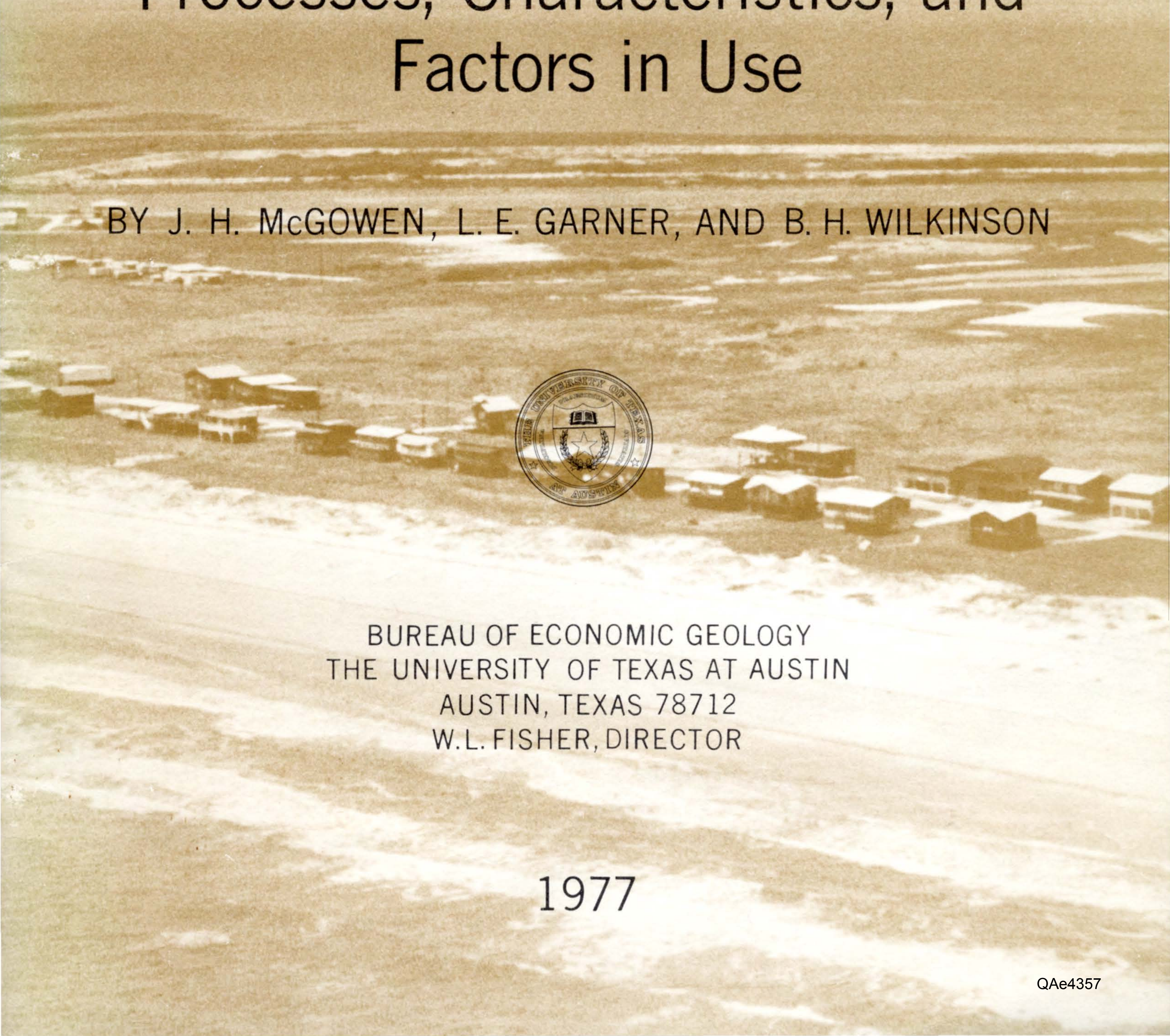
GEOLOGICAL CIRCULAR 77-3

THE GULF SHORELINE OF TEXAS: Processes, Characteristics, and Factors in Use



BY J. H. McGOWEN, L. E. GARNER, AND B. H. WILKINSON

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THE GULF SHORELINE OF TEXAS: PROCESSES, CHARACTERISTICS, AND FACTORS IN USE

by

J. H. McGowen, L. E. Garner, and B. H. Wilkinson

ABSTRACT

The State of Texas has about 367 miles of open Gulf shoreline, most of it typified by rather broad, sandy beaches and a comparatively mild climate that permits almost year-round use of this recreational resource. All but about 87 miles of the Gulf beach is accessible to the general public.

During the past 10 years or so, the Texas Gulf shoreline has experienced unprecedented development. Much of this development proceeded without proper consideration of the geomorphological features that constitute the Texas Gulf shoreline, the permanence or stability of these features, and the coastal processes that molded or that are presently modifying these features. Shoreline features that make up the Texas Gulf shoreline are erosional deltaic headlands (for example, the area between Sabine Pass and Rollover Pass), peninsulas, barrier islands, and one Modern delta (Brazos delta). Each of these major groups of features differs with respect to origin, history of development, and composition and size of materials. Most of the headlands, peninsulas, and barrier islands are being eroded. Approximately 60 percent of the shoreline is undergoing erosion.

Erosion is generally rapid along peninsulas and the erosional deltaic headlands (between Sabine Pass and Rollover Pass, San Luis Pass and Brown Cedar Cut, and from Brazos Santiago Pass to the mouth of the Rio Grande); it is less rapid along barrier islands. Deltaic headlands and peninsulas erode rapidly because waves commonly approach them at a high angle, thereby setting up longshore currents which transport sand-sized material away from the area. In addition, sand deposits associated with or which compose these features are commonly thin, a factor which promotes erosion. The beach and shoreface of barrier islands that lie in the vicinity of latitude 27° North are relatively stable because this is a zone of net longshore drift convergence; shorelines in this region will accrete slightly or remain in equilibrium for some time if barriers to longshore sediment transport are not erected to the north or south.

Shoreline stability is a factor that should be considered prior to developing any segment of the Texas Gulf shoreline. Other factors equally important include width of a particular shoreline feature, density of vegetation, presence or absence of fore-island dunes, and number and size of storm channels that transect the barriers, peninsulas, or deltaic headlands. Width of a particular shoreline feature is in part a function of sand availability; examples of broad shoreline features are barrier islands such as Galveston and Matagorda Islands. Man-made structures (motels, family dwellings, etc.) are relatively protected from hurricane wind and storm surge if they are situated on broad barrier islands behind fore-island dunes. Similar structures may be severely damaged or destroyed if placed on erosional deltaic headlands or on the narrow, low-profile peninsulas.

A variety of Gulf shoreline features exist along the Texas coast. Variability results from such factors as Pleistocene depositional and erosional history, sand availability, climatic conditions, density of vegetation, direction of wave approach, and direction of longshore sediment transport. Superimposed upon the natural setting are man's activities that tend to tip the balance toward disequilibrium. When man begins altering the coastal setting, the very processes which have interacted over the past 3,000 years or so to construct the Gulf shoreline features become agents of destruction.

INTRODUCTION

Development of Geomorphic Units

Texas Gulf shoreline is a complex of numerous geomorphic elements: erosional deltaic headlands, peninsulas, barrier islands, and one active delta being constructed by the Brazos River. There is a close relationship between Pleistocene depositional and erosional features and the distribution of modern coastal geomorphic features (McGowen and Garner, 1972; McGowen and others, 1972). Wisconsin strandplain sand bodies and Wisconsin deltaic deposits had a pronounced influence on the development of the present geomorphic elements of the Texas Gulf coast.

In addition to Pleistocene depositional features, erosion resulting from a sea-level drop during the Wisconsin glacial stage also affected development of the present shoreline. Deep valleys were scoured by the major Texas streams as sea level dropped between 350 and 400 feet during the Wisconsin. During the Holocene sea-level rise, stream valleys were flooded; most of the bays and estuaries along the Texas Gulf coast are representative of drowned valleys.

When sea level reached approximately its present position, the shoreline was very irregular, characterized by drowned valleys (estuaries), divides, and incipient barrier islands. All wide barrier islands on the Texas Gulf coast formed on divides capped by Pleistocene strandplain sands (parts of Galveston, Matagorda, St. Joseph, Mustang, and northern Padre Islands).

Drowned valleys served to trap all of the bedload material either in point bars, distributary channels, or channel-mouth bars associated with bayhead deltas. Wash load was deposited both within the bays and estuaries and on the continental shelf. Major Texas streams did not contribute sand to the longshore drift system for the development and maintenance of barrier islands until they had filled their estuaries. Therefore, features such as south Padre Island and Matagorda Peninsula are younger than, have origins different from, and have depositional histories different from the previously mentioned barrier islands. South Padre Island and Matagorda Peninsula are spits which accreted in a direction down longshore drift from the Holocene Brazos-Colorado and Rio Grande deltas, respectively (Lohse, 1962; McGowen and others, 1976a).

The smaller streams and some relatively large streams that have a high suspension load/bedload ratio have not filled their estuaries. These streams are slowly filling their respective drowned valleys by progradation of bayhead deltas and by deposition of suspension load within the bays.

All major tidal inlets of the Texas coastal area were initially positioned along or near the right banks of drowned river valleys. Examples of major tidal passes are Bolivar Roads, Pass Cavallo, and Corpus Christi Channel (now closed). These passes migrated toward the southern limits of their respective bays under the influence of southwesterly longshore currents, spit accretion, and strong gulfward-flowing currents generated by northers (Price, 1952). The present passes have migrated some distance from their initial positions; for example, Pass Cavallo has migrated to the southwest approximately 7 miles.

The Gulf shoreline has progressed through an early accretionary phase and a middle equilibrium stage and is now in an erosional condition; this is a natural sequence of events. Erosion can be aggravated by certain activities of man, such as construction of dams on major rivers that cut off the supply of sediments nourishing barrier islands or bayhead deltas. In general, the deltaic headlands and peninsulas experience the most rapid erosion because of a paucity of sand. Barrier islands, on the other hand, are being eroded less rapidly; they are thick, broad sand bodies that are less susceptible to storm breaching and washovers than are peninsulas.

Coastal Activities

The Texas Coastal Zone is characterized by a relatively mild climate which permits almost year-round recreation. Access to beaches and bay and Gulf waters, coupled with mild climatic conditions, attracts more than three million tourists to the Texas coastal area each year. Approximately a third of the State's population lives within 50 miles of the Gulf shoreline.

Large industrial complexes are situated in the Coastal Zone, with the greatest concentration occurring in the Houston and Beaumont-Port Arthur areas. Many of these industries depend upon sea and intracoastal transport for supplying raw materials and for exporting finished products. The major ports of entry are Beaumont-Port Arthur, Galveston-Houston, Freeport, Corpus Christi, and Brownsville.

Metropolitan areas, with the exception of Galveston, are situated near the heads of bays or along rivers within a few tens of miles of the Gulf shoreline. Because of these growing population centers in the Coastal Zone and the recent growth in tourism, Texas Gulf beaches are now more than ever important recreational areas. Summer cottages, motels, condominiums, and supporting facilities are being constructed at an unprecedented rate.

The current energy crisis has focused additional attention on the Coastal Zone. Favorable sites, both onshore and offshore, are being sought for construction of conventional and atomic-powered electrical generating plants. The Texas Offshore Terminal Commission recently evaluated several segments of the inner shelf and adjacent Gulf mainland shorelines as potential areas for constructing monobuoys and for dredging channels and deep-water ports specifically to offload crude oil from deep-draft supertankers. The shortage of fossil fuel has also rekindled exploration activities on the continental shelf. Impact of each of these activities will focus on the barrier islands, peninsulas, and deltaic headlands of the Texas coast.

All ongoing or proposed activities in the area where the sea meets the land can be jeopardized if the dynamic processes operating in the Coastal Zone are not taken into account during the planning of coastal development. The purpose of this paper is to present an overview of the Texas Gulf shoreline, processes acting on the shoreline, and conditions of shoreline stability—all fundamental to prudent conservation and development of the Texas shoreline. The precise data on which this general review is based occur in open-file notes, in published scientific reports, and in scientific reports currently in preparation and in press at the Bureau of Economic Geology in Austin. Open-file maps, charts, and profiles are available for perusal.

CHARACTERISTICS OF THE TEXAS GULF SHORELINE

The Texas Gulf shoreline tends east-northeast along the upper coast and approximately north-south along the lower coast. The climate is mild; there are only a few days during the winter when temperatures along the central and upper coast are freezing. Average annual rainfall is 55 inches at the Texas-Louisiana border and decreases steadily southward to the Texas-Mexico border where precipitation is 26 inches per year (fig. 1A). Mean annual temperature increases from 68°F along the upper coast to 74°F along the lower coast (fig. 1B). Trends in rainfall and temperature are reflected in the density of vegetation and morphology of peninsulas and barrier islands, and these in turn reflect the basic character of the shoreline.

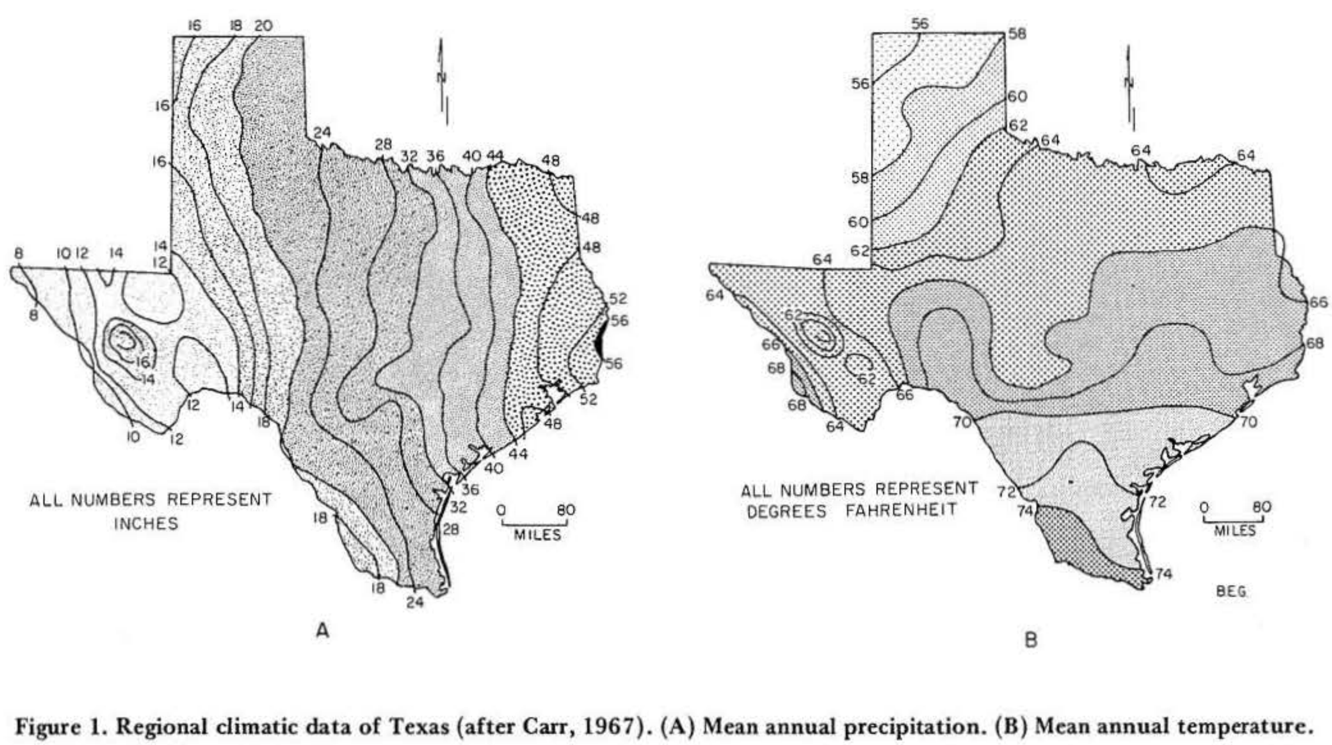

Figure 1. Regional climatic data of Texas (after Carr, 1967). (A) Mean annual precipitation. (B) Mean annual temperature.

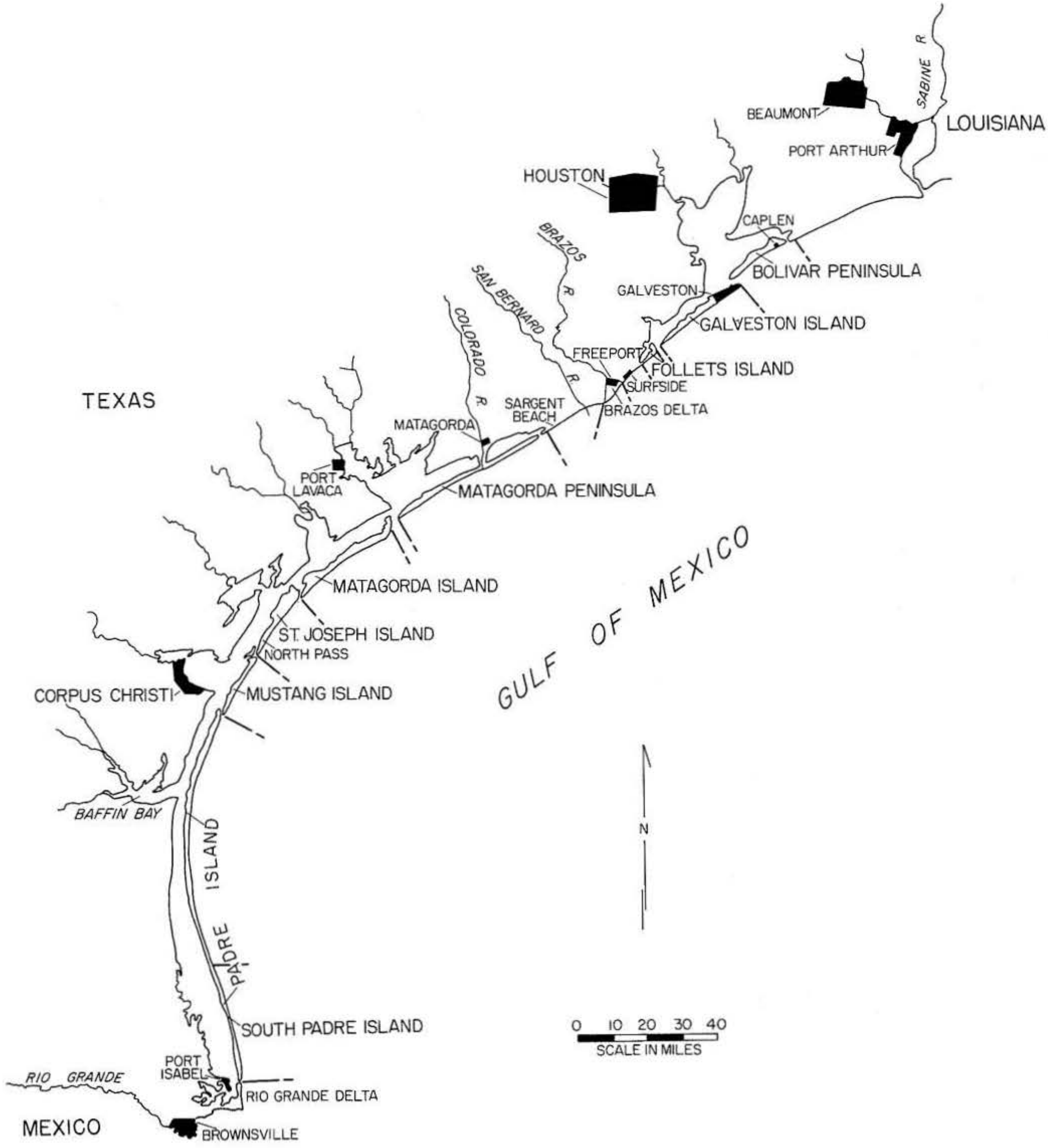

Figure 2. Index map, geographic and place names used in this report. Heavy lines perpendicular to shoreline serve to separate the various shoreline features.

With the exception of the Beaumont-Port Arthur, Freeport, and Port Isabel areas, the Texas Gulf shoreline consists of barrier islands and peninsulas (fig. 2). Rather large water bodies—bays, lagoons, and estuaries—lie between barriers and peninsulas and the mainland shoreline. Bays, lagoons, and estuaries are connected with the Gulf of Mexico through natural and man-made tidal passes. Several large rivers and streams discharge water and sediment into the bays. Three of the largest Texas rivers, the Brazos, Colorado, and Rio Grande, discharge directly into the Gulf of Mexico (fig. 2).

In general, the coastal plain is a relatively flat, featureless area that dips gently seaward. Elevation along the mainland shoreline ranges from near sea level, where streams have built deltas along bay margins, to 40 feet above sea level, where bay shorelines are cliffs cut into Pleistocene deposits of the upland. The Gulf shoreline is, for the most part, of low relief. Highest elevations, up to 50 feet, occur where fore-island dunes are well developed. The largest fore-island dunes are situated on Mustang Island and north Padre Island (Brown and others, 1976; Brown and others, in press).

GEOLOGICAL PROCESSES THAT MOLD THE TEXAS GULF SHORELINE

Texas Gulf shoreline features are the products of the interaction of a variety of factors among which are climatic regime, tides, relative sea-level change, tropical cyclone frequency, volume of terrigenous sediment delivered to the Gulf of Mexico, and the rate of dispersal of that sediment by waves and currents. Processes operating along the Texas Gulf shoreline can be divided into two broad classes: the normal processes that are active each day throughout the year and the short-duration, high physical energy processes that occur seasonally.

Normal daily processes appear to be insignificant in effecting changes along the shoreline when compared to the spectacular changes produced by hurricanes and tropical storms. However, many of the less dramatic processes have a significant long-term impact on the shorelines and on man's activities along the shorelines.

Daily Processes

Normal daily processes that have constructed and that are presently modifying Texas Gulf shoreline features are: (1) astronomical tides, (2) wind, (3) waves, (4) longshore currents, (5) river processes, and (6) subsidence or relative sea-level changes.

Astronomical tides are low along the Texas Gulf shoreline. Wind regime greatly influences coastal processes by raising or lowering water level along the Gulf shoreline and by generating waves and longshore currents (Price, 1954; Hayes, 1965; Watson, 1968; Watson and Behrens, 1970).

Rivers, such as the Brazos, Colorado, and Rio Grande, have influenced the Gulf shoreline by filling their respective estuaries and creating a bulge in the shoreline through the complex process of delta progradation. In addition to creating salients that project seaward beyond the average shoreline position, rivers are the only sources of additional sand required to nourish the Gulf shoreline features.

Subsidence or relative sea-level change is also operative in the coastal area (Brown and others, 1974; Kreitler, 1976). Subsidence is a natural process that may be accelerated by certain of man's activities. The end result of subsidence is a relative rise in sea level.

Astronomical tides

Tides in the Gulf of Mexico are dominantly diurnal (one high and one low water per day). Mean tidal range along the Texas Gulf coast is low, ranging from about 1.5 to 2.0 feet (U. S. Department of Commerce, 1973a). Neap tides have a range of about 0.7 feet and spring tides about 3.0 feet. Rise and fall of the water level during the tidal cycle produces currents in the open Gulf. The role played by these currents with respect to sediment transport on the shelf and shoreface is poorly understood. Tidal effects are most pronounced in tidal-pass areas. Here currents attain velocities up to 4 knots (U. S. Department of Commerce, 1973b). Current velocities in tidal passes are asymmetrical. Ebb tides are of shorter duration and attain higher velocities than flood tides.

Both suspension-load material and bedload material move through tidal inlets. Flood-tidal currents transport sediment into bays and lagoons where part of the sediment load accumulates as flood-tidal deltas (fig. 3). With a change in tide (ebb), sediment moves from the bays and lagoons into the open Gulf. Part of the bedload is deposited at the Gulf end of inlets as ebb-tidal deltas. Most of the bedload material moves laterally away from the pass to nourish beaches in the downcurrent direction.

Wind

Wind direction is onshore approximately 10 months of the year (fig. 4). Wind is perhaps the single most important geologic agent affecting the Texas Gulf shoreline. It transports loose sand and deposits it as dunes of many types and sizes. The wind stress along the water surface creates waves and causes a rise in the water surface, called wind tide, which inundates areas that are not normally affected by astronomical tide. Where approaching waves strike the shoreline at an angle, longshore currents are created as the waves break in shallow water (fig. 5). Direction that these longshore currents move is important with respect to shoreline stability. Wind direction, hence direction of wave approach, and shoreline orientation determine the direction of movement of longshore currents.

Wind is effective in constructing fore-island dunes in areas where there is an adequate supply of sand on the backbeach and where there is sufficient vegetation to trap and stabilize the sand. Fore-island dunes are best developed in the area from northern Matagorda Island to central Padre Island (fig. 2). Scattered, vegetated fore-island dunes occur between Port Mansfield jetties and the Rio Grande. Southeast wind moves sand from the beach area into the dune or vegetated area along the entire Texas Gulf shoreline. Southwest wind moves sand from the beach into the sea along the south and central Texas Gulf shoreline. Northers have the opposite effect; they transport sand offshore along parts of the upper and central coast and onshore (into the dunes) along parts of the central and lower coast.

Wind tide.—Wind blowing across the surface of a water body generates waves and causes a rise in the water surface in the direction that the airmass is moving. An increase in height of the water surface is known as wind tide. Onshore winds cause the water to rise along Gulf beaches. Offshore winds lower the water level along the beaches.

Wind tides have an effect on shoreline sedimentation and erosion by increasing the beach area subjected to wave activity. Strong onshore wind coupled with spring high tide and a barometric low create tides that may be 2 to 3 feet higher than normal astronomical high tide. Excessively high tide (wind tide) may flood the backbeach and waves may break on the forebeach, thereby accelerating erosion.

Waves and longshore currents.—Perhaps the most important role played by the wind is generation of waves and longshore currents. Waves are

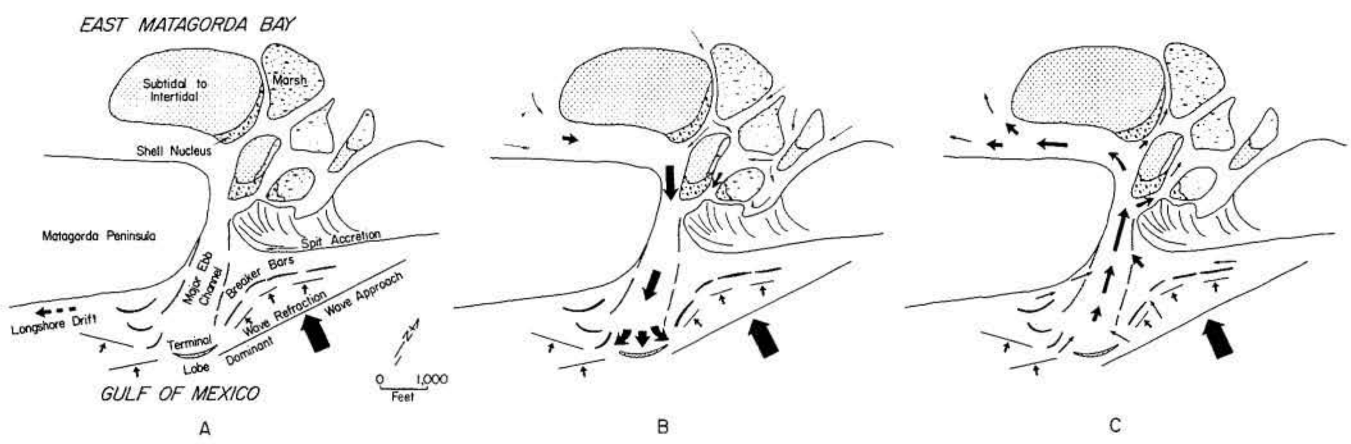

Figure 3. Generalized tidal delta. (A) Depositional features associated with tidal deltas (nomenclature after Hayes and others, 1973). Ebb delta is, for the most part, entirely inundated. Ebb features are the major ebb channel and terminal lobe. Flood delta consists of shell nuclei, marsh islands, and subtidal to intertidal sandflats. (B) Water movement during ebb tide. (C) Water movement during flood tide. Widths of arrows indicate relative current strength (after McGowen, 1974).

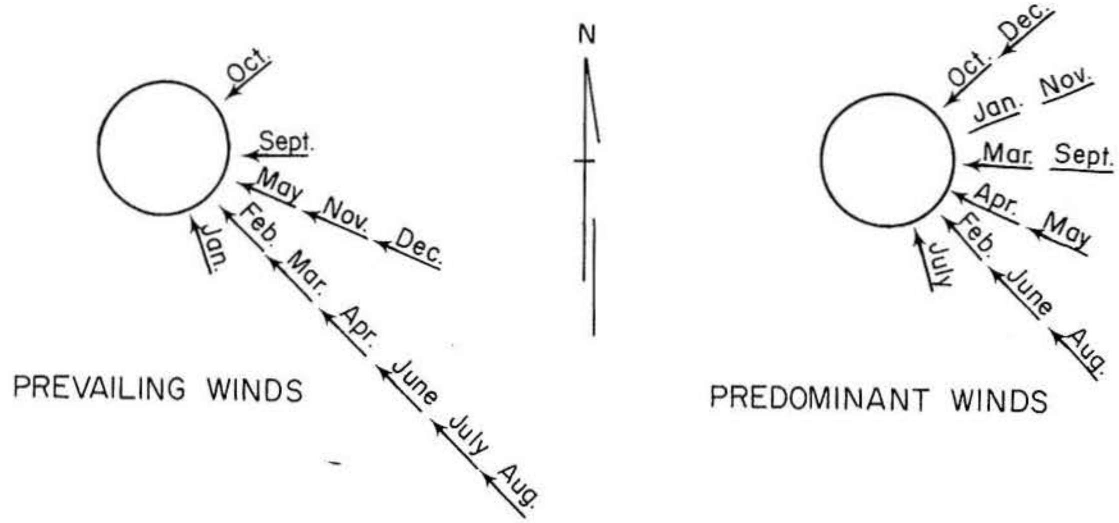

Figure 4. Prevailing and predominant wind (after Lohse, 1955). Prevailing wind direction is the direction that winds blow most of the time during each month. Predominant wind direction is the direction in which surface winds expend the greatest amount of energy month by month.

generated by prevailing southeast wind, northers, and tropical storms and hurricanes. Waves which are generated by prevailing southeast wind and storms move onshore and their geologic effects are most obvious along the Gulf shoreline. Northers produce waves that generally move offshore on the upper coast and onshore along the lower coast.

Waves and longshore drift are the principal agents of sediment transport, deposition, and erosion in the nearshore zone. Predominant wind is from the southeast quadrant and waves principally approach the shoreline from that direction. Waves that are generated near shore by strong winds attain heights between 2 and 6 feet, are steep, and have a relatively short wave length. High, steep waves erode the shoreface and beach, whereas swell tends to result in deposition. Swell is the more rounded, symmetrical waves which are generated by storms or winds many miles offshore. When asymmetrical waves pass out of the area where they are generated, they decrease in height and become more rounded and symmetrical (Johnson, 1919). Swell is the gentle undulations of the sea surface on relatively calm days.

Wave steepness and approach direction, coupled with shoreline trend, determine direction and rate of sediment transport. High, steep waves that strike the shoreline at a high angle not only erode the shoreface and beach, but they also set up strong longshore currents that move sediment out of the area. The significance of these conditions is that (1) predominant wind and wave approach is from the southeast, (2) the Texas Gulf shoreline is concave, or open, to the southeast, and (3) steep, high waves strike the shoreline of the upper and lower coast at high angles more frequently than they strike the central coast. The net results of the interaction of predominant southeast wind, steep, high waves, and shoreline orientation are excessive erosion of the shoreline of the upper and lower coast, transport of sand toward the central coast, and net convergence of longshore currents in the area of latitude 27° North (fig. 6).

The direction of bottom current and sediment movement is variable along the lower shoreface. In the zone seaward of breakers, sand moves shoreward as ripples (Johnson and Eagleson, 1966). In the breaker zone along the upper shoreface (fig. 7), turbulence level is high and sediment movement as suspension load is prevalent. Troughs lying between breaker bars serve as channelways for longshore currents. Waves are generally small or diffuse in the surf zone (fig. 7), but longshore currents are strong. Frequently, current velocities are sufficient to transport both sand- and gravel-sized material. The forebeach (fig. 7) is a seaward-sloping surface that lies between mean low water and the limit of uprush from breaking waves. Fine-grained terrigenous sand is the dominant

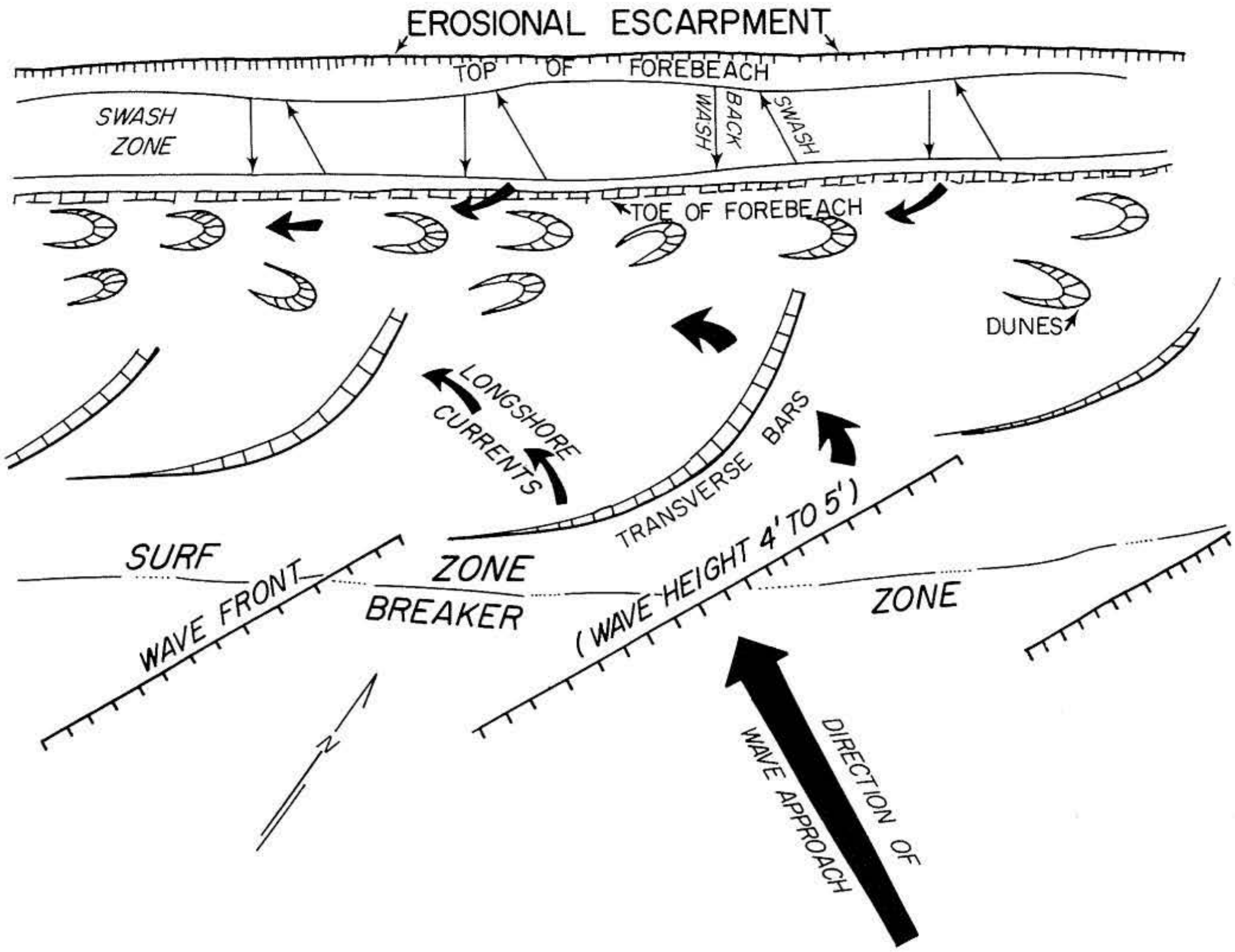

Figure 5. Relationship between shoreline orientation, direction of wave approach, and longshore sediment transport. This sketch was made of the beach and surf zone (May 1972) along Matagorda Peninsula about midway between the Colorado River and Greens Bayou. The wind was gusting to about 30 knots, and wave height (measured with alidade and stadia rod) was 4 to 5 feet. Waves approached the shoreline at a high angle, and strong southwest longshore currents developed. Bedforms in the surf zone were transverse bars and dunes; slip faces were oriented generally to the southwest. Shell debris was in transit in both the surf and swash zones, and the beach was being eroded.

sediment type found in the swash zone. Coarse materials, such as shell, accumulate at the top of the swash zone and at the toe of the forebeach.

Northers.—Northers are polar airmasses that penetrate the Coastal Zone as frequently as 15 to 20 times per year (Hayes, 1965). High-velocity wind, generally from the northeast, is an attendant feature of northers. Wind velocities range from 15 to 50 knots. Northers create wind tides that inundate the bayside of barriers and peninsulas, generate high-velocity ebb currents which transport sand through tidal passes to the Gulf of Mexico, and transport sand from dune and beach areas into the swash zone. Waves are created by northers. These waves move offshore along the upper coast (thus neutralizing the erosive capability), move approximately parallel to shore along the central coast, and strike the shoreline of the lower coast at a high angle. Waves associated with northers tend to erode parts of the central and lower coastal shoreline and create strong longshore currents that move sand southward along these shoreline segments.

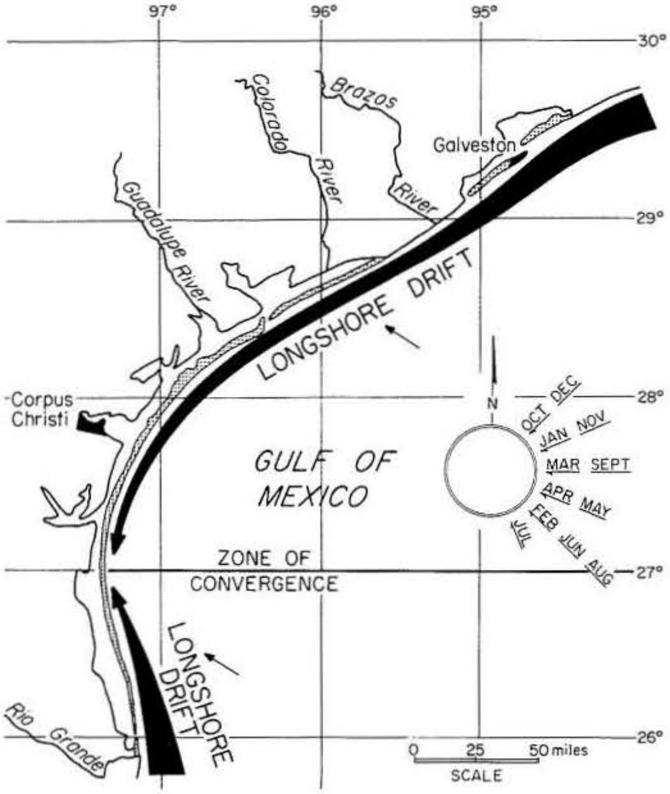

Figure 6. Net longshore drift convergence (after Watson, 1968).

Modern Rivers

Three major rivers, Brazos, Colorado, and Rio Grande, discharge directly into the Gulf of Mexico (fig. 2). These rivers, in conjunction with the smaller San Bernard River, are the only sources of additional sand being supplied to the Texas Gulf beaches from outside the coastal system (fig. 8). Until recently these rivers played a significant role in shoreline maintenance. Dams that impound both water and bedload material have been constructed across the Brazos, Colorado, and Rio Grande. Several reservoirs have been created on the Brazos River (Dowell and Petty, 1973). The dam for Possum Kingdom Lake, with a drainage of 22,500 square miles, was completed in 1941. Whitney Lake, whose drainage area is 17,656 square miles, was completed in 1951, and Lake Granbury, with a drainage network of 24,691 square miles, was completed in 1969. The dam across the Colorado River that is nearest the coast was completed at Austin in 1893. This reservoir, Lake Austin, receives water and sediment from a 38,240-square-mile drainage area (Dowell and Petty, 1971). The first large reservoir on the Rio Grande, Falcon Reservoir, was completed in 1954. This reservoir has a contributing area of 164,482 square miles (Dowell and Petty, 1971). Much of the bedload material that would have reached the Gulf of Mexico and would have nourished the beaches is now retained in these reservoirs. Other rivers and streams discharge into bays and estuaries where bedload sediment is trapped; this bedload sediment does not become part of the longshore drift system.

Subsidence

Subsidence is a natural geologic process throughout the Texas Coastal Zone. The most spectacular rates of subsidence are in the Houston area where subsidence has been accelerated

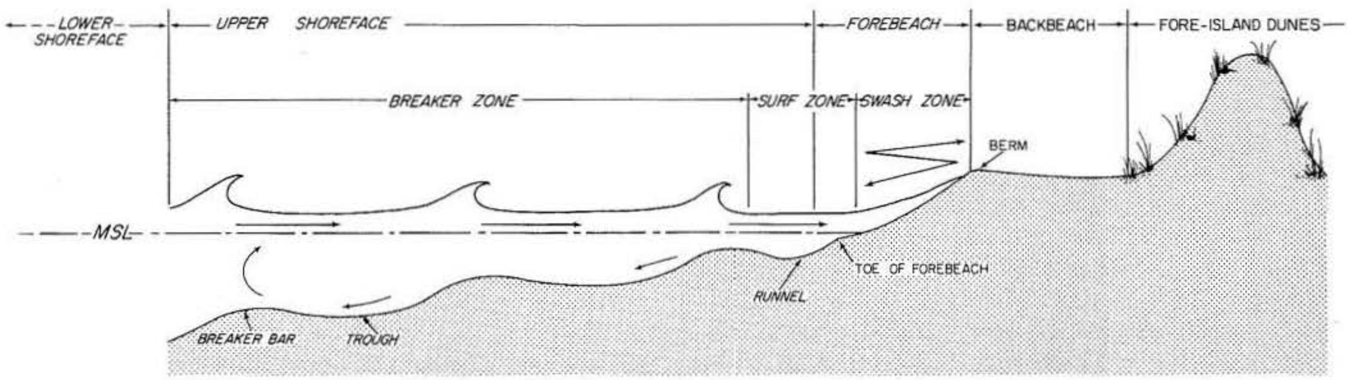

Figure 7. Generalized profile from upper shoreface to fore-island dunes. The profile shows the association between physiographic features (for example, upper shoreface and forebeach) and the various energy zones (for example, the breaker and swash zones).

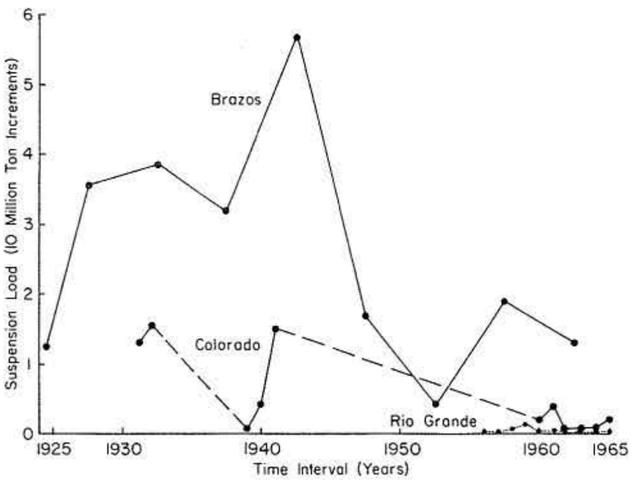

Figure 8. Comparison of suspension loads of Brazos and Colorado Rivers and Rio Grande (data from Stout and others, 1961; Adey and Cook, 1964; Cook, 1967, 1970); gaging stations on the Brazos at Richmond, on the Colorado near Eagle Lake, and on the Rio Grande at Brownsville. The Brazos clearly dominates the coastal scene. Both the Brazos and Colorado show a decrease in suspension load. Suspension load at Brownsville was monitored only after the completion of Falcon Dam (1954) and does not, therefore, reflect the contribution of sediment to the Gulf of Mexico via the Rio Grande prior to its alteration.

through ground-water withdrawal (Fisher and others, 1972; Kreitler, 1976). From Florida to Mexico, subsidence is a natural geologic process that has been accelerated locally by the activities of man. Subsidence rates are great in the area of the Mississippi delta (4.3 meters, or about 14 feet, per hundred years) but are considerably less along the Texas coast. Subsidence rates for Sabine Pass, Freeport, and Port Isabel in meters per hundred years are 1.25 (4 feet), 1.12 (3.7 feet), and 0.5 (1.6 feet), respectively (Swanson and Thurlow, 1973).

Subsidence causes movement, or displacement, of the shoreline in a landward direction. If the rate of subsidence is constant for the next 100 years, the Sabine Pass area will subside 4 feet, the Freeport area will subside 3.7 feet, and the Port Isabel area will subside 1.6 feet. It is possible that the mainland shoreline could be displaced a few miles inland across the Rio Grande delta plain.

Statements made relative to subsidence are correct only if no sediment accumulates in the areas mentioned. Sediment accumulates on parts of the Laguna Madre flats at rates up to 2 feet per 100 years (Fisk, 1959). In the Port Isabel area, the postulated shoreline shift of a few miles inland, across the Rio Grande delta plain, assumes no sedimentation. If, on the other hand, sediment accumulates at a rate comparable to the rate on Laguna Madre flats, then a net seaward shift in the mainland shoreline position would result. However, since the Rio Grande no longer delivers sediment to the delta plain, there should be a transgression of the shoreline.

Tropical Cyclones: Hurricanes and Tropical Storms

The Texas coast is struck by hurricanes or tropical storms about once each 2 years. Hurricanes and tropical storms are airmasses with counterclockwise winds that are hundreds of miles in diameter. Characteristics of the storms are high-velocity winds along the periphery of the storm, a calm area (the eye) at the center of the storm, low barometric pressure, torrential rainfall, and tornadoes.

A hurricane is a storm of tropical origin with a cyclonic wind circulation of 74 miles per hour or higher (Dunn and Miller, 1964). Hurricanes originate within the tropics and occur most frequently in August, September, and October. Associated with hurricanes are: (1) a barometric low and wind stress that cause a rise in water level along the Gulf and mainland shorelines; (2) strong winds that change direction as the storm approaches, makes landfall, and passes inland; (3) large waves that break higher on Gulf and mainland shorelines than waves associated with normal sea conditions; and (4) heavy rainfall (Hayes, 1967; Scott and others, 1969; McGowen and others, 1970; Brown and others, 1974).

Historical records indicate that hurricanes differ. One hurricane may generate a large storm surge, another may be remembered for its torrential rainfall, and a third may be characterized by exceptionally high wind velocities. Chief effects of hurricane processes on the Gulf shoreline features are beach and dune erosion, scour of storm-surge channels across barriers and peninsulas, deposition of sand and shell at the terminus of storm channels as washover fans, and extensive salt-water flooding that may kill large areas of vegetation. During the passage of a hurricane, shorelines may be eroded a few tens to several hundred feet in a few hours

(Shepard, 1973; Brown and others, 1974; McGowen and Brewton, 1975). Considerable erosion along the inner shelf and shoreface may also occur during the passage of a hurricane; evidence of erosion is the granule- to boulder-sized fragments of sandstone, beach rock, limestone, and coral found in certain storm deposits on barrier islands, peninsulas, and erosional deltaic headlands. Not only are subaerial shoreline features modified or destroyed by hurricane processes, but also the seaward extension of barriers and peninsulas (shoreface) may be drastically altered.

TYPES OF GULF SHORELINE FEATURES

Four distinct types of shorelines characterize the Texas Gulf coast (McGowen and Garner, 1972; McGowen and others, 1972; McGowen and Scott, 1975). Each of these shorelines is typified by its own morphology, composition of beach materials, and condition of shoreline stability. Erosional deltaic headlands, peninsulas, barrier islands, and a single Modern progradational delta (Brazos delta) constitute the Texas Gulf shoreline (fig. 9).

Most of the 367 miles of Texas Gulf shoreline is in an erosional state, a secondary portion is in equilibrium, and a mere 7 percent of the shoreline is accretionary (Brown and others, 1974; Morton and Pieper, 1975a, 1975b; Morton, 1974, 1975). Most of the equilibrium shorelines lie between Pass Cavallo and Port Mansfield jetties, a distance of approximately 147 miles (fig. 9A). Approximately 220 miles of shoreline is predominantly erosional. About 60 percent of the Gulf shoreline is erosional, 33 percent is in equilibrium, and 7 percent is accretionary.

Erosional Deltaic Headlands

The most highly erosional segments of the Texas Gulf shoreline are the three deltaic headlands: (1) between Sabine Pass and Rollover Pass, (2) between Freeport Ship Channel and Brown Cedar Cut, and (3) between Brazos Santiago Pass and the mouth of the Rio Grande (fig. 9). Long-term trend for the Rio Grande area has been accretionary (Morton and Pieper, 1975a). Three factors contribute to rapid shoreline retreat in these areas: (1) deficiency of sand-sized sediment, (2) high angle of wave approach, and (3) subsidence or relative sea-level rise. Short-term erosional rates along these headlands range from a few feet per year to a high of about 80 feet per year (fig. 9). Average annual erosional rates of 25 to 40 feet per year are common in these areas.

Coastal features (fig. 10A) of Sabine Pass and Freeport areas are similar. Older deltaic deposits are exposed offshore on the bottom of the inner shelf and shoreface. Erosion of these deposits from the seabed and onshore transport of sand, shell, and rock fragments provide the only significant source of materials supplied to these shoreline segments. Older deltaic and Modern marsh deposits are commonly exposed in the swash zone (fig. 11A). Beaches, attendant berms, and shell ramps consist of a mixture of sand, shell, and rock fragments. The coarsest sediment occurs in berms and ramps. Berms and ramps consist predominantly of gravel-sized shell and rock fragments; sand content is variable. Tops of berms and ramps are 5 to 7 feet above mean sea level; shell ramps extend a few hundred feet inland where they commonly override marshes. Berms and ramps are built by tropical storms and hurricanes. Sand dunes are rare in these areas, but where present they are a maximum of 5 feet high and discontinuous.

Shoreline features associated with the Rio Grande delta (fig. 12) differ from those of the upper coast. Most of the sand that is supplied to the shoreface and beach is derived by the erosion of extensive submerged Rio Grande deltaic deposits. The shoreline is significantly affected by the wind. This southernmost shoreline segment is characterized by relatively wide sand beaches (deltaic and tidal-flat deposits are locally exposed in the swash zone), vegetated fore-island dunes (up to 35 feet high), storm channels, and washover deposits.

Peninsulas

Peninsulas are sediment bodies composed of a mixture of sand, shell, and rock fragments. Peninsulas are tied to a headland, and they are generally elongate in the direction of net longshore drift (figs. 9 and 10B). Some have been separated from the headland by creation of natural or man-made passes. Bolivar Peninsula, Follets Island, Matagorda

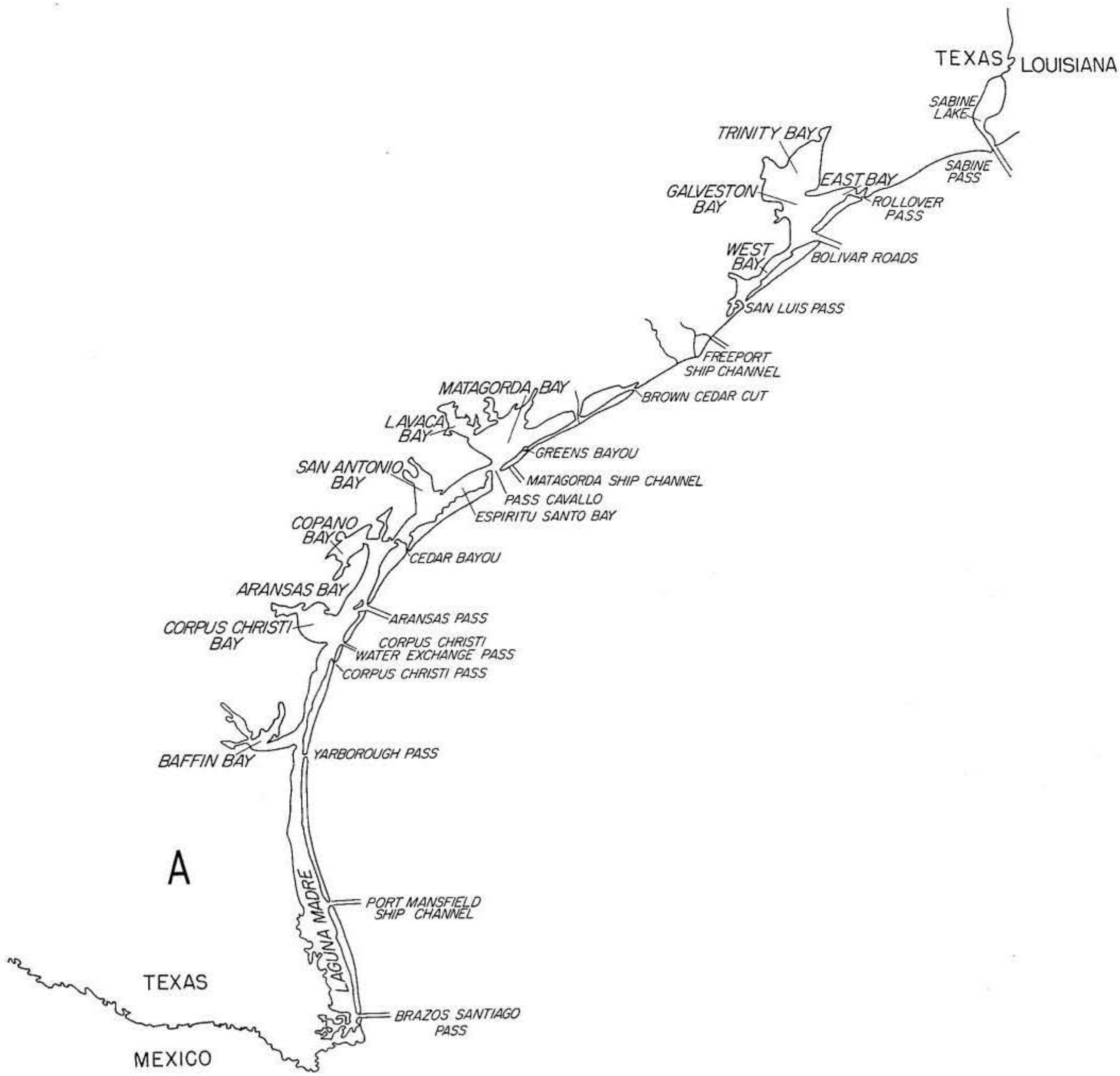

Figure 9. (A) Location of natural tidal passes and man-made cuts through barrier islands and peninsulas. Major, natural tidal passes are Sabine Pass, Bolivar Roads, San Luis Pass, Pass Cavallo, Aransas Pass, and Brazos Santiago Pass. Lesser, natural passes are Brown Cedar Cut, Greens Bayou (closed), Cedar Bayou, and Corpus Christi Pass (a former major pass, now open only after the passage of a hurricane). Man-made passes, specifically for shipping, are Freeport Ship Channel, Matagorda Ship Channel, and Port Mansfield Ship Channel. Fish passes, or water exchange passes, are Rollover Pass, Corpus Christi Water Exchange Pass, and Yarborough Pass (now closed).

Peninsula, and south Padre Island are the peninsulas of the Texas Gulf shoreline (fig. 2).

Peninsulas are erosional throughout most of their length except Bolivar Peninsula. West of Caplen, Bolivar was in equilibrium and became accretionary adjacent to the north jetty of the Galveston Ship Channel (Bolivar Roads) (figs. 2 and 9); recently, parts of this shoreline segment have undergone erosion in excess of 10 feet per year (Brown and others, 1974; Morton, 1975). Bolivar Peninsula differs from other peninsulas by having a well-developed ridge-and-swale accretionary topography and by being densely vege-

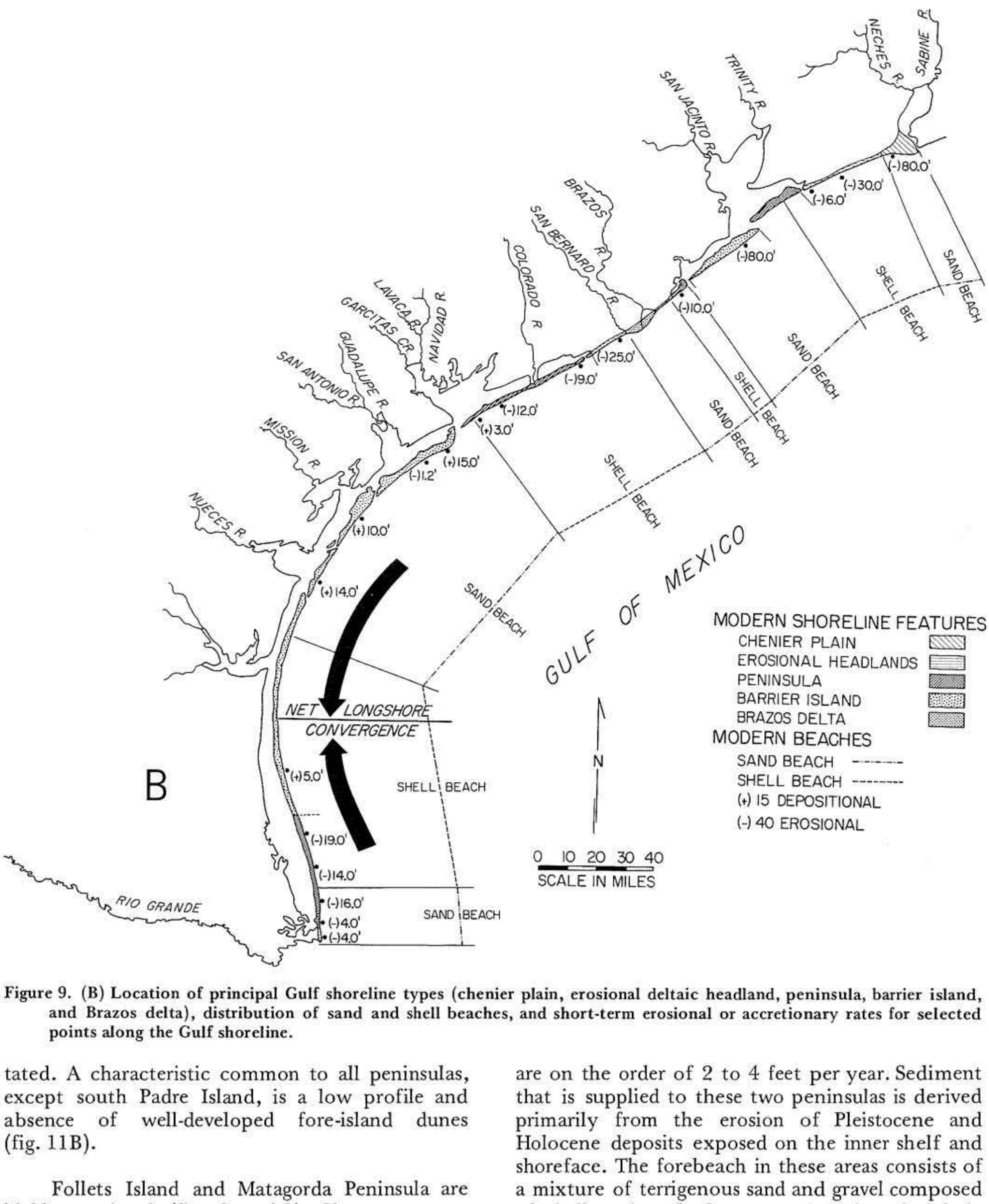

Figure 9. (B) Location of principal Gulf shoreline types (chenier plain, erosional deltaic headland, peninsula, barrier island, and Brazos delta), distribution of sand and shell beaches, and short-term erosional or accretionary rates for selected points along the Gulf shoreline.

tated. A characteristic common to all peninsulas, except south Padre Island, is a low profile and absence of well-developed fore-island dunes (fig. 11B).

Follets Island and Matagorda Peninsula are highly erosional (figs. 2 and 9). Short-term erosional rates vary along these peninsulas; maximum rates are about 25 feet per year and minimal rates are on the order of 2 to 4 feet per year. Sediment that is supplied to these two peninsulas is derived primarily from the erosion of Pleistocene and Holocene deposits exposed on the inner shelf and shoreface. The forebeach in these areas consists of a mixture of terrigenous sand and gravel composed of shell and rock fragments. Marsh and deltaic muds are commonly exposed in the swash zone. Coarsest materials—whole shell and rock fragments

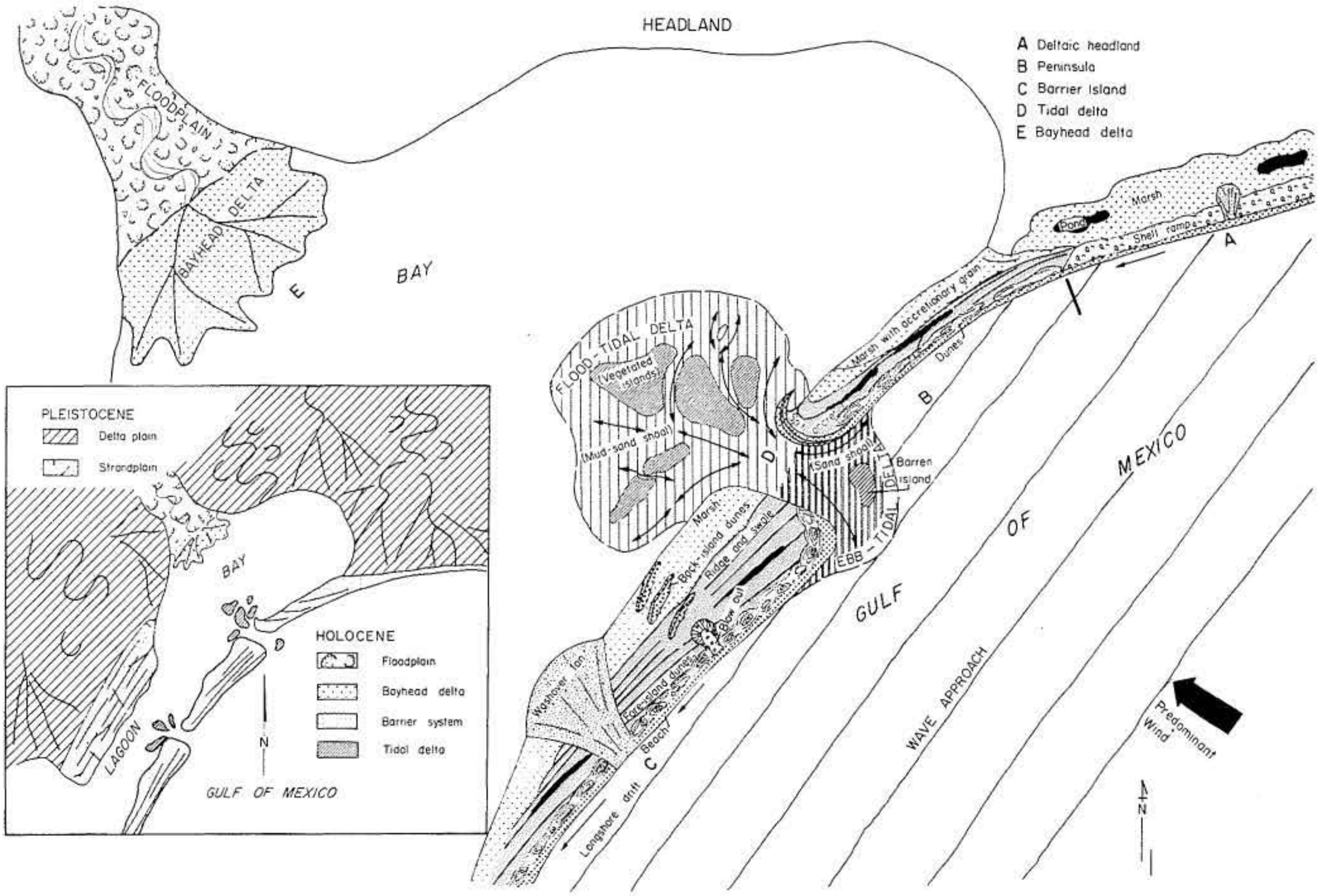

Figure 10. Schematic showing relationships of Texas Gulf shoreline features. Predominant wind and wave approach is from the southeast quadrant. Longshore drift is to the southwest. Pleistocene features, shown on the index map, are delta plain and strandplain. Also shown on the index map are bays and lagoons separated from the Gulf of Mexico by peninsulas and barrier islands. Holocene features, generalized on the index map, are floodplain, bayhead delta, barrier island system, and associated tidal delta. (A) Erosional deltaic headland and its associated ephemeral beach, shell ramp, washover fan, and marsh. (B) Down longshore drift from A, a peninsula (modeled after Bolivar Peninsula) whose beaches are in equilibrium to accretionary; it displays accretionary grain. (C) Barrier island which is predominantly terrigenous sand; it is considerably wider than beaches and berms associated with erosional headlands and is wider than peninsulas; the number of morphological features is greatest on barrier islands, that is, barrier islands consist of beaches, fore-island dunes, blowouts, washover fans, ridges and swales, back-island dunes, and marshes or tidal flats. (D) Tidal pass/tidal delta that separates barrier islands and peninsulas and serves to exchange water between the Gulf of Mexico and bays and lagoons. (E) Bayhead delta; all of the sand delivered to the bay is deposited at the river mouth; none reaches the Gulf beaces.

up to 2 feet in diameter—occur on berms and shell ramps. Tops of berms and shell ramps are 5 to 7 feet above sea level. These features are constructed by hurricanes and tropical storms. Shell ramps, which are up to 2,000 feet wide, slope gently toward the bay; they commonly terminate as a steep avalanche face on the vegetated flat. Because of the paucity of sand-sized material, dunes are not well developed on the peninsulas. Continuous fore-island dunes, with crests 12 to 15 feet above mean sea level, are present immediately to the east of the mouth of the Colorado River and from Greens Bayou westward to the Matagorda Ship Channel jetties (fig. 13).

South Padre Island was at one time probably tied to the Rio Grande deltaic headland (Lohse, 1962); it is now separated from the headland by Brazos Santiago Pass. Like Follets Island and Matagorda Peninsula, the south Padre Island shoreline is undergoing erosion (figs. 2 and 9). Short-term erosional rates range along the island from

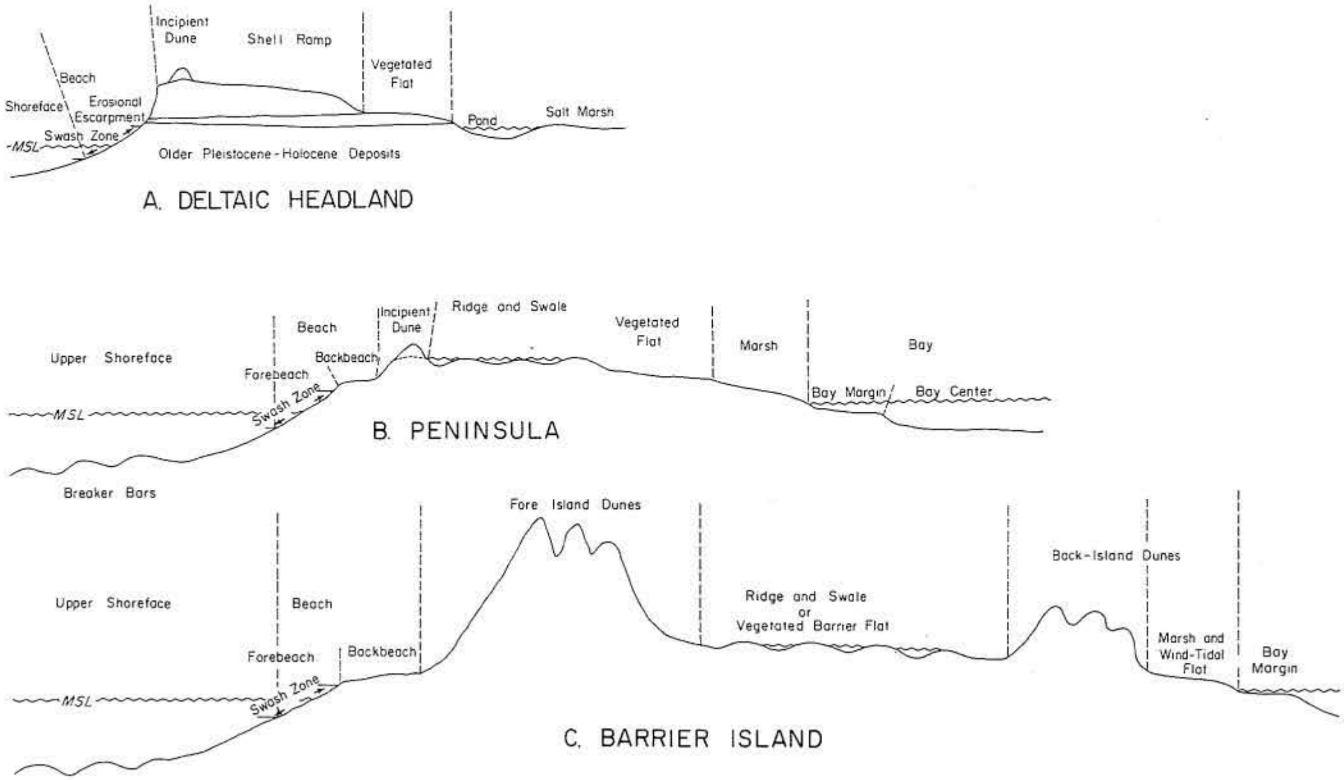

Figure 11. Generalized profiles across shoreline features associated with (A) erosional deltaic headlands, (B) peninsulas, and (C) barrier islands. A, B, and C are shown in plan on figure 10.

about 3 to 46 feet per year (fig. 14). Sediment supplied to south Padre Island is derived primarily from erosion of Holocene and Pleistocene deltaic and strandplain deposits exposed on the inner shelf and shoreface. Marsh, tidal flat, and deltaic muds are exposed locally in the swash zone. Forebeach sediment is thin and is dominated by terrigenous sand, whereas backbeaches are dominated by shell. Many of the shells are whole or fragments of *Mercenaria mercenaria*, a bay species; *Mercenaria* have been observed in bay sediment that is now overlain by south Padre Island. Fore-island dunes are well developed along segments of south Padre Island. At least two generations of dunes are present. Remnants of vegetated fore-island dunes, which probably formed a continuous dune ridge prior to the drought and overgrazing during the late 1800's (Price and Gunter, 1943), form vegetated islands in a field of actively migrating dunes. Numerous storm channels cut across south Padre Island; these occur most commonly in areas of unvegetated dunes which afford little resistance to storm surge.

Shorelines associated with peninsulas are eroding because (1) sand supply is low, (2) subsidence is occurring, and (3) thin sediment bodies, overlying relict tidal-flat, lagoon, and deltaic deposits, can be readily eroded by both normal and storm processes. Behind the dune field, south Padre Island is composed of only 5 to 6 feet of sand; just south of Port Mansfield Ship Channel, it is only 10 feet thick.

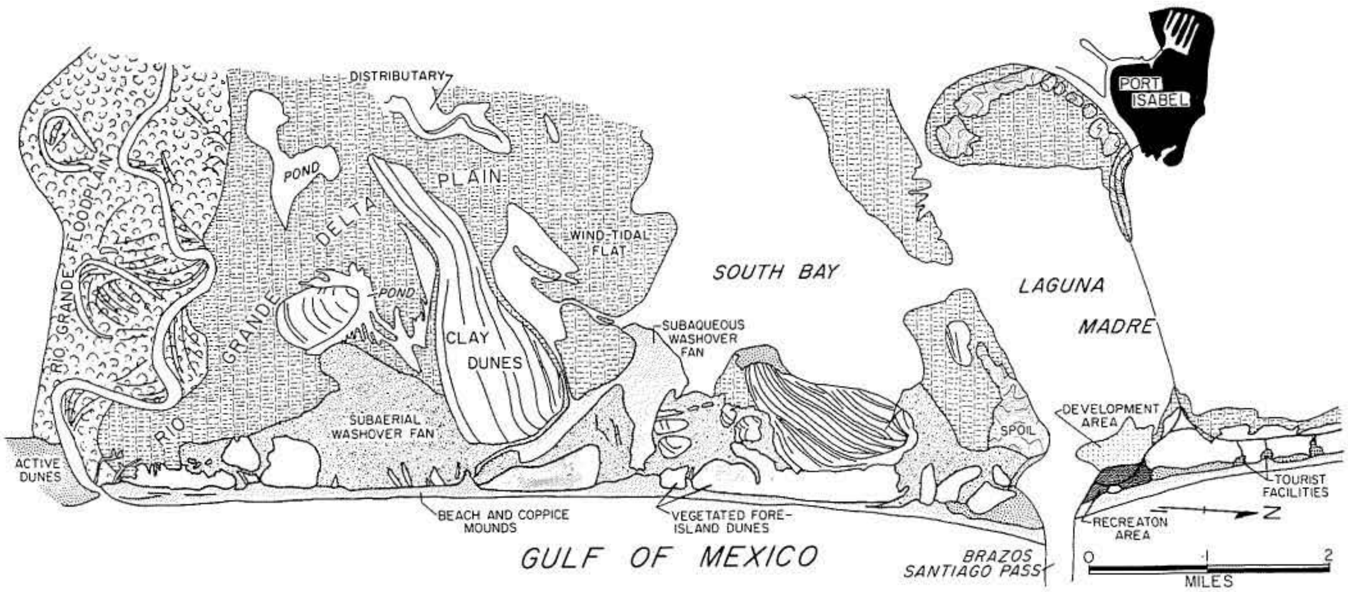

Figure 12. Shoreline features (beach, dunes, and washover deposits) developed on the erosional Rio Grande delta. Shoreline deposits consist of terrigenous sand with minor amounts of shell. Rio Grande delta plain is characterized by abandoned distributaries, ponds, wind-tidal flats, and clay dunes. The Rio Grande meanders to the Gulf of Mexico; its floodplain is characterized by oxbow lakes and meander scrolls. Fluvial sand, near the mouth of the Rio Grande, is about 30 feet thick, whereas beach and washover sand overlying the delta plain is only 5 to 20 feet thick. Mapping was done on color positives flown by NASA on June 13, 1969.

Barrier Islands

Barrier islands are elongate sediment bodies that are fronted by the Gulf of Mexico and have bays or lagoons separating them from the mainland (fig. 10C). Barriers are separated from each other and from peninsulas by natural tidal passes. In general, barrier islands are broader than peninsulas (fig. 11B and 11C) and, with the exception of a segment of Padre Island lying between Yarborough Pass and Port Mansfield Ship Channel, barriers have a higher percentage of sand and less shell and rock fragments than peninsulas (fig. 9). From east to south, the Texas barrier islands are Galveston, Matagorda, St. Joseph, Mustang, and Padre.

With the exception of parts of Galveston, Matagorda, and St. Joseph Islands, beaches associated with barrier islands are generally in equilibrium with sand supply and coastal processes; some beach segments of these islands have recently experienced erosion in excess of 10 feet per year (Brown and others, 1974). Between the winter of 1970 and spring of 1973, the Galveston Island beach segment just west of the end of the Galveston seawall eroded at a rate of about 80 feet per year. Characteristics of the beaches changed somewhat between 1970 and 1973; the forebeaches were narrower locally and the ratio of shell to sand had increased.

Three of the barrier islands, Galveston, Matagorda, and St. Joseph, have similar morphological features. The back-island area is serrated by a complex of tidal channels that are open only to the bays; the area between the back island and the backbeach or fore-island dunes has prominent ridge-and-swale accretionary topography, and each has, or had, relatively wide beaches. Chief differences among these islands are the degree of development of fore-island dunes and the modification of these dunes by blowouts. Galveston Island is, for the most part, densely vegetated and has a poorly developed fore-island dune system. Matagorda Island is not as densely vegetated as Galveston Island, but it has a continuous fore-island dune system part of which developed since 1934 (Wilkinson, 1974). Dunes average about 15 feet above mean sea level, and maximum height is about 30 feet. St. Joseph Island has somewhat less vegetation than Matagorda Island and, like Matagorda, has a well-developed fore-island dune

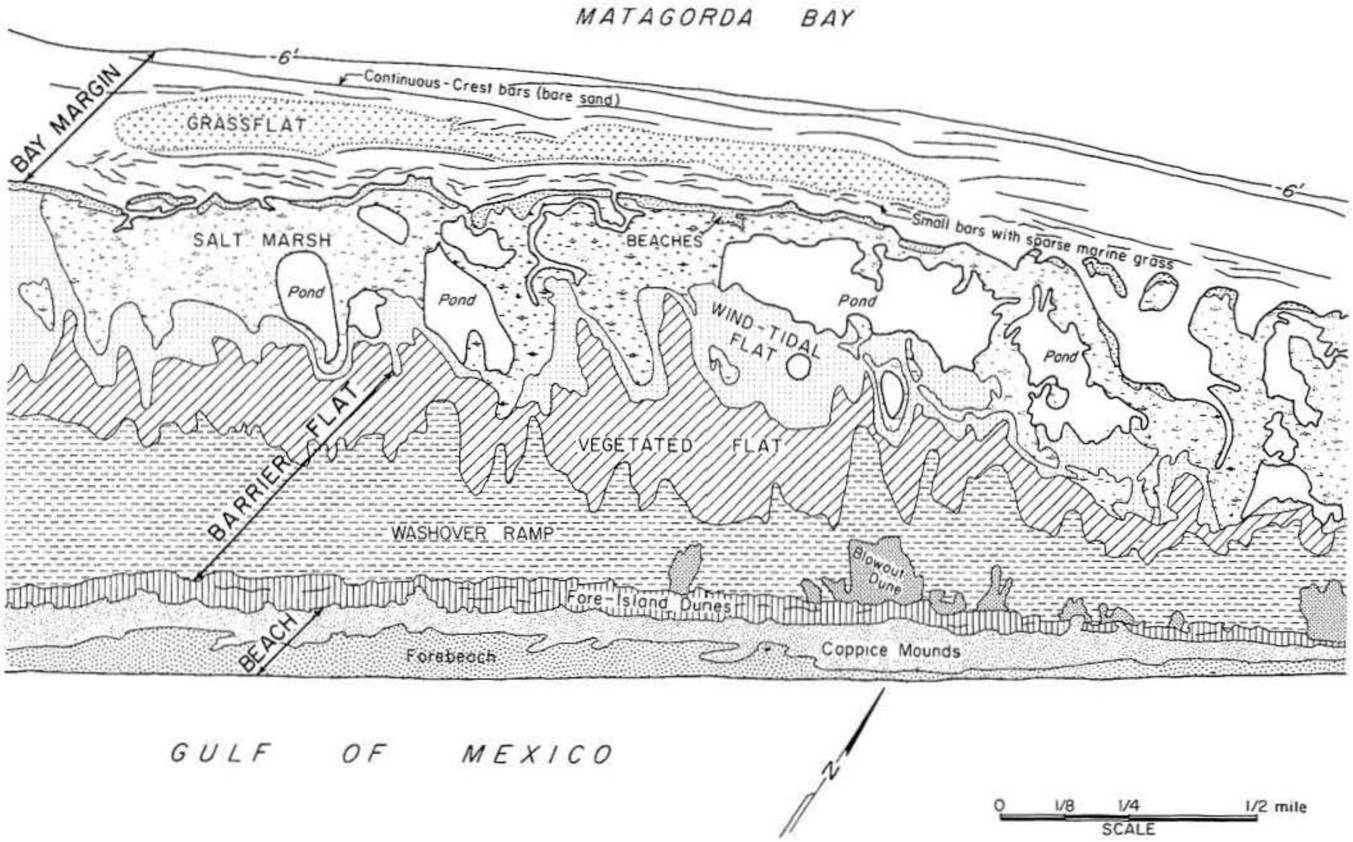

Figure 13. Depositional features associated with a segment of Matagorda Peninsula (see figure 9A for location) beginning 1.5 miles west of Greens Bayou. Fore-island dunes are continuous in this area; although Hurricane Carla (1961) caused severe erosional damage to parts of Matagorda Peninsula east of this shoreline segment, these dunes protected the area behind them. The washover ramp predates development of fore-island dunes. Mapping was derived from U. S. Department of Agriculture photography (May 1952) (after McGowen, 1974).

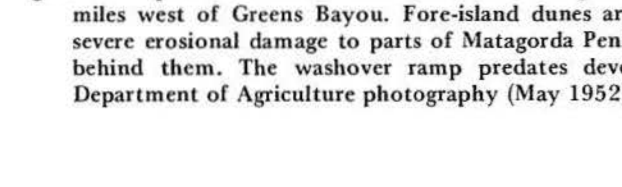

Figure 14. South Padre Island erosional shoreline. Profiles run at this station in February 1972, May 1973, and December 1973 show that the beach has eroded approximately 85 feet and that as much as 3.5 feet of sand has been removed. The wellhead, which was used as a datum, is situated about 19 miles north of Brazos Santiago Pass. This well was drilled 330 feet from shore in 1956 by Magnolia Oil Company. The shoreline retreated 365 feet in 17.6 years; average rate of retreat was 20.7 feet per year. Average erosional rate for the interval February 1972 to December 1973 was 46 feet per year.

system. The dune system on St. Joseph Island has been breached in several places by blowouts, and the southern part of the island, North Pass area (fig. 2), has been stripped of dunes and vegetation by frequent hurricane washovers (Price, 1956; Nordquist, 1972).

Mustang Island and part of Padre Island have similar morphological features. Broad sand beaches, high fore-island dunes, hummocky vegetated barrier flats, and active back-island dunes characterized this area. Fore-island dunes attain maximum height of 50 feet above sea level in this area. Also, the number of blowouts, hurricane channels, and washover fans is greater on Mustang and northern Padre Island than on barriers to the east. On Padre Island, beach sediment grades southward from terrigenous sand to a mixture of sand and shell in the vicinity of Baffin Bay (figs. 2

and 9); this beach segment is known as "Little Shell" because of the dominance of the surf clam *Donax*. As shell content increases, beach morphology changes; the forebeach becomes narrow and steep, elevation of the backbeach above mean sea level increases, and the width decreases (fig. 15).

Little Shell Beach persists for about 10 miles where it grades southward into coarser shell debris; this southern area is known as "Big Shell" (Brown and others, in press). Big Shell beaches are steeper, narrower, and higher above mean sea level than the finer grained shell beaches on Padre Island.

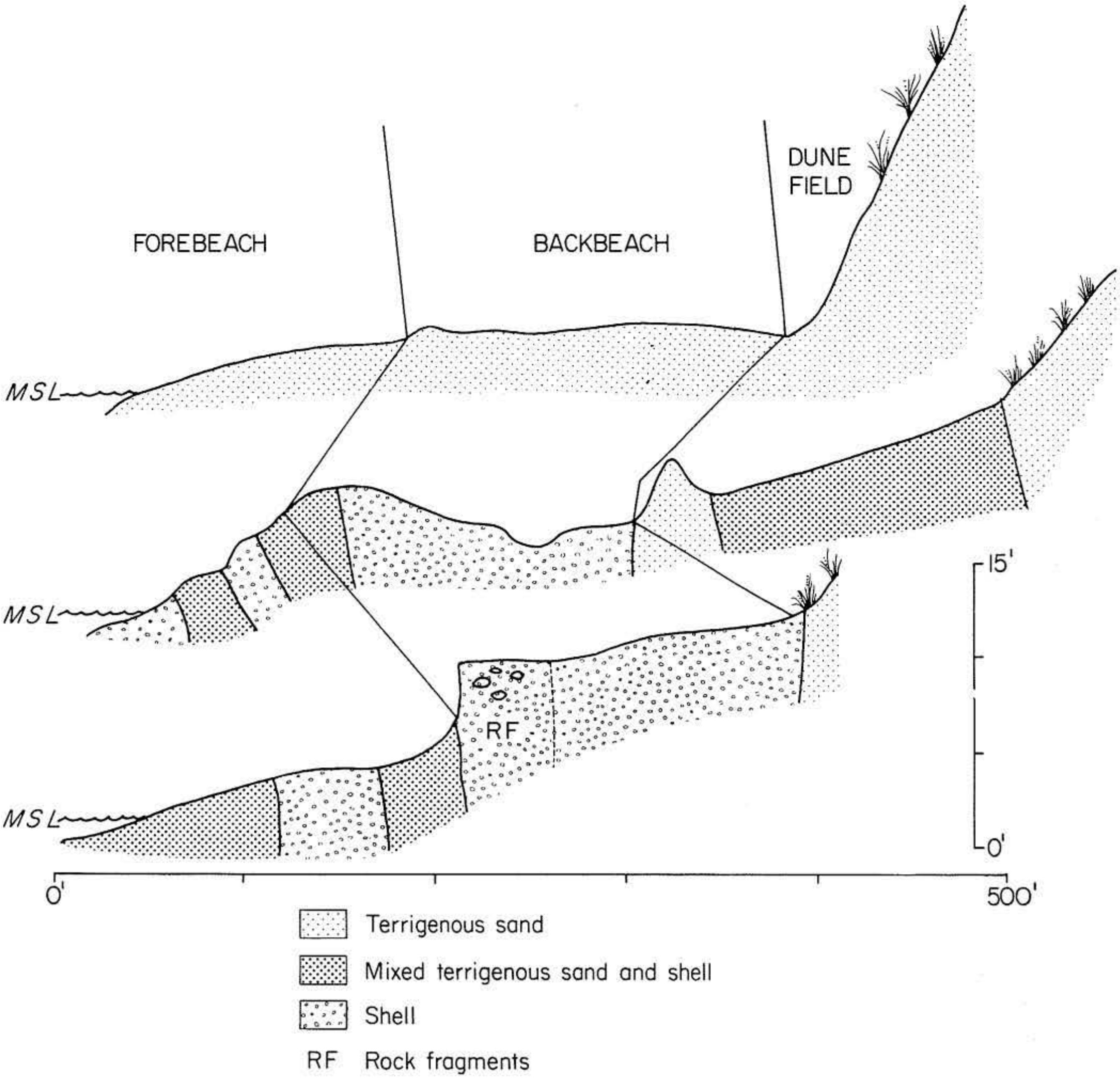

Figure 15. Padre Island beach profiles (January 1972). From top to bottom the profiles are (1) about 8 miles south of the junction between Padre Island and Mustang Island, (2) midway between the junction of Padre and Mustang Islands and the Port Mansfield jetties, and (3) 0.25 mile north of the Port Mansfield jetties. These profiles show only the surface distribution of sediment texture and composition. Beaches become narrow and steep, and height of the backbeach above mean sea level increases as shell content increases.

Although the beach morphology changes as texture and composition changes from terrigenous sand, to fine shell, and finally to coarse shell debris, other morphological features remain virtually the same for north Padre Island. At a point about 30 miles north of Port Mansfield jetties, however, continuity of the fore-island dunes is broken by numerous storm channels. In this central Padre Island area, back-island dunes coalesce to form a continuous, active dune field that is migrating northwestward into Laguna Madre. Fore-island dunes decrease in height to the south; at the Port Mansfield Ship Channel, dunes are low (less than 5 feet), discontinuous, hummocky, and sparsely vegetated.

Active Deltas

Although the Brazos, Colorado, and Rio Grande all discharge directly into the Gulf of Mexico, only the Brazos River is contributing sufficient bedload material to prograde the shoreline. The Colorado River has been discharging into the Gulf of Mexico since 1936. Subsequent to building a delta across Matagorda Bay (Wadsworth, 1966), a channel was dredged through Matagorda Peninsula, and the Colorado River began to discharge into the Gulf of Mexico. No delta exists at the present mouth of the Colorado. Like the Colorado, the Rio Grande is not prograding the Gulf shoreline. Marine processes dominate the area where the Rio Grande enters the Gulf of Mexico; this dominance is indicated by (1) a meandering river pattern to the shoreline, (2) presence of delta-plain muds in the swash zone, (3) erosion of the shoreline, and (4) development of a spit that extends the river course northward parallel to shoreline.

The Brazos River has discharged water and sediment directly into the Gulf of Mexico in the Freeport area for approximately 1,800 years (subsurface data in the Freeport area that are now being evaluated indicate that the 1,800 year date may be too young). During that time interval, the river discharged at three different points. Until about 1,000 years ago, the river discharged about 0.5 mile east of Surfside (Bernard and others, 1970). From about 1,000 years ago until 1929, it discharged about 1.0 mile west of Surfside. Since 1929 the river has discharged about 7.5 miles west of Surfside. At each of these positions, the river constructed a delta. The delta east of Surfside has been completely destroyed by erosion; only a remnant of the second delta 1.0 mile west of Surfside remained in 1974. The river was diverted to its present position by the U. S. Army Corps of Engineers in 1929. From 1929 until 1971, the river prograded the shoreline about 1.25 miles (fig. 16).

The Brazos delta area has the highest rate of shoreline advance found on the Texas coast (Seelig and Sorensen, 1973). Although the Brazos River continues to discharge a relatively large sediment load into the Gulf of Mexico, parts of the delta have experienced erosion (fig. 16). There was rapid

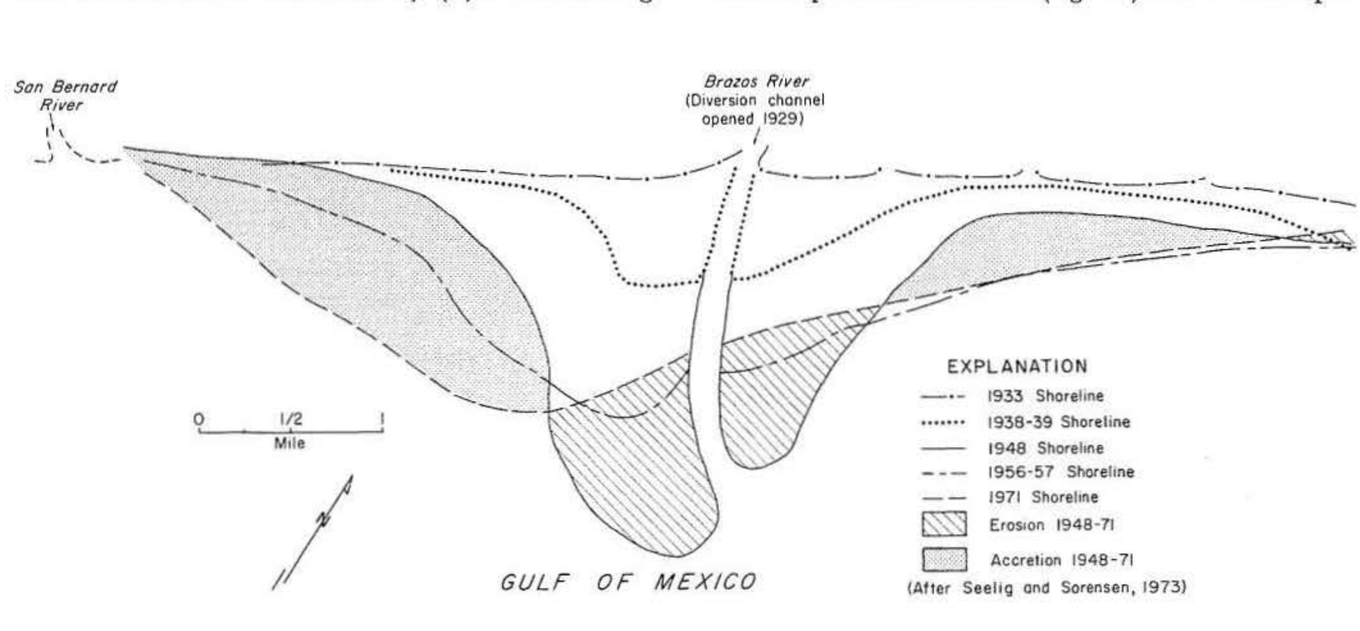

Figure 16. Shoreline changes associated with the Brazos deltas, 1852-1971 (modified from Seelig and Sorensen, 1973).

progradation of the Brazos delta adjacent to the river mouth during the 1933-1948 time interval. After 1948 there was erosion of the delta adjacent to the river (during the 1948-1971 time interval); at the same time, there was shoreline accretion east and west of the river mouth. An estimated total erosion for both the east and west parts of the delta (for 1948-1971) was about 635 acres, whereas accretion to the east and west (during the same time interval) was about 530 acres. The delta continues to prograde the shoreline, but the site of most rapid accretion has shifted westward away from the river mouth (Seelig and Sorensen, 1973).

Although the Brazos River carries the largest sediment load relative to its discharge of any river that empties into the Gulf of Mexico (Nienaber, 1963), the shoreline is undergoing erosion only 4 miles west, down longshore current, from the river mouth (figs. 2 and 9). Sediment is lost from beaches west of the Brazos delta under storm and normal sea conditions. Sediment removed from beaches west of the San Bernard River is not replaced by Brazos River sand, which would normally be expected to move alongshore, because it is trapped in the Brazos delta (Seelig and Sorensen, 1973).

AREAS OF CRITICAL CONCERN

It is evident that most of the Texas Gulf shoreline is in an erosional state. Erosion proceeds slowly with each breaking wave under normal sea conditions but may be as great as a few hundred feet in a matter of hours under storm conditions. Erosion results from the interaction of many variables, and most of these are part of the natural system. First, there is insufficient sand to nourish the beaches, particularly along erosional deltaic headlands. Second, the direction of predominant wind and wave approach, in conjunction with shoreline orientation, determines rates and direction of sediment transport by longshore currents. Direction of wave approach and shoreline orientation dictate rapid sediment transport away from deltaic headlands and away from Follets Island, Matagorda Peninsula, and south Padre Island. Third, subsidence is an important factor because it creates a relative rise in sea level, thereby inundating flat, low-lying coastal areas.

Sand-sized material that is transported by the longshore drift system, which is effective from the shoreline to a depth of about 15 feet, is derived from rivers that discharge directly into the Gulf of Mexico (fig. 17), from erosion of sediment exposed on the inner shelf and shoreface, and from erosion of deltaic headlands. Direction of net sediment transport is away from erosional headlands and river mouths and toward the central and lower coast. Sediment-laden currents moving southwest along the upper coast and north along the lower coast have a net convergence at latitude 27° North (Watson, 1968). The zone of convergence is not fixed; it moves up and down the coast between latitudes 27° and 28° North (based on the work of Bullard, 1942; Lohse, 1952; Curray, 1960; Hayes, 1965; Watson, 1968; Foley, 1974). Because of the longshore drift system and the shifting zone of convergence, beaches that lie within the convergence zone continue to receive sand derived from erosion of other shoreline segments and will, therefore, remain in an equilibrium state for some time. Equilibrium can be disrupted, however, by erecting structures that extend from the shoreline into water depths greater than 15 feet; groins, jetties, or approach channels all serve to trap sand that is transported by the longshore drift system (fig. 17). Natural features may also prevent fluvially transported sand from reaching the beaches. Bays and estuaries are natural barriers to sand transport; sand is trapped near the point where a stream debouches into the bay or estuary. There is no known mechanism that will transport sand from the river mouth across a wide bay bottom and deliver sand to the open Gulf beaches. Dams constructed across major streams that discharge directly into the Gulf of Mexico impound sand that would normally be transported to the Gulf of Mexico to nourish the beaches.

Specific areas of critical concern along the Gulf shoreline include areas in which extensive development coincides with shoreline segments that are undergoing rapid erosion, areas that are characterized by a low profile, and areas of the shoreline that are frequently breached by tropical storms and hurricanes. Principal areas of critical concern are the deltaic headland between Sabine Pass and Rollover Pass, Galveston Island, Follets Island, Sargent Beach, part of Matagorda Peninsula, and south Padre Island (figs. 2 and 9).

Each of these critical areas is in an erosional stage and each is subject to hurricane washover.

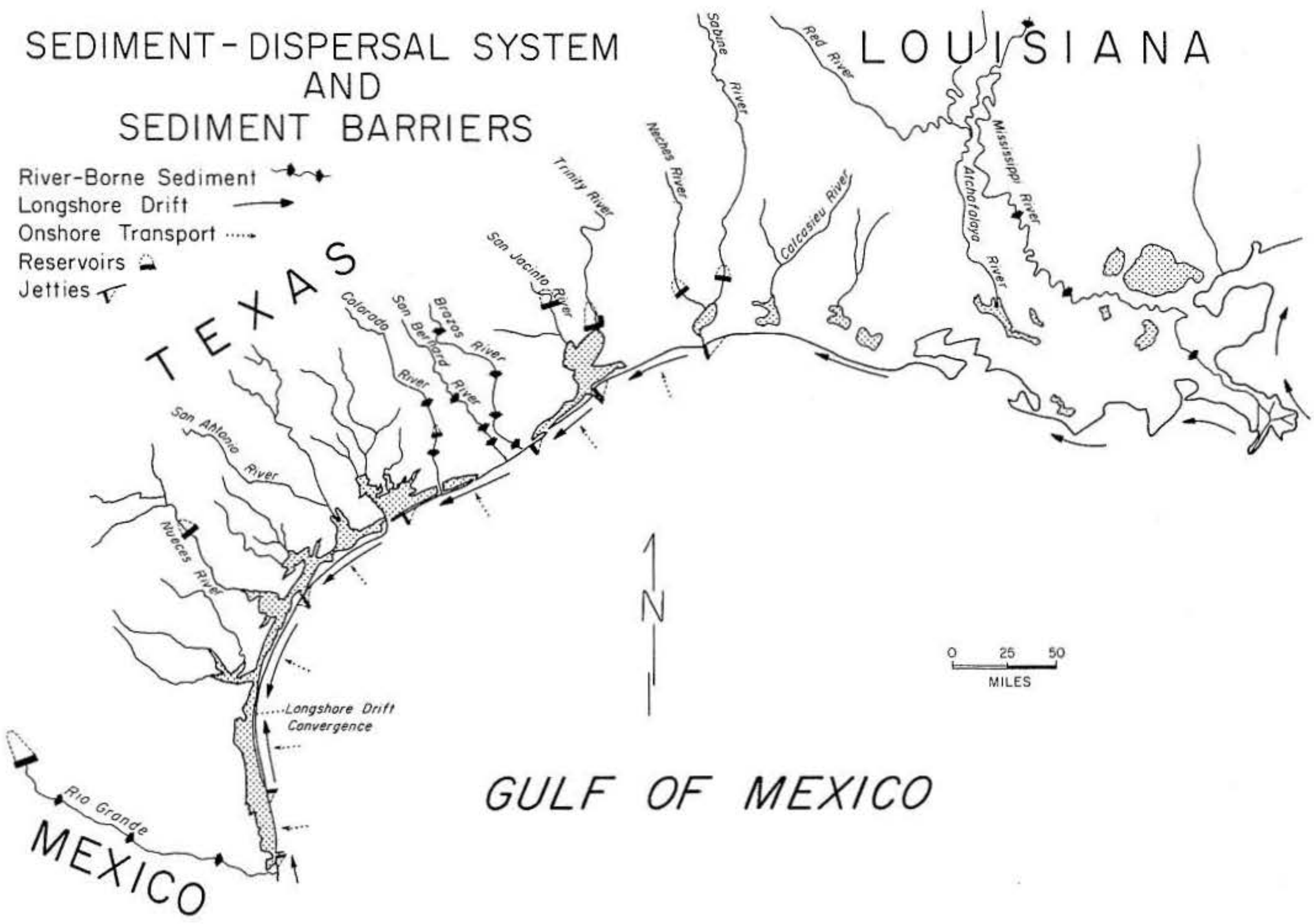

Figure 17. Modern rivers that transport sediment directly to the northwest Gulf of Mexico (the Mississippi, Brazos, San Bernard, Colorado, and Rio Grande), and natural and man-made features that affect sand transport to and along beaches. Additional sediment is transported onshore from the shelf and shoreface. Both shelf and river-borne sediment are transported parallel to the shoreline by longshore currents. On the mainland, dams across major streams trap bedload material, and groins and jetties intercept sand that is transported by longshore currents. Bays and estuaries are natural barriers to sand transport to the Gulf of Mexico.

Much of the development on south Padre Island occurs in an area of rapid shoreline erosion (greater than 10 feet per year) and frequent storm breaching.

Sargent Beach area is eroding rapidly; it is of low relief (2 to 4 feet above sea level) and is washed over by hurricanes and tropical storms. Since the winter of 1970, three rows of beach houses have been moved inland in order to avoid destruction. During that period of time, the shoreline was eroded from 80 to 120 feet. Two groins constructed in the area failed to trap sufficient sand to slow the erosion rate because of the low volume of sand that moved by longshore drift along this coastal segment. Since the groins were placed on marsh and delta-plain mud substrates, they were destroyed. As the shoreline retreated, the groins became detached, and the mud substrate was either squeezed from beneath or eroded from beneath the groins.

Follets Island is eroding rapidly. It is of low relief and readily washed over by storms. This island rests upon marsh, bay, and deltaic muds. It is a thin sand body, about 5 to 8 feet thick, which in part explains rapid shoreline retreat.

Western Galveston Island, which is undergoing erosion, is of low relief and readily washed over by storms. It differs, however, from the other development areas by being relatively wide and densely vegetated. Although this part of Galveston Island is frequently inundated by storm tides, the barrier flat and back-island areas are not eroded and display little physical evidence of the passage of storms. Beaches and incipient dunes are eroded during storms.

Development in the area between Sabine Pass and Rollover Pass has not been extensive. This low-relief area is highly erosional and is frequently washed over by storms. Evidence of destruction of buildings and shoreline retreat is readily apparent. A few wellheads of oil wells that were drilled on the coastal plain are now situated in the swash and surf zones. Pieces of State Highway 87 occur on the beach. This highway, or segments thereof, has been destroyed repeatedly as the shoreline segment has retreated. Pilings of former fishing piers and cottages occur in the swash and surf zones, and parts of concrete foundations and septic systems litter segments of the beach.

Parts of Matagorda Peninsula are currently being developed. Morphology of this peninsula is chiefly the product of storm processes (McGowen and Brewton, 1975). Large storms such as Hurricane Carla (1961) eroded the shoreline west of the Colorado River as much as 800 feet and literally segmented the peninsula into several islands (fig. 18). Matagorda Peninsula and central and south Padre Island are modified more by hurricanes than any other segment of the Texas Gulf shoreline. Hurricane washover channels are numerous in these areas (Brown and others, 1974).

SUMMARY AND CONCLUSIONS

The Texas Gulf coastline is composed of about 367 miles of barrier islands, peninsulas, and erosional deltaic headlands. Peninsulas and barrier islands are separated from the mainland by lagoons and funnel-shaped bays or estuaries. Numerous Texas rivers transport water and sediment to the Coastal Zone. Of these major streams, only the Brazos, San Bernard, Colorado, and Rio Grande discharge directly into the Gulf of Mexico, thereby supplying new sediment for shoreline maintenance to the longshore drift system.

Natural processes that sustain or modify the Gulf shoreline of Texas are generated by, or are the result of, relatively continuous but low-energy (1) astronomical tides, (2) wind regimes, (3) river flow, and (4) slow compaction/tectonic subsidence. Sudden catastrophic changes in the coastline result from the almost yearly impact of tropical storms and hurricanes. Astronomical tides generate currents which move sediment in and out of bays via tidal passes, build tidal deltas, and erode tidal channels. Persistent southeasterly winds and short-lived northers erode the sandy barrier island, transport sand, and construct dunes. Wind is ultimately responsible for generating the system of longshore drift which moves sediment along the shallow bottom adjacent to the Gulf beaches. Persistent winds also generate wind tides that flood broad, flat coastal areas within the bay lagoon system. The Brazos, Colorado, and Rio Grande supply sediment to the longshore sediment-transport system, but dams and irrigation in recent years have diminished the water and sediment discharge into the Gulf of Mexico. Natural subsidence, along with the potential for man-induced subsidence resulting from ground-water discharge, presents a potential for significant changes in shorelines during coming decades. Tropical cyclones and hurricanes produce tidal surges that breach barrier islands and flood lower coastal areas; aftermath rainfall produces severe river flooding.

Shorelines are significantly altered by short-lived hurricane impact, but lower energy, long-term processes generated by tides, winds, rivers, and subsidence are also responsible for modification of the Gulf shorelines. Approximately 60 percent of the Texas Gulf shoreline is in an erosional state, 33 percent is in a state of equilibrium, and 7 percent is currently accretionary. Deltaic headlands, the most highly erosional areas of the Texas coast, occur between Sabine Pass and Rollover Pass, Surfside and Brown Cedar Cut, and Brazos Santiago Pass and the Rio Grande; these areas have exhibited short-term erosion ranging from a few to 80 feet per year and have averaged about 25 to 40 feet per year. Factors controlling shoreline retreat along deltaic headlands include sand deficiency, high angle of wave approach, and subsidence.

Peninsulas along the Texas coast are all erosional except for parts of Bolivar Peninsula west of Caplen that are mostly in an equilibrium or accretionary phase; local areas have recently

Figure 18. Effects of Hurricane Carla, 1961, on a segment of Matagorda Peninsula that lies 1.5 to 6.0 miles west of the Colorado River (see figure 2). (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 (300 feet landward of its pre-Carla position) (after McGowen, 1974).

eroded at rates in excess of 10 feet per year (Brown and others, 1974). Erosional rates for Follets Island and Matagorda Peninsula have ranged from about 2 to 25 feet per year; south Padre Island, a peninsula at one time connected to the Rio Grande delta, displayed erosional rates from about 3 to 46 feet per year. Peninsula shorelines are erosional principally because of sand deficiency, subsidence, and thinness of the sand body. Segments of the beaches of the barrier islands, Galveston, Matagorda, and St. Joseph, have recently become erosional. Other barrier island beaches are in an equilibrium stage. Wide beaches are generally characteristic of barrier islands. Active accretion is associated with the Brazos River delta, but most of the sand entering the Gulf accumulates within a few miles of the river mouth and is not readily available for nourishment of beaches that occur down longshore drift to the southwest.

Longshore currents tend to erode deltaic headlands and move sediment southwest along the Texas upper coast and north along the lower coast to converge between 27° and 28° North latitude. Beaches within the zone of longshore convergence receive sufficient sediment to remain generally in equilibrium. Groins, jetties, and dredged channels that extend into greater than 15 feet of water tend to trap longshore sediment and therefore disrupt the state of equilibrium; deposition caused by artificial structures commonly results in accelerating erosion immediately downdrift from the structure (fig. 19).

Shorelines between Sabine Pass and Rollover Pass, parts of Galveston Island, Follets Island, Sargent Beach, Matagorda Peninsula, parts of Matagorda and St. Joseph Islands, south Padre Island, and between Brazos Santiago Pass and the Rio Grande are generally undergoing erosion. In addition, these areas are also subjected to some of the most intensive breaching by hurricane tides along the entire coastline. With the exception of parts of Matagorda Peninsula, Matagorda and St. Joseph Islands, and the area between Sabine Pass and Rollover Pass, these areas are also undergoing some of the most intensive development in the Coastal Zone. Therefore, these are critical areas because of potential property loss. It is important that development proceed according to the reality of the natural coastal processes and natural hazards.

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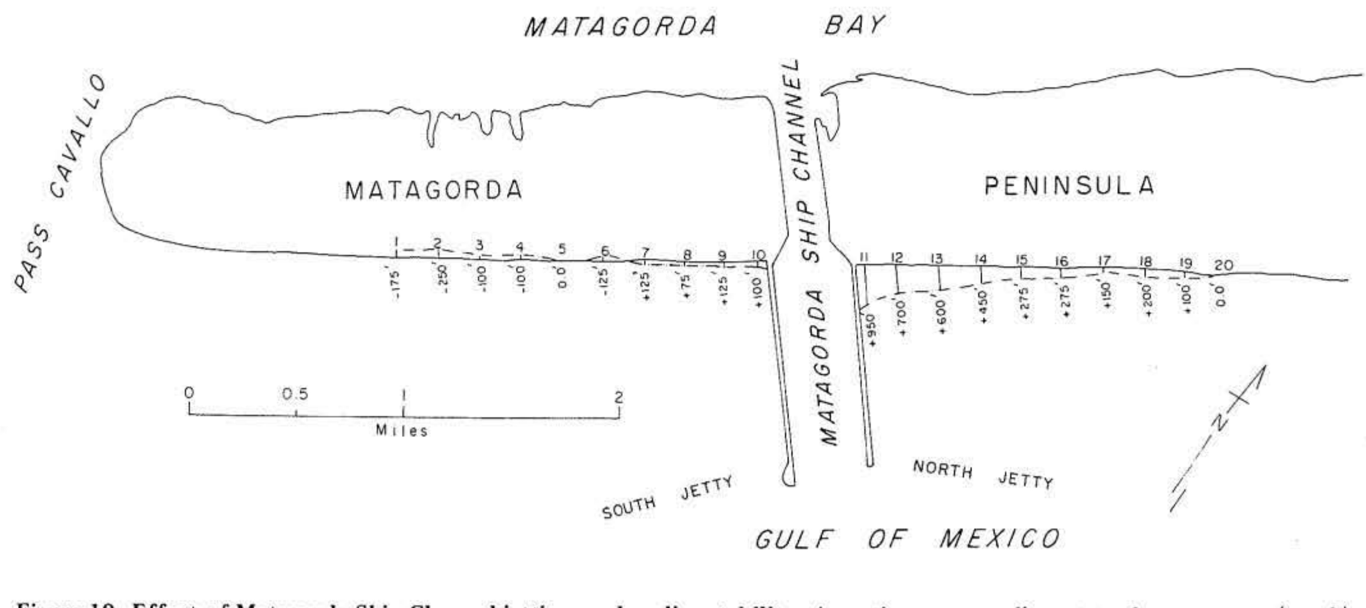

Figure 19. Effect of Matagorda Ship Channel jetties on shoreline stability. Accretion occurs adjacent to the upcurrent (north) jetty; erosion occurs downcurrent from the south jetty. Data (1964 through 1971) from Galveston District, U. S. Army Corps of Engineers (after McGowen, 1974).

from numerous coastal projects conducted by the Bureau of Economic Geology, either in-house or sponsored by the General Land Office of Texas.

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