost through the natural process of erosion and through man's activities. Man's activities, dredging of the Intracoastal Waterway, resulted in burial of marsh by spoil and by creation of a barrier (spoil mounds) between marsh and the bay.

LAVACA BAY SOUTH AREA (5)

Mainland shoreline
1856 marsh—3,759.18 acres
1957 marsh—4,164.16 acres

For the 100-year period, there has been an increase in marsh area of approximately 404.98 acres. Most of this gain has been in the area of Powderhorn Lake and in the area lying between Powderhorn Bayou and Indian Point. Powerhorn Lake area was not completely mapped in 1856. New marsh areas were created between Powderhorn Bayou and Indian Point by partial filling of shallow water bodies with sediment during storms and by spit accretion.

LAVACA BAY NORTH AREA (6)

Change in marsh area for the period 1856-1957 is not accurate for this area because mapping in 1856 was incomplete along Chocolate Bayou, Placedo Creek, Agula Creek, and the Lavaca delta.
1856 marsh—3,134.56 acres
1957 marsh—4,296.86 acres

According to the calculations of acreages for the two vintages of marsh, there has been a net gain of about 1,162 acres. Accretion of 137.73 acres occurred on the Garcitas delta; this is new marsh land. Accretion of 95.51 acres occurred at the mouth of the Lavaca River; this is new marsh land. At Noble Point, 127.64 acres of marsh have been lost by erosion during the period 1856-1957.

CARANCAHUA BAY AREA (7)

Complete data are not available for this map since 1856 marsh mapping did not extend up Keller Creek and Carancahua Creek.
1856 marsh—3,310.74 acres
1957 marsh—4,239.66 acres

There was an increase of 928.92 acres in marsh area for the period 1856-1957.

TRES PALACIOS BAY AREA (8)

With exception of the small delta at the head of Tres Palacios Bay, the 1856 marsh mapping was complete.
1856 marsh—3,793.50 acres
1957 marsh—3,539.54 acres

There has been a decrease in marsh area for the 100-year period amounting to approximately 253.96 acres (the loss would be even more if the 1957 marsh at the head of Tres Palacios Bay were not included in the calculations). Most of the 1856 marsh south of Palacios and east of Turtle Point has been removed. At Turtle Point, the marsh was destroyed by dredging shell from the Turtle Point spit. East of Turtle Point, much of the 1856 marsh was at least 5 feet above bay water level; most of this was probably fresh-water marsh.

Summary

During the mid 1800's, there was a large area of salt marsh on the bay side of Matagorda Peninsula and on the flood-tidal delta associated with Pass Cavallo. Total area of the 1856 salt marsh was 15,670.51 acres. In 1957, the salt marsh acreage was only 7,390.24. There was a decrease in marsh area amounting to approximately 8,280.27 acres (a reduction in area of about 53 percent).

Total marsh area for the mainland shoreline in 1856-1859 amounted to 30,600.85 acres. Total marsh area for the mainland shoreline 1956-1957 amounted to 29,927.03 acres. There was a loss in marsh area for the 100-year interval of approximately 673.82 acres (or a reduction in area of only 2 percent).

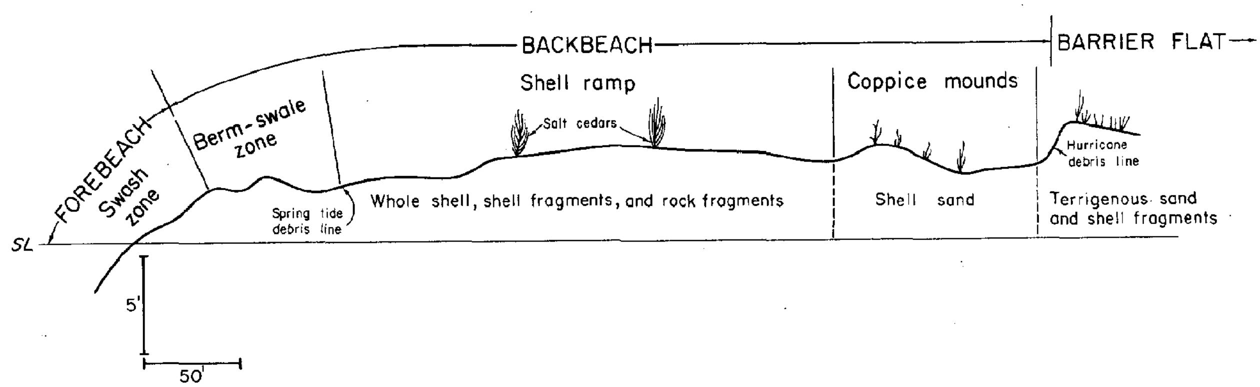
Several areas of marsh were not mapped in 1856. Marsh areas mapped on the 1956-1957 photos but not on 1856-1859 charts are: (1) along Placedo Creek—648.27 acres; (2) along Garcitas Creek—549.88 acres; (3) along Keller Creek—97.62 acres; (4) at the head of Carancahua Bay—551.41 acres; and (5) at the head of Tres Palacios Bay—453.02 acres. This is a total of 2,302.18 acres. In order for the 1856 and 1957 comparison of marsh areas to be valid, the above marsh areas must be deleted from the 1956-1957 marsh area calculations. The new value is 27,624.85 acres. Using this value, there was a loss of approximately 2,976 acres of marsh for the period 1856-1957. Reduction in marsh acreage results primarily from natural causes.

Several marsh areas have been dammed in order to create fresh- to brackish-water ponds. Salt marsh areas that have been dammed are: (1) Blind Bayou area—312.69 acres; (2) northwest of Carancahua Pass and northeast and across the bay from Port Alto—75.5 acres; (3) Piper Lakes area—237.95 acres; and (4) Buttermilk Slough—379.04 acres. This is a total of 1,005.18 acres. Total marsh area lost by natural processes and man's activities is 3,981.18 acres. Man's activities are responsible for at least 25 percent of the reduction in marsh area.

APPENDIX C

CHARACTERISTIC PROFILES OF GULF AND MAINLAND SHORELINE FEATURES

Details of Gulf and mainland shorelines are exhibited by the following 21 profiles. The profile numbers correspond to those shown on figure 11. Characteristics of the five shoreline types, as shown on figure 10, are depicted by these representative profiles.



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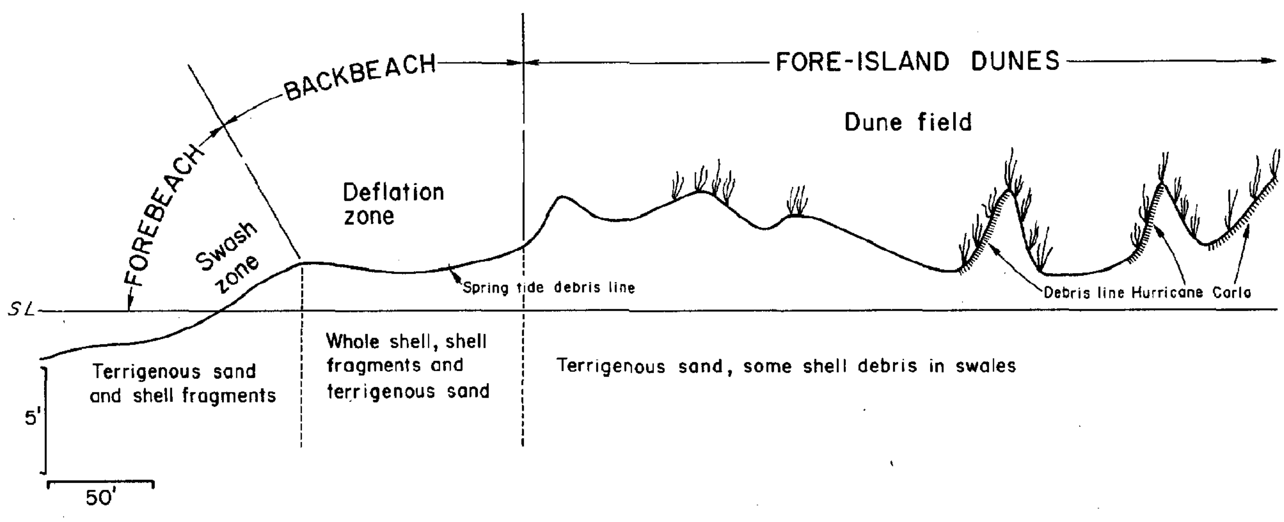

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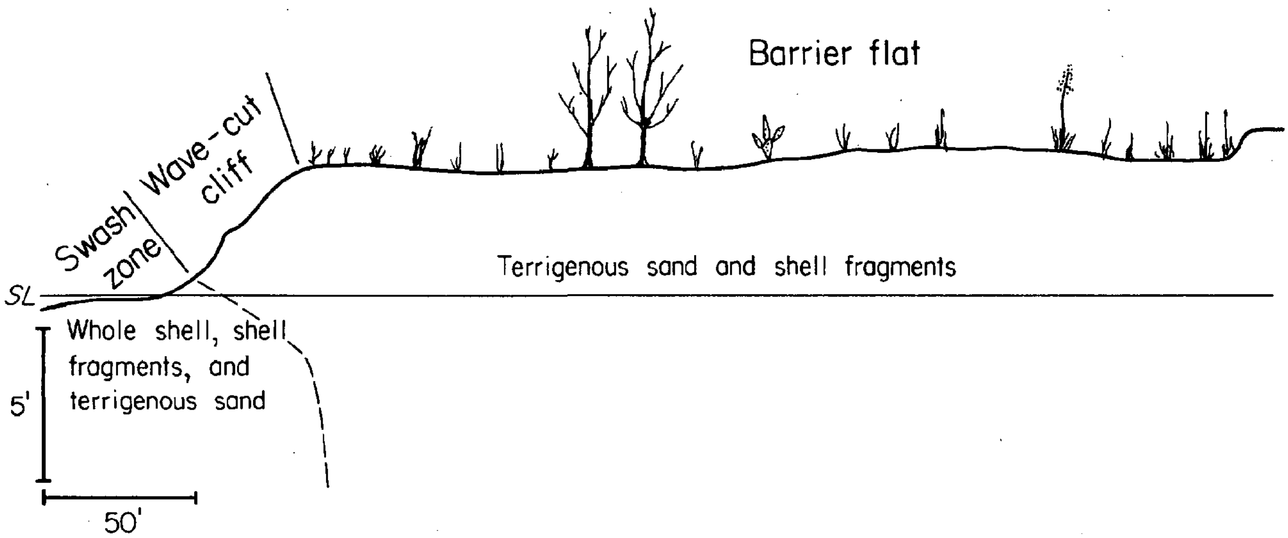

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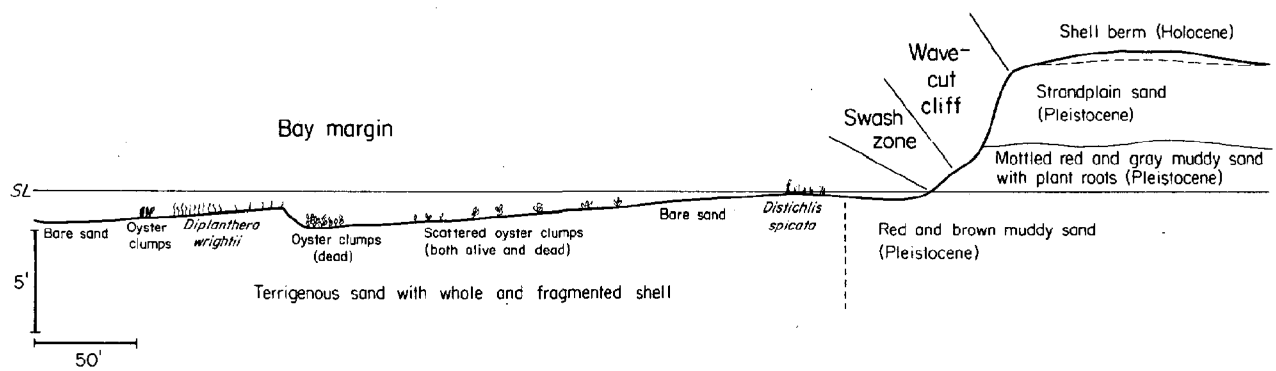

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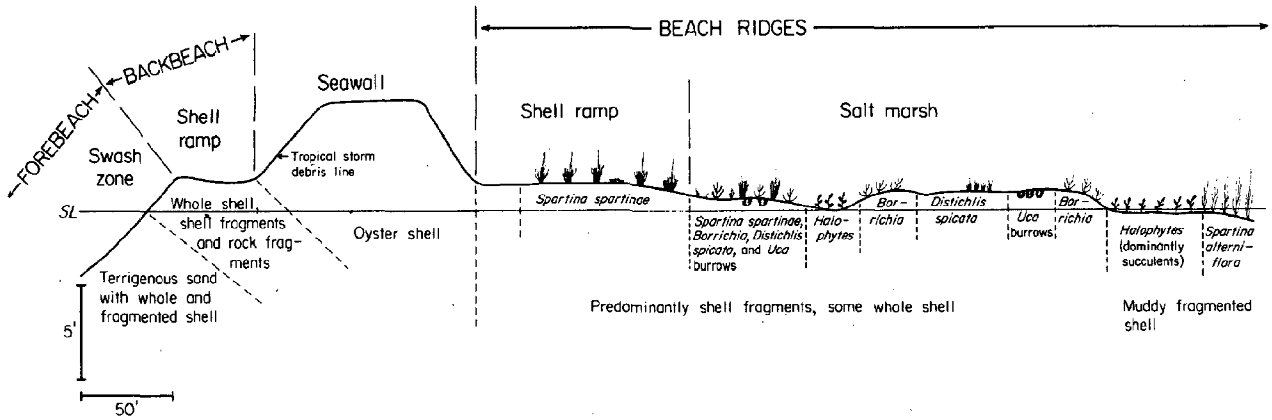

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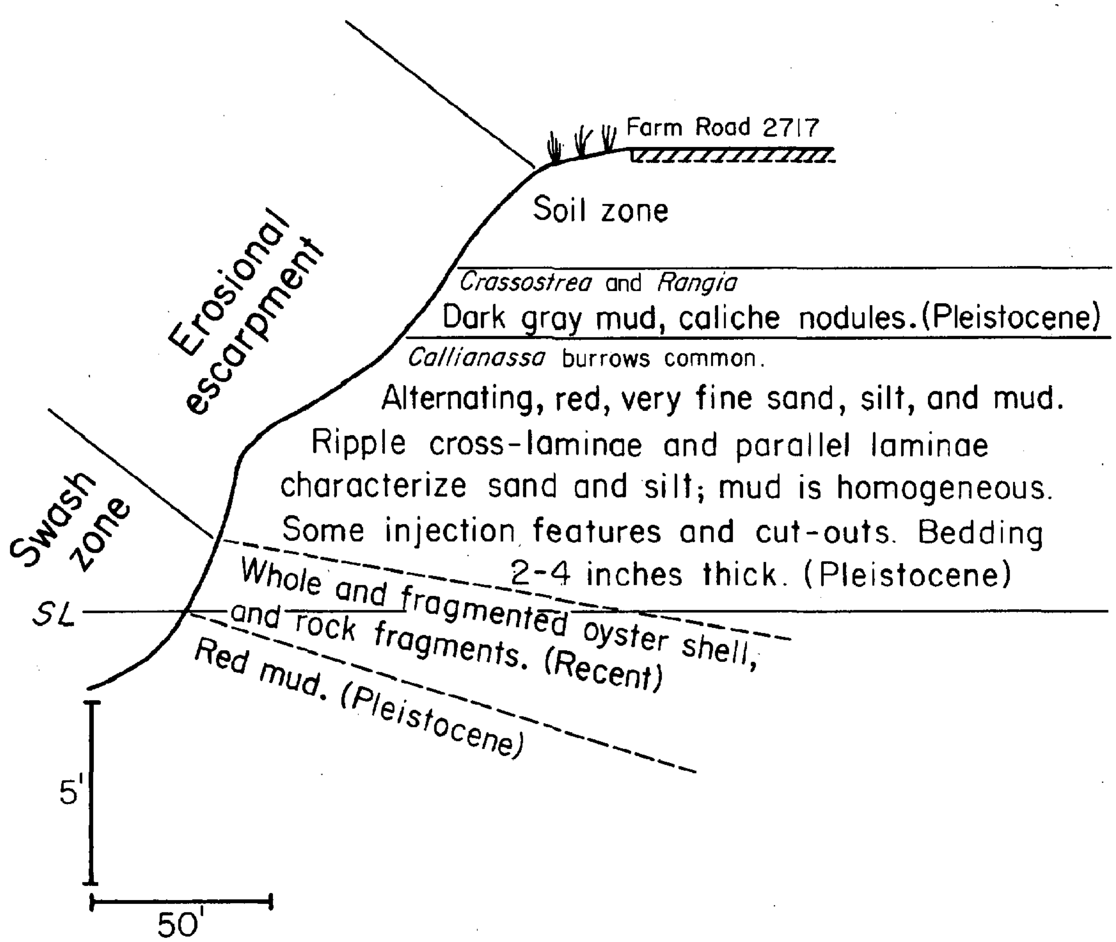

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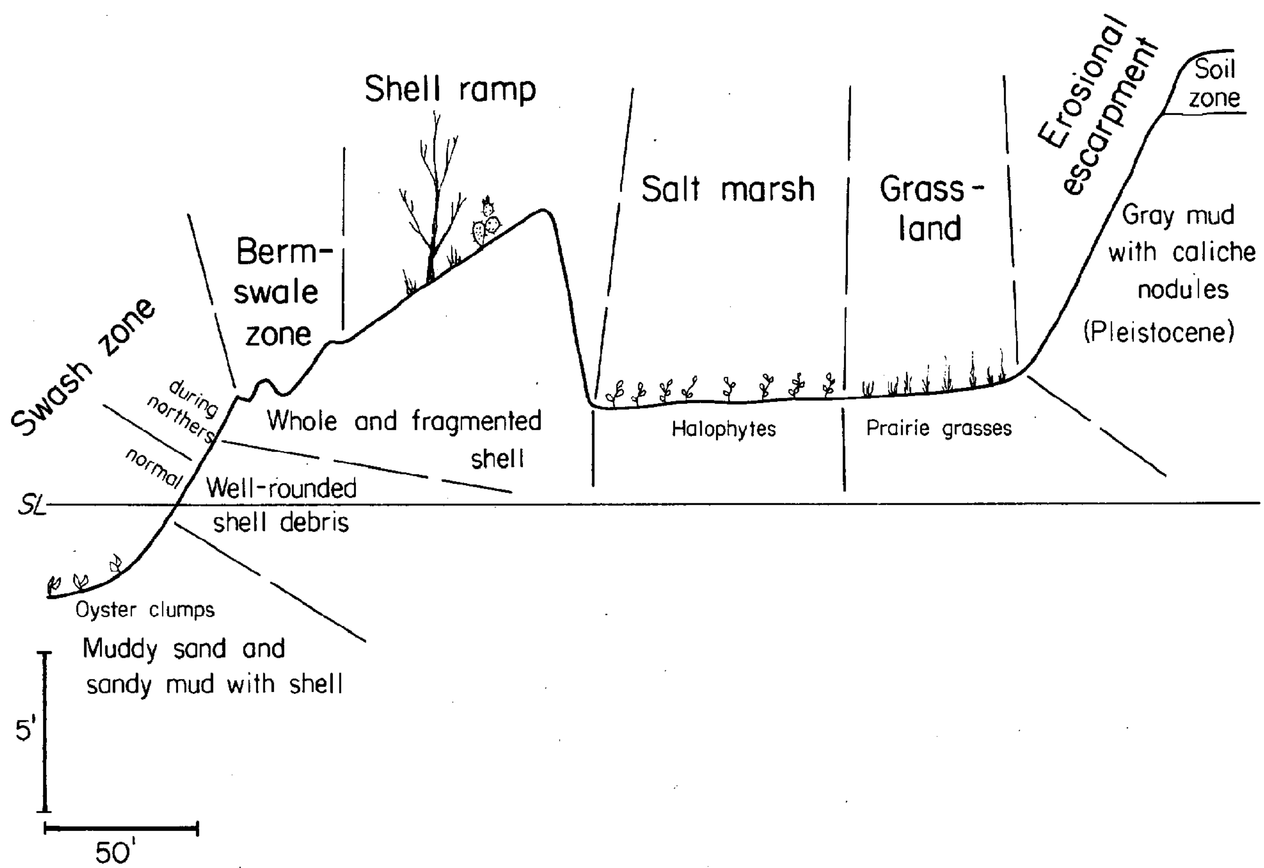
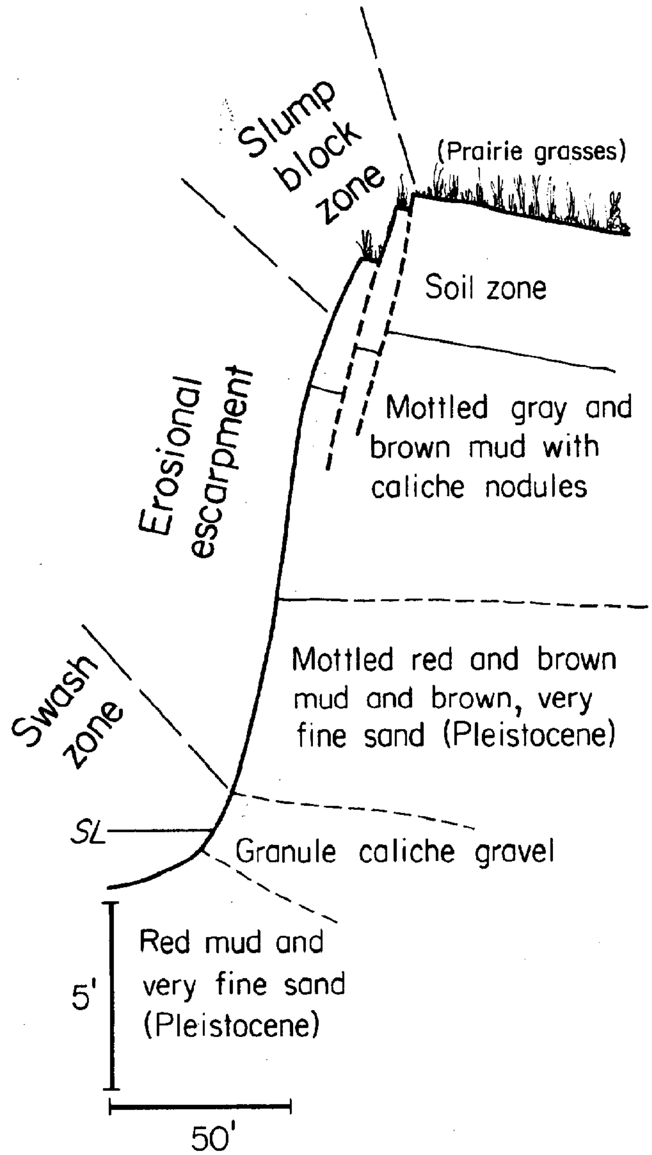
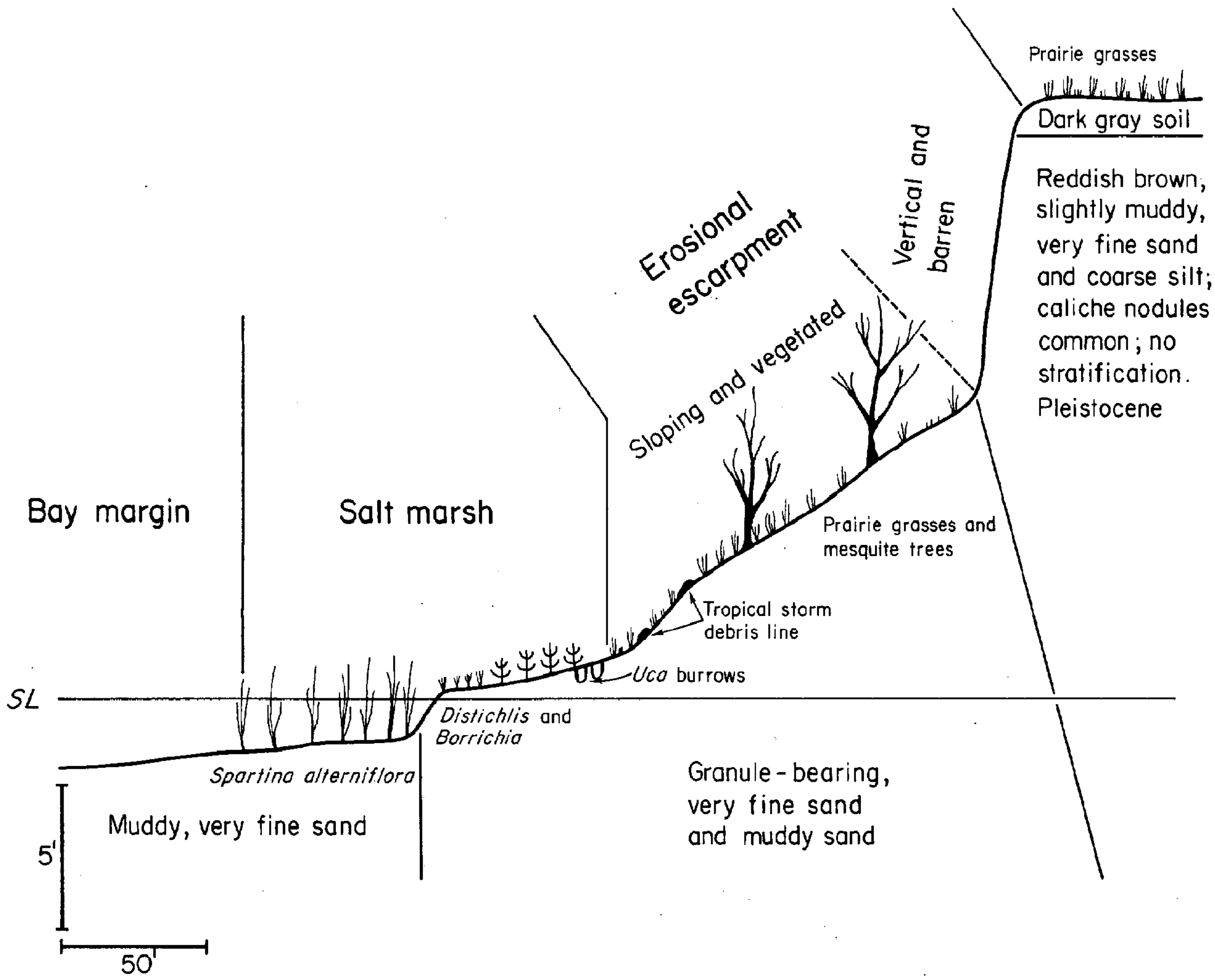

Shell ramp
Salt marsh
Grass-
land
Erosional
escarpment
Soil
zone
Berm-
swale
zone
Swash zone
during
northers
normal
Whole and fragmented
shell
Halophytes
Prairie grasses
Gray mud
with caliche
nodules
(Pleistocene)
SL
Well-rounded
shell debris
Oyster clumps
Muddy sand and
sandy mud with shell
5'
50'

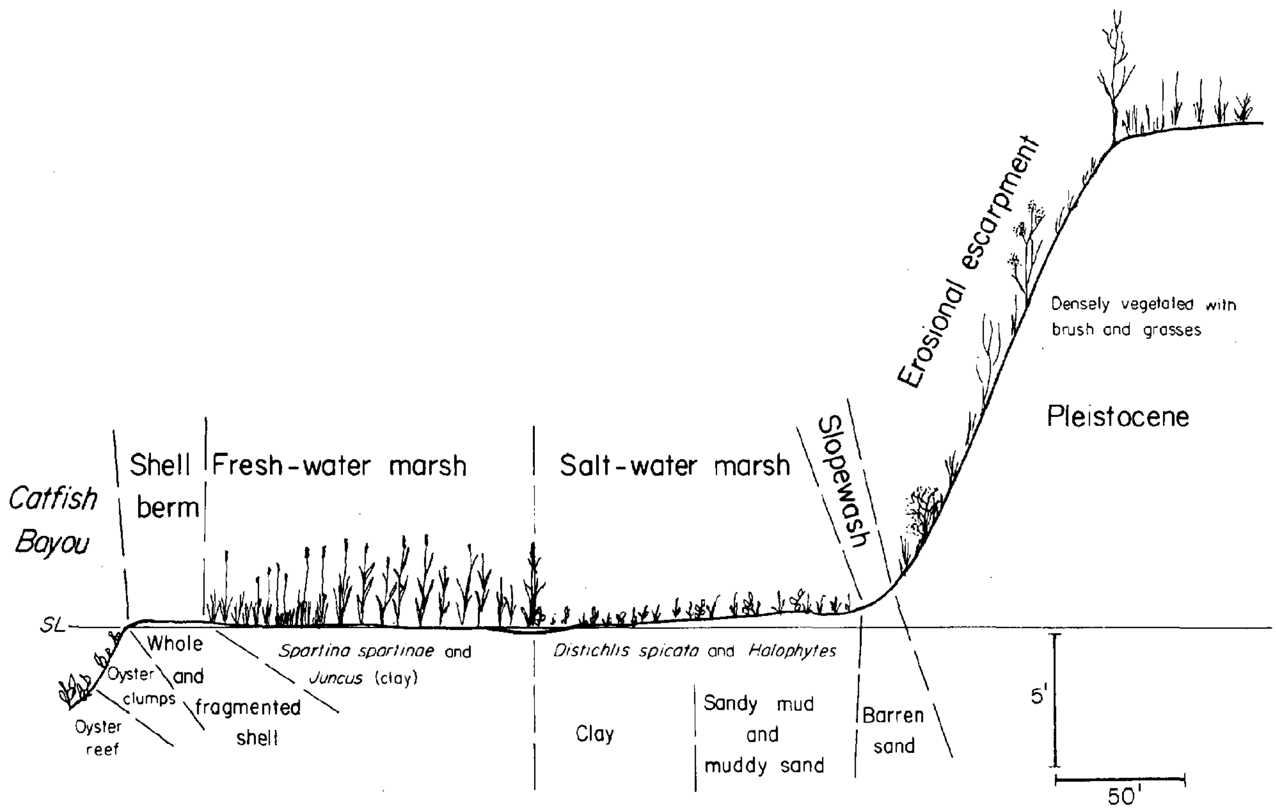
Profile 48


Slump block zone
(Prairie grasses)
Soil zone
Erosional escarpment
Mottled gray and brown mud with caliche nodules
Mottled red and brown mud and brown, very fine sand (Pleistocene)
Swash zone
SL
Granule caliche gravel
Red mud and very fine sand (Pleistocene)
5'
50'

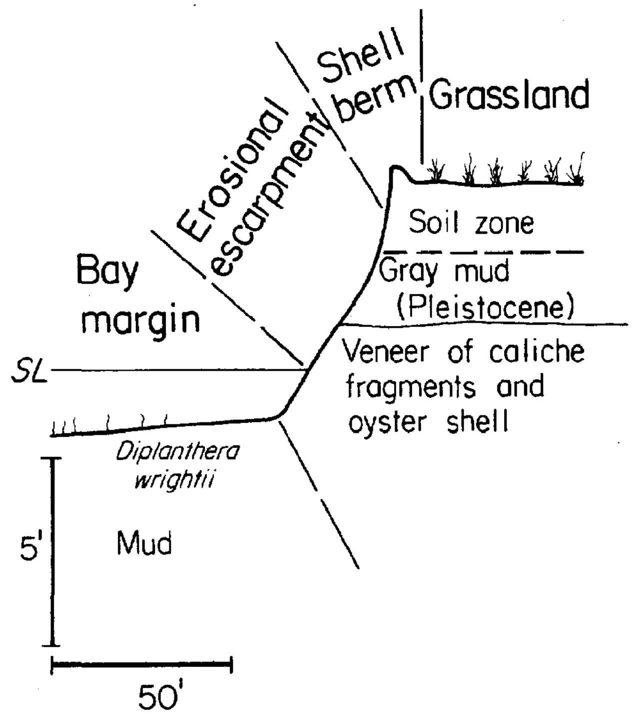
Profile 51


Prairie grasses
Dark gray soil
Reddish brown, slightly muddy, very fine sand and coarse silt; caliche nodules common; no stratification. Pleistocene
Vertical and barren
Erosional escarpment
Sloping and vegetated
Bay margin
Salt marsh
Prairie grasses and mesquite trees
Tropical storm debris line
Uca burrows
SL
Distichlis and Borrichia
Spartina alterniflora
Muddy, very fine sand
Granule-bearing, very fine sand and muddy sand
5'
50'

Profile 52


Catfish Bayou
Shell berm
Fresh-water marsh
Salt-water marsh
Slopewash
Erosional escarpment
Densely vegetated with brush and grasses
Pleistocene
SL
Oyster reef
Oyster clumps
Whole and fragmented shell
Spartina spartinae and Juncus (clay)
Distichlis spicata and Halophytes
Clay
Sandy mud and muddy sand
Barren sand
5'
50'

Profile 54



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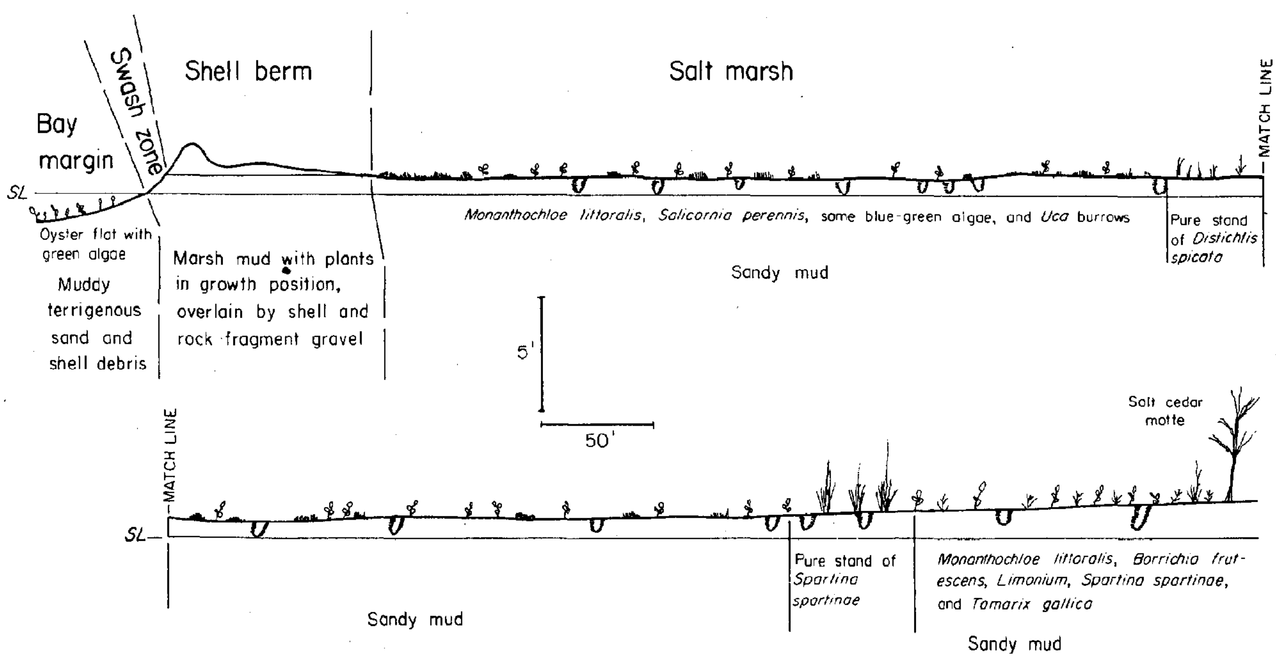

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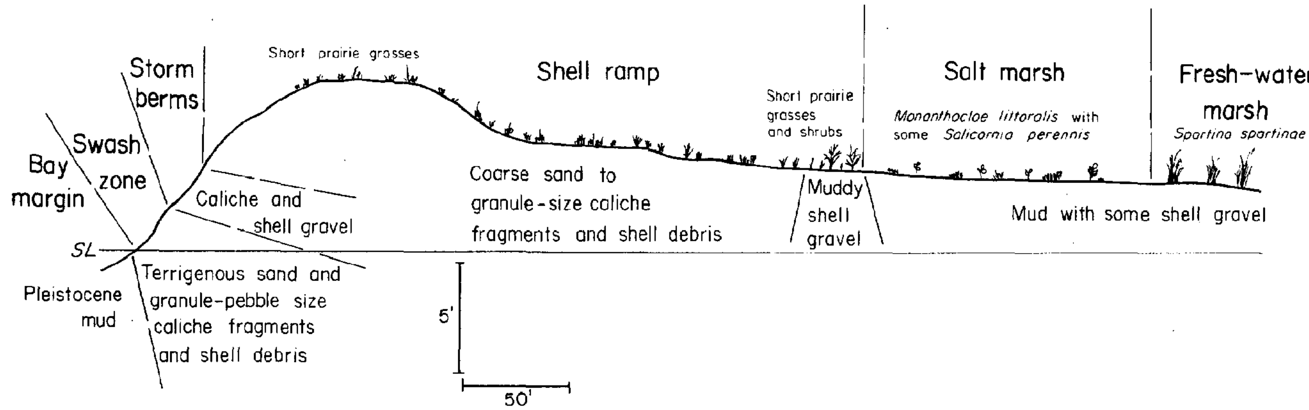

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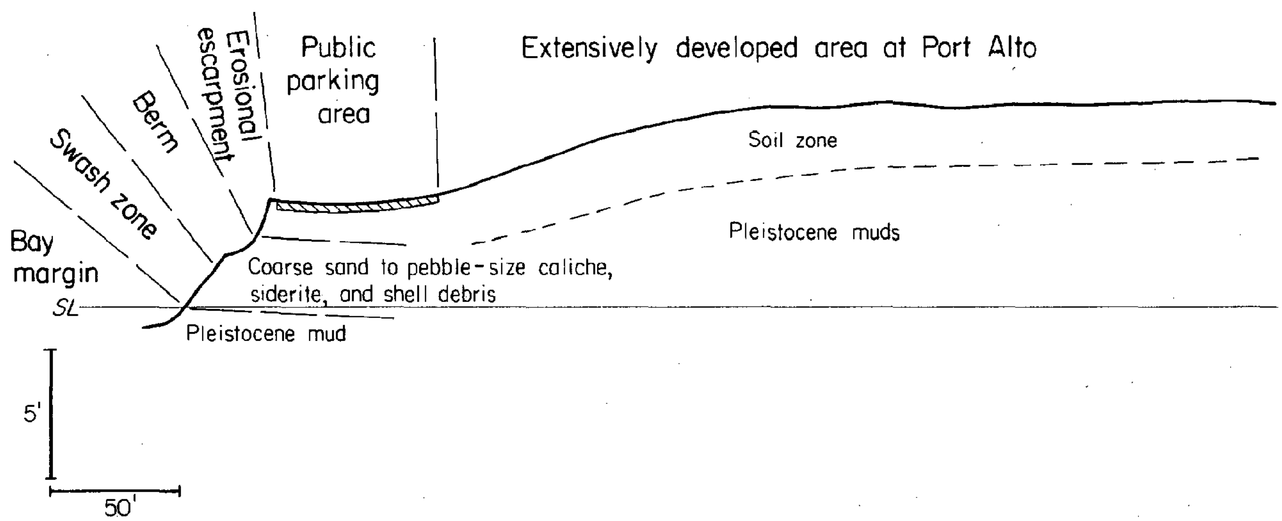

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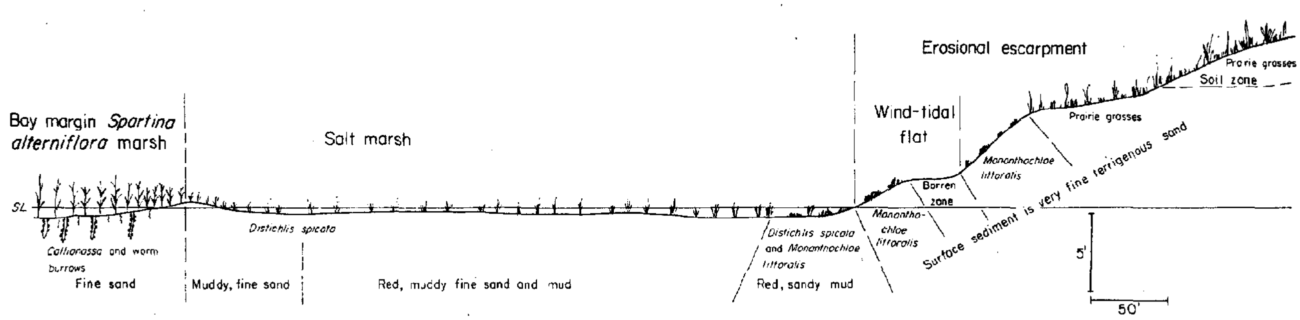

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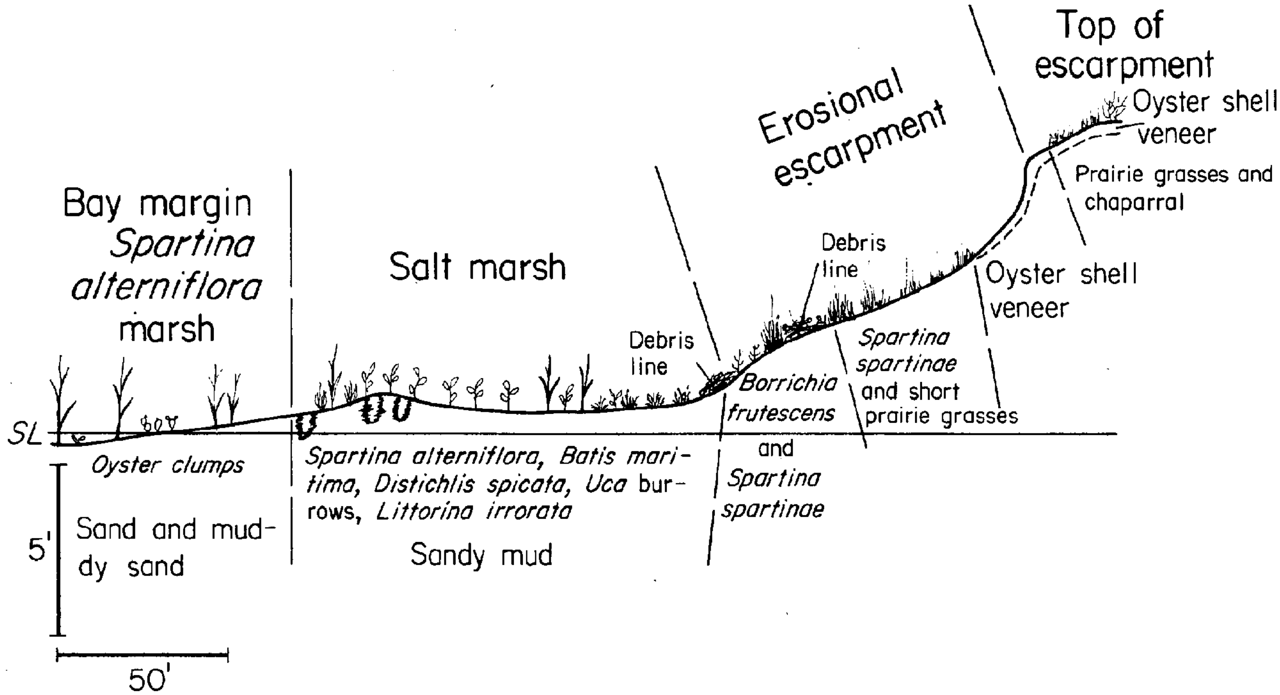

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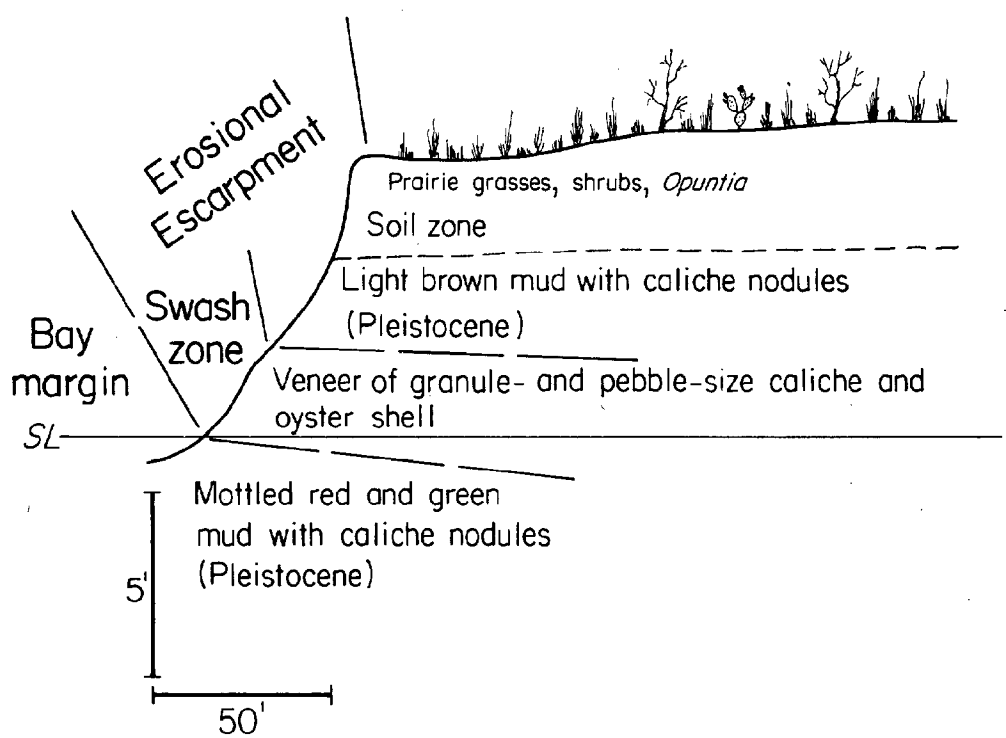

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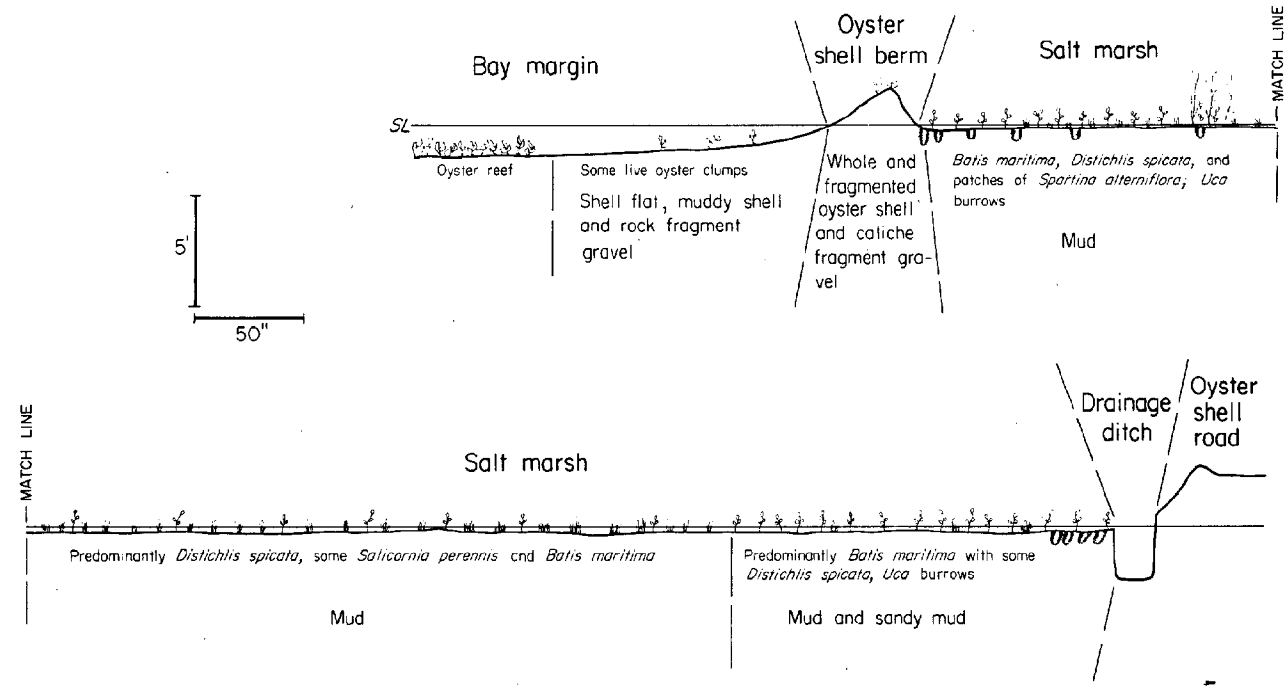

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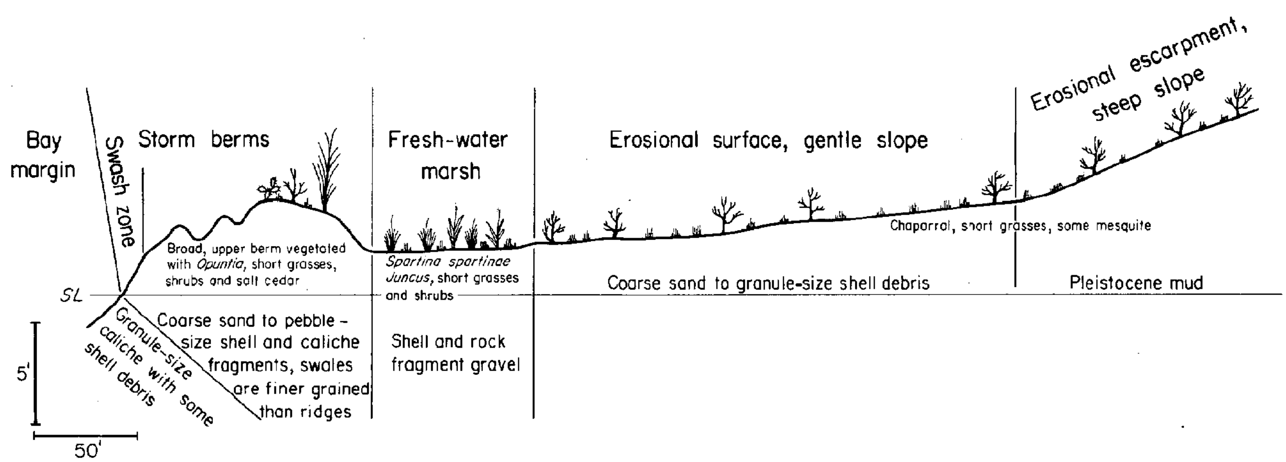

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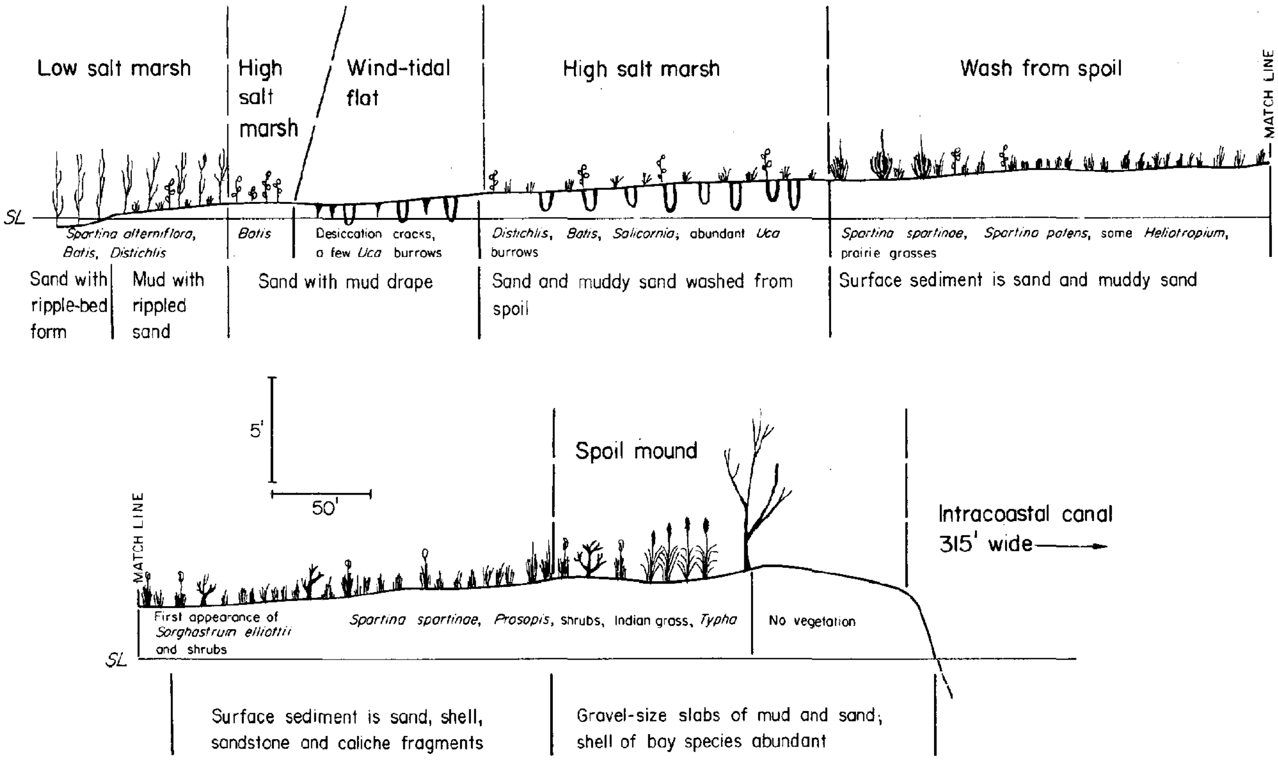

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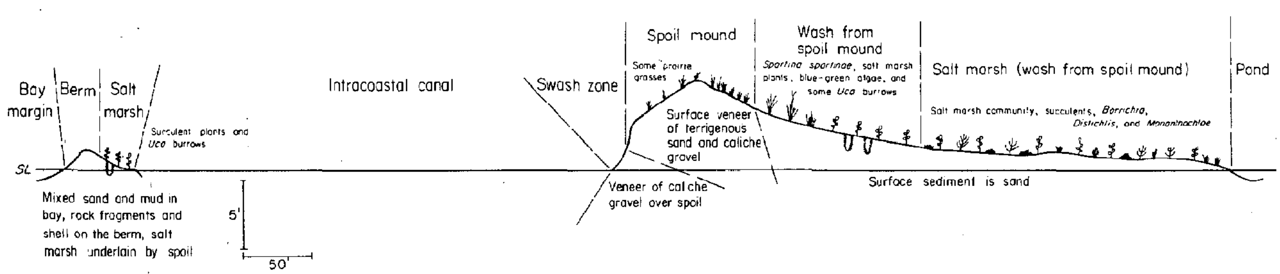

Profile 76

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