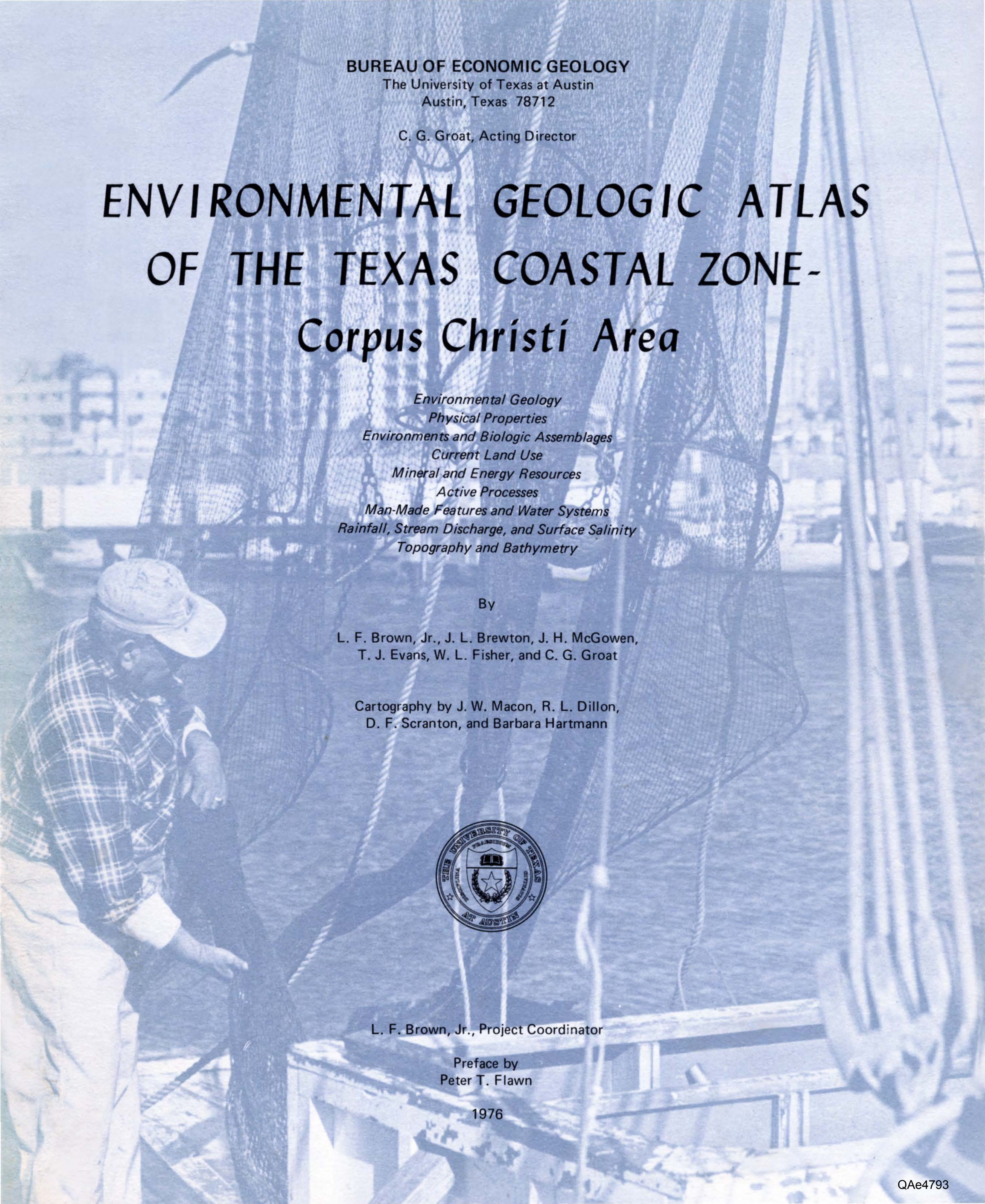

BUREAU OF ECONOMIC GEOLOGY
The University of Texas at Austin
Austin, Texas 78712

C. G. Groat, Acting Director

ENVIRONMENTAL GEOLOGIC ATLAS OF THE TEXAS COASTAL ZONE-

Corpus Christi Area

Environmental Geology
Physical Properties
Environments and Biologic Assemblages
Current Land Use
Mineral and Energy Resources
Active Processes
Man-Made Features and Water Systems
Rainfall, Stream Discharge, and Surface Salinity
Topography and Bathymetry

By

L. F. Brown, Jr., J. L. Brewton, J. H. McGowen,
T. J. Evans, W. L. Fisher, and C. G. Groat

Cartography by J. W. Macon, R. L. Dillon,
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Preface by
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Cover photograph courtesy of the Corpus Christi Chamber of Commerce, 1968.

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PREFACE

The Texas Coastal Zone includes 1,800 miles of bay and Gulf shorelines and 2,100 square miles of shallow bays and estuaries, adjacent to 18,000 square miles of coastal lands. Within the Coastal Zone are more than 135 distinct environments ranging from those relatively stable to those delicately balanced. There is a wide range in climate. The Texas Coastal Zone is a dynamic natural system with a spectrum of active geological, physical, biological, and chemical processes. Shoreline erosion and accretion operate continually to alter the boundary between land and water. Throughout much of the Coastal Zone, this changing land-water boundary is also the boundary between private and public ownership. Continued land loss and land gain are natural processes. Hurricanes strike the Texas coast with almost yearly impact, flooding more than 3,200 square miles of coastal lowlands in the past decade. Active and potentially active faults abound. Land-surface subsidence occurs locally.

The Texas Coastal Zone is richly endowed with natural resources. Mineral production from the Zone, largely oil and gas, has a value of nearly $1 billion per year. The products of commercial fisheries are valued at more than $200 million per year, and the fertile soils of the Zone yield agricultural products valued at $500 million per year. The beaches and waters of the Coastal Zone are a recreation resource that attracts large numbers of tourists and sport fishermen. Three million tourists spend nearly $200 million per year in the Texas Coastal Zone.

Concentrated in this Zone of dynamic natural systems and abundant natural resources are nearly one-third of the State's population and nearly one-third of its total industry. Mineral resources from the Coastal Zone support a huge petrochemical and refining industry. The largest petrochemical complex in the world is in the upper part of the Texas Coastal Zone. Traffic on extensive artificially constructed intracoastal waterways and channels supports major port cities with a large volume of imports and exports. The State is the owner of more than 15 percent of the Coastal Zone, as well as the three-league offshore extension. The State's 15 percent includes the bays and estuaries. The other 85 percent is privately owned.

The Environmental Geologic Atlas of the Texas Coastal Zone, the product of more than 25 man-years of research and analysis at the Bureau of Economic Geology, The University of Texas at Austin, is designed to provide an urgently needed inventory for this most vital area of the State. It is the first of its kind—a truly innovative series of maps to provide data on land and water. The basic environmental geology map delineates and depicts in detail resource units of first-order environmental significance. The accompanying series of eight special-use maps is designed for particular information needs. Included are physical properties and land use suitability, current land use, active physical processes, mineral and energy resources, land (topographic) and submerged land (bathymetric) configuration, natural and artificial water systems, and climate. Statistical tables define and inventory the more than 250 natural and cultural features of the Texas Coastal Zone. A descriptive text explains the data presented, their utility, and means of extrapolating for other special uses. Although predominantly based on original research and mapping by the Bureau of Economic Geology, the Atlas makes use of data from many sources. In designing the Atlas, hundreds of potential users were consulted.

Through inventory and evaluation of Coastal Zone resources, environments, and land and water uses, programs can be established that will permit use of natural resources and maintenance of environmental quality by adjusting use to resource capability. This Environmental Geologic Atlas of the Texas Coastal Zone provides the information framework necessary for management. Within the Texas Coastal Zone, especially in the heavily industrialized and populated upper part of the Zone, land and water uses are extensive, varied, commonly competitive, and in some cases incompatible. Water bodies, for example, are used simultaneously for transportation, for commercial and sport fishing, for recreation, for shell dredging, for oil and gas well locations, for pipelines, and as a part of a waste disposal system. Multiple uses of adjacent coastal lands are as varied and as competitive. A management plan for proper and prudent land and water use must rest on full comprehension of the environments and natural resources that exist in the Coastal Zone, including their capabilities and limitations in sustaining varying levels and kinds of resource use.

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ENVIRONMENTAL GEOLOGIC ATLAS OF THE TEXAS COASTAL ZONE—

CORPUS CHRISTI AREA

L. F. Brown, Jr., J. L. Brewton,[1] J. H. McGowen, T. J. Evans, W. L. Fisher,[2] and C. G. Groat

INTRODUCTION

The Texas Coastal Zone is marked by diversity in geography, resources, climate, and industry. It is richly endowed with extensive petroleum reserves, sulfur and salt, deep-water ports, intracoastal waterways, mild climate, good water supplies, abundant wildlife, commercial fishing resources, unusual recreational potential, and large tracts of uncrowded land in close proximity to major population centers. The Coastal Zone is a vast area of about 20,000 square miles, including approximately 2,100 square miles of bays and estuaries, 367 miles of Gulf coastline, and 1,425 miles of bay, estuary, and lagoon shoreline. About one-third of the State's population and one-third of its economic resources are concentrated in the Coastal Zone, an area including about 6 percent of the total area of the State.

The Texas shoreline is characterized by interconnecting natural waterways, restricted bays, lagoons, and estuaries, low to moderate fresh-water inflow, long and narrow barrier islands, and extremely low astronomical tide range. Combined with these natural coastal environments are bayside and intrabay oil fields, bayside refineries and petrochemical plants, dredged intracoastal canals and channels, and a diverse array of satellite industries. The attributes that make the Texas Coastal Zone attractive for industrialization and development also make it particularly susceptible to a variety of environmental problems.

Parts of the Coastal Zone are among the fastest developing industrial, urban, and recreational regions in Texas; the Zone is at best a precariously balanced natural complex of dynamic environments with a history of almost yearly hurricane impact. Adequate plans to meet the potential problems of pollution, land and water use, and conservation are critically needed to insure proper use of this vital Texas region. Regional analysis and inventory of the total coastal resources of Texas are vitally important and must be based on accurate maps of physical and biological environments, landforms, areas of significant processes, genetic sedimentary or substrate units, and man-made features. The Environmental Geologic Atlas of the Texas Coastal Zone is designed to present information on the nature of the Coastal Zone, what is happening to it, and at what rate changes are taking place. Such information is needed for long-range resource planning and management. Mapping is the fundamental base necessary to provide answers to these critical questions.

ROLE OF ENVIRONMENTAL GEOLOGY IN THE COASTAL ZONE

Development of guidelines for proper and prudent management of the Texas Coastal Zone depends upon adequate knowledge of the nature and distribution of natural environments, land and water capability, and man's impact on the Coastal Zone. Processes and environments are a fundamental part of the geological character of this dynamic region. Many areas of the Coastal Zone are changing under man's accelerating impact. Because the area is balanced in terms of hurricane impact damage, salinity variations within bays and estuaries, plant stabilization of sediments, and a myriad of other critical features, man's impact can significantly affect the natural environmental balance. At the same time, the necessity of resource use in man's modern industrial society is obvious. Development, exploitation, and industrialization practices, however, should be compatible with the natural limitations imposed on the region by its physical, chemical, and biologic setting.

Regional climatic, sedimentary, biologic, and physical process variations along the Texas coast clearly preclude a rigid coastwide system of resource management. Any fair system of management must be based upon the concept of natural variation of environments locally and regionally; correspondingly, flexible guidelines should be firmly based upon these variations in properties, composition, and behavior under various land uses. Environmental geologic maps provide part of the fundamental data needed to create such a system of resource management.

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[2] Assistant Secretary for Energy and Minerals, U. S. Department of the Interior, Washington, D. C.

One principal goal of the Environmental Geologic Atlas of the Texas Coastal Zone is to obtain an understanding of the natural systems *before* human impact irreversibly changes the character of the Zone. Only by understanding the natural coastal system can proper and compatible use of the region be determined. Maps of environmental units within the 367-mile-long Coastal Zone provide a benchmark with which to evaluate future changes and to diagnose appropriate use of the coastal regime.

Wise conservation should include the proper use of Coastal Zone resources within prudent guidelines that will insure minimum modification of the environmental quality of the region. For this reason, each kind of land use should be evaluated in terms of its potential effects on the geological and biological units of the Zone. Proper use will result when each of man's coastal activities is located in a manner that minimizes environmental damage.

The key to proper land and water use is the basic inventory of the coastal environments, sediment types, processes, and biological conditions. The Environmental Geologic Atlas provides this fundamental information that can serve as the basis for evaluating coastal legal problems, socioeconomic problems, industrial development, pollution, recreational needs, problems of public and private ownership, and other factors involving the natural framework of the Coastal Zone.

Several aspects of the Texas Coastal Zone make a long-term resource management program imperative; in turn, this requires a thorough knowledge of the environmental geology of the Coastal Zone. Since the Coastal Zone is the center of rapid geologic and physical changes coupled with a rapidly expanding population, an environmental atlas provides a current record of the status of dynamic coastal environments and processes, as well as a base for continued monitoring of erosion and human modification and exploitation. Dynamic environments can be monitored by periodic mapping that indicates the significant direction and approximate rate of physical, biological, and chemical changes. The environmental map is the common denominator for communication among coastal scientists through which technical input can be integrated and applied. Just as important, economists, planners, utilities specialists, power suppliers, sanitary engineers, lawyers, legislative councils, industrial organizations, regional councils of government, and many other groups can better plan, plot, refer to, and digest environmental data using the Atlas maps.

THE COASTAL ENVIRONMENTAL ATLAS PROJECT

The Environmental Geologic Atlas project was initiated in 1969 when the need for a thorough regional analysis of natural processes, environments, lands, water bodies, and other coastal factors became urgently apparent. Without an adequate environmental inventory, further specialized scientific studies, as well as regional planning for improved use of coastal resources, could proceed neither efficiently nor effectively. Because of impending environmental problems in the region, staff members of the Bureau of Economic Geology assigned the project a high priority and proceeded with the mapping in the summer of 1969. Approximately 30 man-years of geologic and cartographic effort were expended in the five-year period of preparation.

The Coastal Zone, defined from the inner continental shelf to about 40 miles inland, includes all estuaries and tidally influenced streams and bounding wetlands. For purposes of presentation, the Zone was divided into seven areas (fig. 1) from the Texas-Louisiana boundary southwestward to the Rio Grande: (1) Beaumont-Port Arthur, (2) Galveston-Houston, (3) Bay City-Freeport, (4) Port Lavaca, (5) Corpus Christi, (6) Kingsville, and (7) Brownsville-Harlingen. Each of these seven coastal areas is covered by a separate Environmental Geologic Atlas containing a descriptive text, statistical tables, an environmental geology map (scale 1:125,000), and eight special-use environmental maps (scale 1:250,000). The seven coastal atlases cover approximately 20,000 square miles.

Environmental Geology Map

Environmental geology units for the entire Coastal Zone (fig. 1) were interpreted from and plotted on 320 7.5-minute Edgar Tobin Aerial Surveys photomosaics and corresponding U. S. Geological Survey topographic maps, both at a scale of 1:24,000 (approximately 2.5 inches per mile). All environmental maps were printed on a regional base map of the Coastal Zone constructed especially for the Atlas by the Bureau of Economic Geology. The base map was compiled from 7.5-minute U. S. Geological Survey quadrangle maps; 5-foot topographic contours, available bathymetric contours, updated cultural features, and all paved roads are included.

Mapping involved extensive aerial photographic interpretation, field work, aerial reconnaissance, and utilization of available published data for the region. General sources and flow of data used in mapping are shown in figure 2; specific sources of data are noted in the text and itemized under Sources of Supplemental Data. Interpretation and mapping of environmental geologic units were based on a genetic grouping of the major natural and man-made features of the Coastal Zone. Units mapped were interpreted to be of first-order importance to the environmental character of the Zone. First-order environmental units include the following: (1) a wide variety of sedimentary substrates (sand, mud, shell) and associated soil units displaying

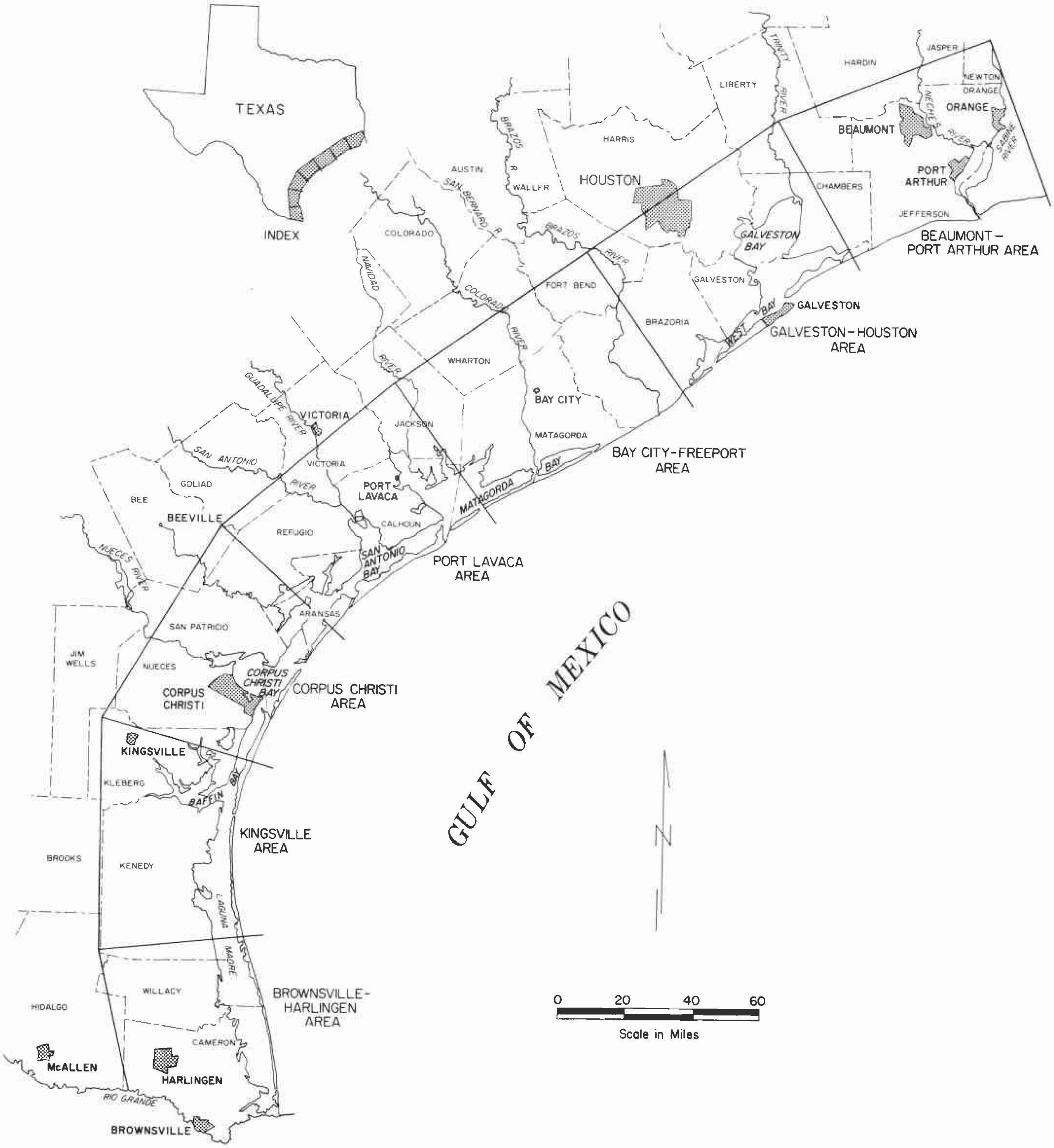

Figure 1. Index of the Environmental Geologic Atlas of the Texas Coastal Zone.

distinct properties and composition; (2) units displaying a variety of natural processes, including storm channels, tidal passes, wind-tidal flats, fluvial channels, wind erosion, and other dynamic properties of significance in maintaining and modifying the coastal environments; (3) biologic features such as oyster reefs, marshes and swamps, subaqueous grassflats, and plant-stabilized sediment where biologic activity is of principal importance; and (4) man-made features such as spoil heaps, reworked spoil, dredged channels, and made land where man's activities have resulted in significant environmental modification. Approximately 150 specific environmental geologic units are recognized and mapped in the Texas Coastal Zone.

Environmental geology map units are grouped into higher order natural systems. Fluvial-deltaic, barrier-strandplain, and bay-estuary-lagoon systems, for example, include a variety of natural substrate, biologic, or process units and environments that are interrelated with respect to their origin and distribution within the Coastal Zone. Man-made features are separately grouped to clearly differentiate natural and artificial features.

Environmental geology maps are presented at a scale of 1:125,000, or 2 miles per inch. Compilation work maps (1:24,000) are maintained on open file at the Bureau of Economic Geology. The currentness of aerial photographs, topographic maps, and navigational charts used in the project can be determined by referring to figure 3, which provides specific information on the dates of photography and map or chart revision. Edgar Tobin Aerial Surveys photomosaics provided uniform coverage of the entire Coastal Zone.

Remapping in future decades with updated aerial photography and other multispectral remote sensing devices carried by aircraft and satellites will provide a valuable historical reference to rates and degree of both natural and man-made changes in the Coastal Zone. The Atlas is, therefore, an open-ended document which can be updated to maintain a current record of the change

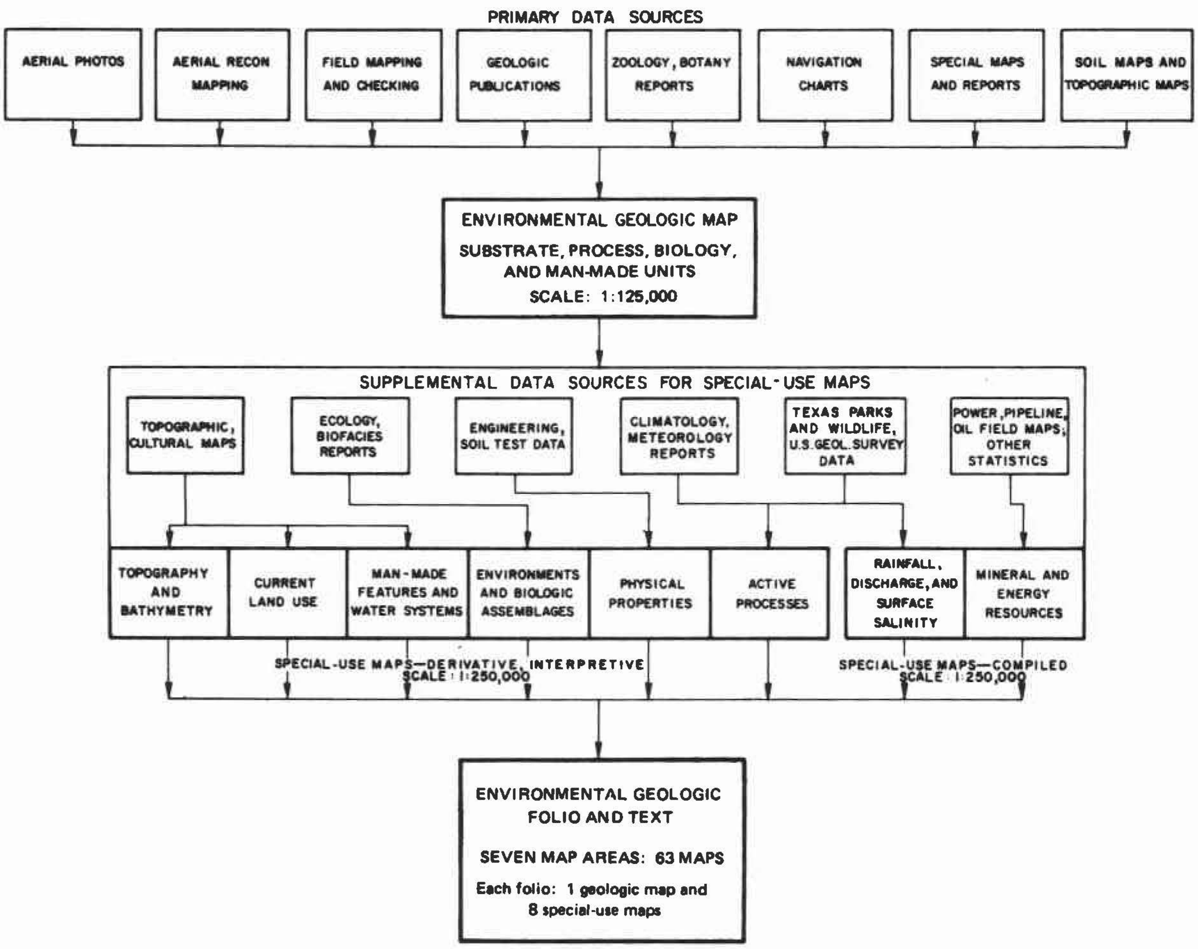

Figure 2. Sources and flow of data for the Environmental Geologic Atlas of the Texas Coastal Zone.

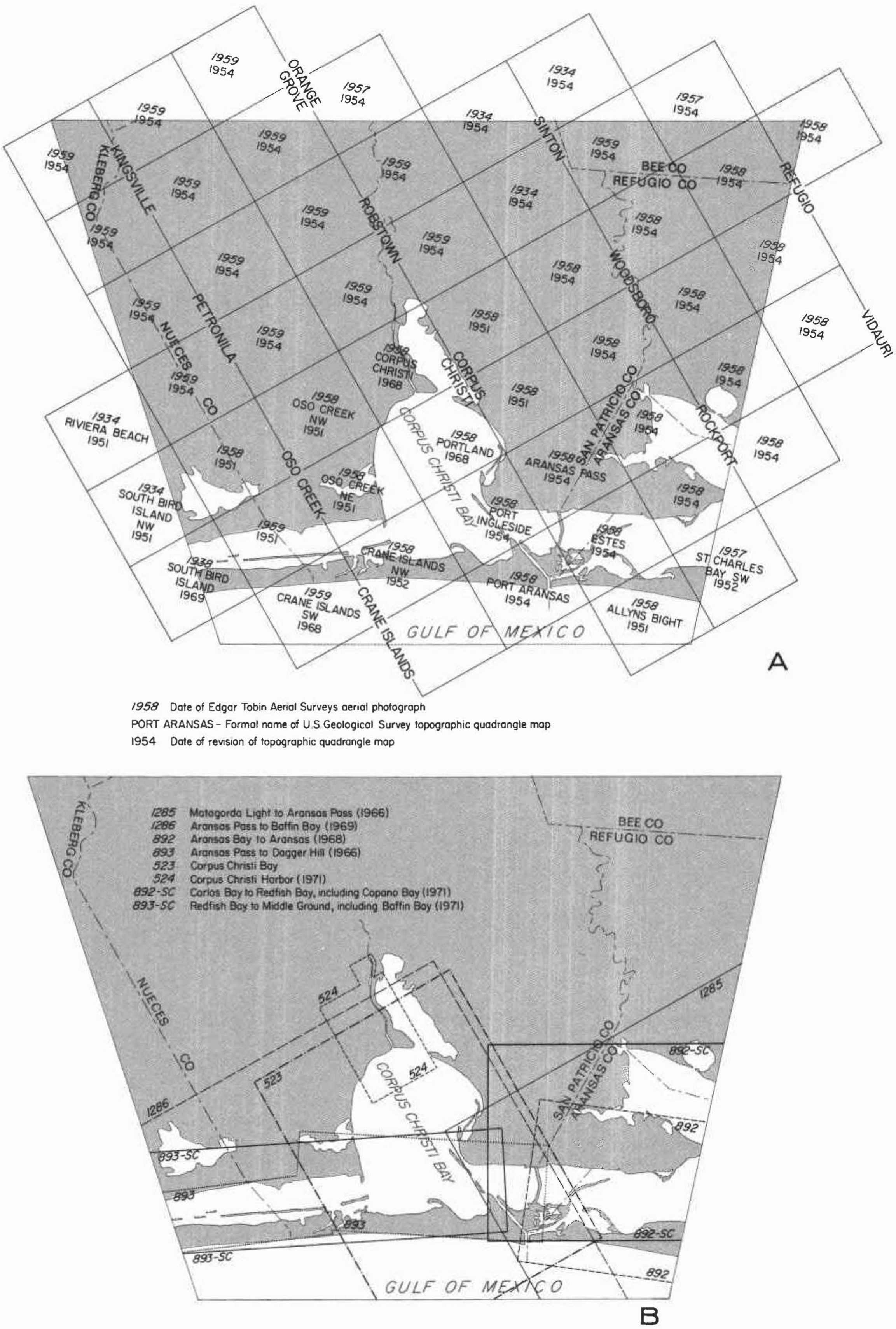

Figure 3. Source and dateline for principal data used in mapping the Corpus Christi map area. (A) U. S. Geological Survey topographic maps and Edgar Tobin Aerial Surveys photographic mosaics showing name, date of map revision, and date of aerial photography. (B) U. S. Coast and Geodetic Survey nautical charts showing chart number, name, and publication date.

and modification of the region. It is also anticipated that the Atlas will serve to stimulate interest in and provide the environmental baseline for many more specialized and localized studies addressed to specific pollution, land use, ecologic, economic, and resource problems.

Special-Use Environmental Maps

Following preparation of the *Environmental Geology Map* for each of the seven areas of the Coastal Zone, a series of special-use environmental maps was prepared to present more specific information for a variety of potential users. These special-use maps represent but a few of the kinds of maps that can be compiled or interpretatively derived from the basic environmental geology map. Maps prepared include the following: (1) *Physical Properties*—characterizing substrate and landform conditions for specific uses such as engineering, construction, and waste disposal, based on properties such as permeability, fluid transmissibility, shrink-swell potential, water-table position, load strength, local relief, and potential for surface faulting; (2) *Environments and Biologic Assemblages*—characterizing bottom-living plants and animals in bays, estuaries, and lagoons, and principal plant communities on land areas; (3) *Current Land Use*—inventorying use patterns in the area, including such classifications as agricultural lands, range-pasture lands, woodland-timber lands, spoil, made land, general recreational lands, wildlife refuges, residential-urban lands, and industrial lands; (4) *Mineral and Energy Resources*—presenting extensive information about current resources and facilities, such as salt, sulfur, oil and gas, quarries, lime and cement plants, LPG storage, major metal-refining and petrochemical complexes, power-generation plants, and pipelines, and about the distribution of potential sources of sand and fill material; (5) *Active Processes*—displaying features such as storm-surge flood areas, shoreline erosion and deposition, areas of rapid and slow deposition, and hurricane-washover areas; (6) *Man-Made Features and Water Systems*—depicting the distribution of features such as made land, types of spoil, jetties or piers, seawalls, residential and industrial developments, artificial and natural water bodies, drainage or irrigation canals, ship channels, abandoned streams and cutoffs, wind-tidal flats, and other related features; (7) *Rainfall, Stream Discharge, and Surface Salinity*—displaying data collected for a representative 3-year period, including U. S. Weather Service rainfall data, U. S. Geological Survey gaging station data, and contour maps of surface salinity within bays, estuaries, and lagoons for periods of high and low rainfall, as well as calculated 3-year averages; and (8) *Topography and Bathymetry*—utilizing U. S. Geological Survey topographic data and U. S. Coast and Geodetic Survey bathymetric data.

Special-use environmental maps focus attention upon properties and characteristics of a specific nature, allowing a user to evaluate the Coastal Zone in terms of specific properties that are desirable or specific conditions to be avoided. Data such as pipeline distribution and oil-field areas are compiled from other sources, but most critical data were derived from the *Environmental Geology Map* by grouping or combining map units possessing common properties.

SOURCES OF SUPPLEMENTAL DATA

The Environmental Geologic Atlas of the Texas Coastal Zone is constituted primarily of basic information generated and presented by the research and cartographic staff of the Bureau of Economic Geology. In addition to field work, mapping, and other basic studies by the Bureau staff, certain published and commercial sources of data were utilized in preparation of the Atlas. The writers are responsible for selection, interpretation, and conclusions based on compiled data used to supplement original work of the research staff. Although a bibliography credits sources of scientific and technical information and ideas, the writers wish to acknowledge specifically those data compiled all or in part from the following sources:

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Brown, L. F., Jr., Fisher, W. L., and Malina, J. F., Jr., 1972, Evaluation of sanitary landfill sites, Texas Coastal Zone—Geologic and engineering criteria: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 72-3, 18 p.

Texas State Health Department, Unpublished data: Austin, Texas State Health Dept.

Water resources. See *ground water, aquifers.*

Water systems, drainage or irrigation ditches and canals, artificial reservoirs, natural lakes and ponds. See *topography.*

Wind. See *climatic data.*

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CORPUS CHRISTI AREA

GENERAL SETTING

The Environmental Geologic Atlas of the Corpus Christi area covers an area of approximately 2,350 square miles, excluding offshore areas. Included in the map area are parts of Aransas, Bee, Jim Wells, Kleberg, Nueces, Refugio, and San Patricio Counties, Texas. The area includes the cities, towns, and small hamlets of Annaville, Aransas Pass, Banquete, Bayside, Bishop, Bonnie View, Calallen, Clarkwood, Copano Village, Corpus Christi, Driscoll, Edroy, Flour Bluff, Fulton, Gardendale, Gregory, Highway Village, Ingleside, Lon Hill, McNorten, Midway, North Beach, Odem, Papalote, Peary Place, Petronila, Port Aransas, Portland, Rabb, Robstown, Rockport, San Juan, Sinton, St. Paul, Taft, Violet, West Sinton, West St. Paul, and Woodsboro.

Approximately 1,960 square miles of land occur within the Corpus Christi map area. Broad areas of relatively flat coastal prairies, chaparral pasture land, and farm land occur inland from the extensive bays. The broad, flat uplands are broken into several segments by west-trending Corpus Christi and Nueces Bays, southwest-trending Copano Bay, and by Petronila, Oso, and Chiltipin Creeks, and Nueces, Aransas, and Mission Rivers. Water-tolerant hardwoods extend along the upper reaches of Aransas and Mission Rivers; willows occur along the banks of the Nueces River, and mesquite and huisache occupy the adjacent floodplain.

The coastal plain is gently inclined gulfward at about 3 feet per mile; slope is as high as 5 feet per mile in the northeastern map area between the Aransas and Mission Rivers. Maximum elevation in excess of 140 feet above mean sea level (MSL) occurs in the northeastern part of the area, in Bee County just south of Burkes Ridge.

Marshes in the Corpus Christi map area are smaller than those to the east. Marshes are present on the bayside of barrier islands, along mainland shorelines, and adjacent to coastal lakes such as Laguna Larga. The most extensive marshes are situated on the Nueces and Mission delta plains; the largest fresh-water marshes are adjacent to Laguna Larga and just inland of Live Oak Ridge. Most marshes are developed in areas inundated by a few inches of bay water to areas about 5 feet above MSL. Marshes extend from the distal delta plain (salt-water marsh) upriver a distance of 5 (Mission River) to 11 miles (Nueces River). Swamps are poorly developed in the map area but occur in oxbows along the Mission and Nueces Rivers. Marshes and swamps are commonly flooded during hurricanes.

Valleys of Nueces, Aransas, and Mission Rivers cut into the coastward-sloping land surface. Approximately 50 feet of relief occurs locally along the Nueces valley, and about 20 feet of relief is present along both the Aransas and Mission Rivers. Steepest slopes of the Nueces River valley occur along the south bank near the head of Nueces Bay. Steepest slopes along Aransas River are just above the confluence with Chiltipin Creek, and those along Mission River are in the vicinity of the confluence with Melon Creek.

Approximately 40 percent of the map area is underlain by muddy sediments and various associated clay soils. Highly permeable sand substrates and soils with local relief up to 25 feet occur in a north-northeast trend chiefly along the bay shores of Aransas and Redfish Bays and Laguna Madre; these sands occupy about 6 percent of the map area. Padre, Mustang, and St. Joseph[3] Islands are constructed of highly permeable sand and shell bodies having maximum elevation of about 45 feet above MSL and ranging in thickness from about 30 to 75 feet. Mission, Aransas, and Nueces river valleys are floored with sand, muddy sand, and mud. Other sand and muddy sand deposits represent ancient river courses that trended north to southeast. Width of

[3]Subsequent to printing the maps in the Corpus Christi Atlas, the Topographic Division of the U. S. Geological Survey changed the name of St. Joseph Island to San Jose Island.

these preserved river deposits is about 0.5 mile to 1.5 miles for single systems; the systems coalesce in some areas to form belts up to 16 miles wide. These ancient river courses generally display less than 5 feet of local topographic relief.

Mission, Copano, Aransas, Redfish, Corpus Christi, and Nueces Bays, Laguna Madre, and associated water bodies occupy about 350 square miles of the area. Bays are generally less than 6 feet deep with maximum depth of approximately 13 feet in Corpus Christi Bay. Dredged channels are maintained at various depths by the U. S. Army Corps of Engineers for deep- and shallow-water access to ports at Harbor Island, Aransas Pass, and Corpus Christi. A single natural pass and one artificial pass connect the bays with the Gulf of Mexico. These are Aransas Pass and Fish Pass (Corpus Christi Water Exchange Pass), respectively. Aransas Pass, now stabilized by jetties and frequently dredged by the U. S. Army Corps of Engineers, is about 42 feet deep. Fish Pass, dredged in 1972, had a depth of 8 to 11 feet and is gradually filling with sediment. On the gulfside of St. Joseph, Mustang, and Padre Islands, the sea floor slopes gulfward at about 32 feet per mile from 0 to 3 fathoms, about 21 feet per mile from 3 to 5 fathoms, and about 6 feet per mile from 5 to 8 fathoms.

RESOURCE ACTIVITIES

Land use within the Corpus Christi map area is divided principally among agricultural land, range-pasture land, industrial land, urban-residential and urban-commercial land, recreational land, park and recreational facilities, military installations, and marsh-covered tracts with abundant wildlife. Cropland is concentrated primarily on the gently sloping coastal plain or prairie. Ranching, also an important enterprise, is conducted throughout the area on barrier islands, prairies, river valleys, and uplands. Industry is situated in the Ingleside-Portland area, near Woodsboro, and in the Corpus Christi area. Major industrial sites are the aluminum plant between Portland and Ingleside and refineries and petrochemical plants in the Corpus Christi port area. Oil and gas fields are distributed throughout the map area with the larger fields occurring in the Robstown-Driscoll-Bishop region. Railroads, highways, dredged channels, pipelines, and major power transmission systems are uniformly distributed throughout the area.

Natural lakes and ponds are present in the valleys of Melon Creek and Mission, Aransas, and Nueces Rivers. Large holding ponds have been constructed adjacent to Port Bay, near Gregory, on Encinal Peninsula, and near Bishop. A large surface reservoir has been built in the southwest corner of the map area west of San Fernando Creek, and a drainage system has been constructed to drain parts of the predominantly agricultural land in the central part of the map area.

Coastal marshlands constitute important waterfowl habitats and provide nesting sanctuaries along the Texas Gulf coast. Padre Island National Seashore is an extensive legally protected sanctuary.

Dredge spoil occurs along the Intracoastal Waterway, Corpus Christi Ship Channel, Lydia Ann Channel, La Quinta Channel, Viola Channel, Tule Lake Channel, and the Turning Basin at Corpus Christi. There are several small to large airfields available to the private citizen within the map area with several large airfields in the vicinity of Corpus Christi. Small airstrips are present near Sinton, Fulton, Aransas Pass, Port Aransas, and Robstown.

Resources produced in the area include oil and gas, sand, clay, and gravel. Agricultural products include cattle, hogs, poultry, horses, grain sorghums, corn, cotton, flax, and vegetables. Refineries, petrochemical and carbon plants, and facilities for aluminum processing and fish processing are situated near ship channels in the Corpus Christi map area. Aransas Pass provides access to the open Gulf for recreational and commercial fishing. A large volume of both deep-water and intracoastal shipping flows into and out of the Corpus Christi area.

The bay and estuary waters of the Corpus Christi map area are subject to multiple and often conflicting uses. They are sites of commercial and sport fishing, recreation, transportation, and mineral production including fill material and oil and gas.

GEOLOGY AND GEOLOGIC HISTORY

The Texas Coastal Zone is composed of several active, natural systems of environments: fluvial-deltaic, barrier-strandplain-chenier, and bay-estuary-lagoon systems, as well as an eolian (wind) system in South Texas and a well-developed marsh-swamp system in the more humid middle and upper coastal regions. Geologists are also aware that the Coastal Zone is underlain by sedimentary deposits that originated in ancient but similar coastal systems. These sediments were deposited by the same natural processes that are actively shaping the present coastline, for example, longshore drift, beach swash, wind deflation and deposition, tidal currents, wind-generated waves and currents, delta outbuilding, and river point-bar and floodbasin deposition.

Active and relict coastal systems in the Corpus Christi area (fig. 4) are divided into three principal groups based on their relative ages: (1) natural systems that originated more than 18,000 years B. P. (before present) during various interglacial periods of the *Pleistocene* ice age; (2) natural systems termed *Holocene* that originated between approximately 18,000 and 4,500 years B. P.; and (3) natural systems herein termed *Modern* that have been developing since about 4,500 years B. P. and are currently active (fig. 5). Carbon-14 dates (for example, Nelson and Bray, 1970) indicate that, following numerous late Pleistocene glacial and interglacial episodes, sea level began its final rise about 18,000 years B. P. (fig. 5C). Sea-level rise was punctuated by numerous stillstands and even some reversals.

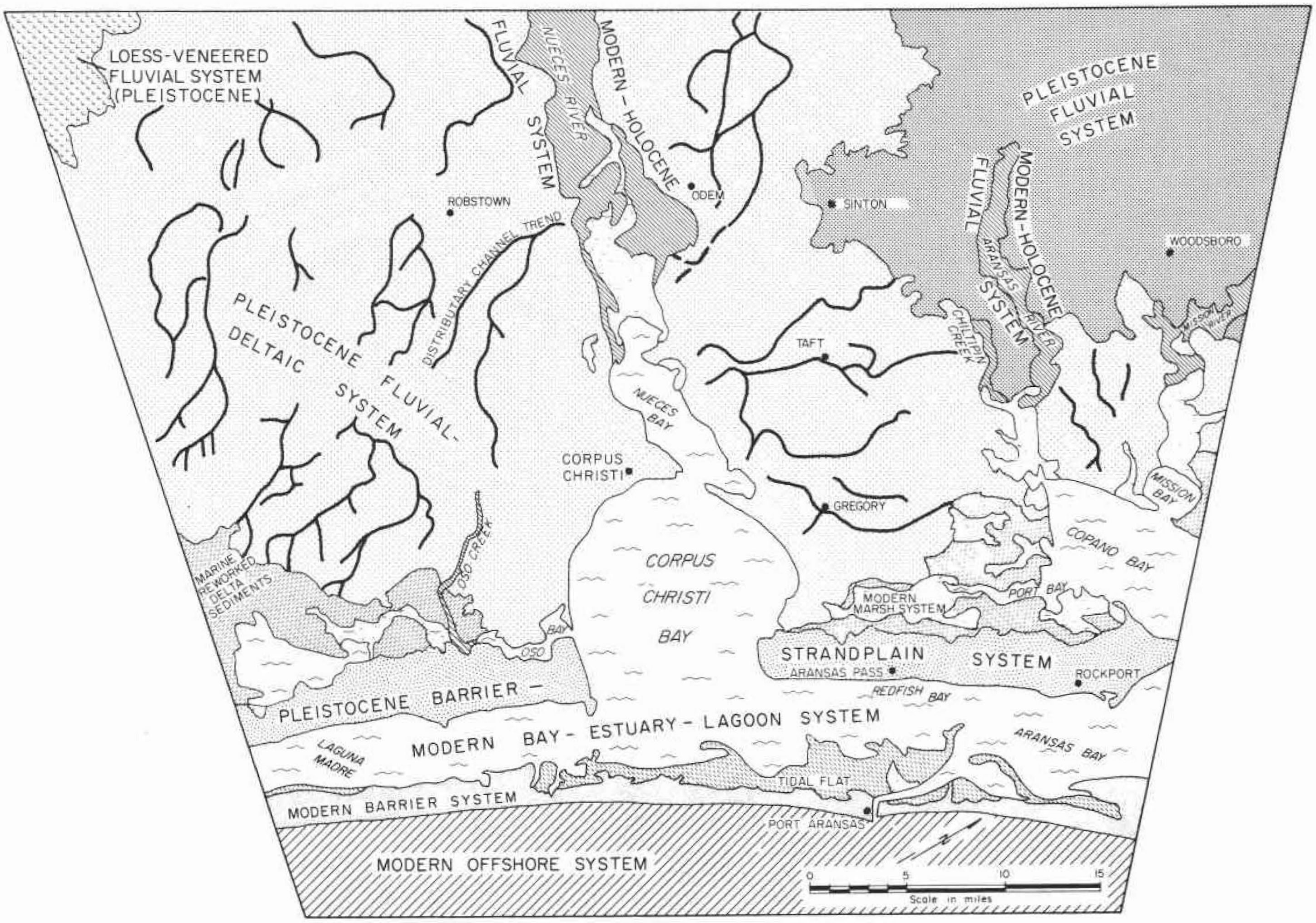


Figure 4. Natural systems defined by environmental mapping in the Corpus Christi area. These systems are composed of genetically related environments, sedimentary substrates, biologic assemblages, areas of significant physical processes, and man-made features. Simplified from the *Environmental Geology Map* of the Atlas.

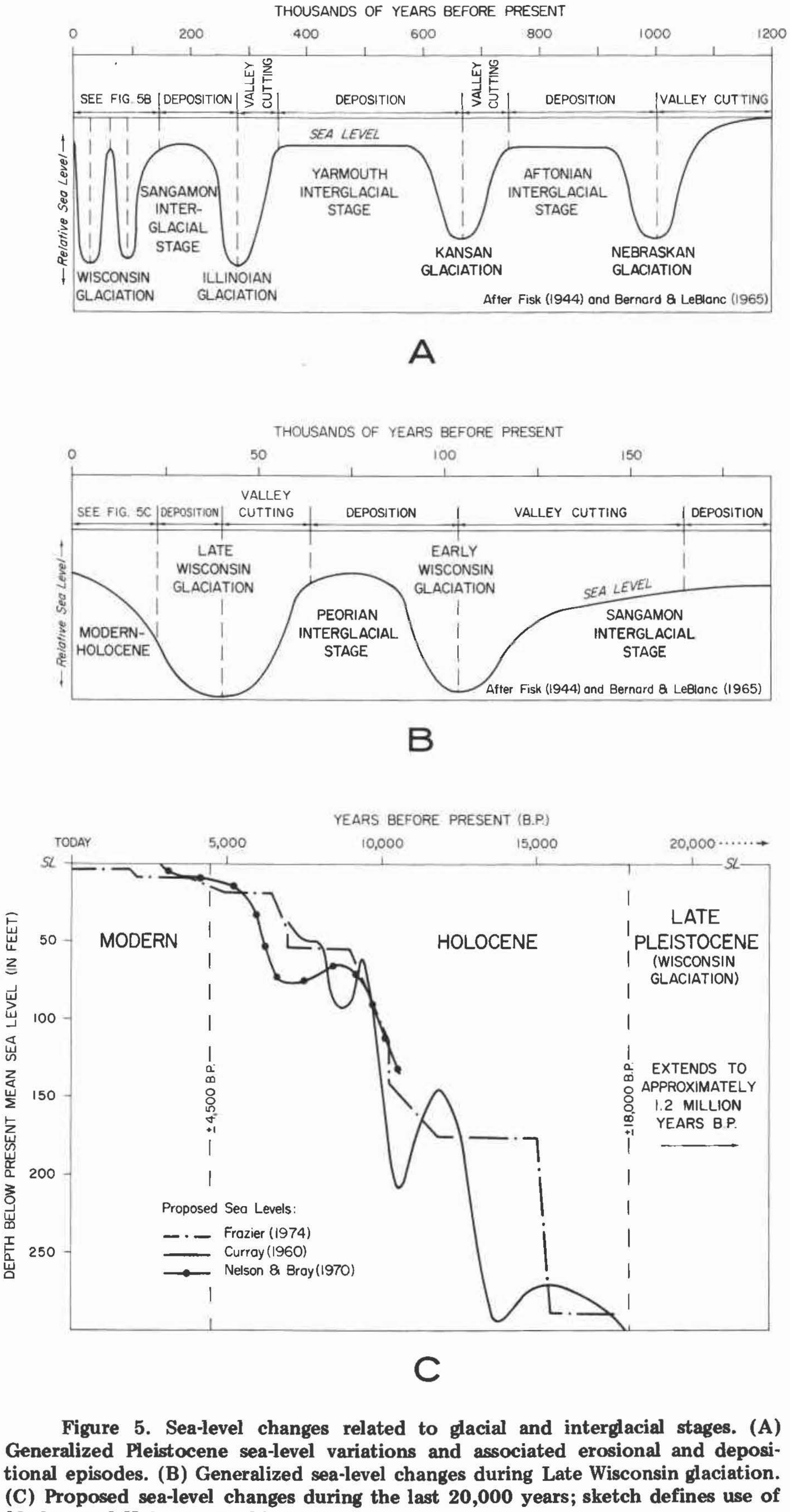


Figure 5. Sea-level changes related to glacial and interglacial stages. (A) Generalized Pleistocene sea-level variations and associated erosional and depositional episodes. (B) Generalized sea-level changes during Late Wisconsin glaciation. (C) Proposed sea-level changes during the last 20,000 years; sketch defines use of *Modern* and *Holocene* used in text.

At 6,600 years B. P., sea level was -72 feet MSL (present mean sea level); at 3,600 years B. P., it was -16 feet MSL; and by 2,800 years B. P., sea level had reached approximately its present level. At about 4,500 years B. P., many significant coastal processes began that are still in operation today. For convenience in this Atlas, therefore, post-Pleistocene time has been divided into Holocene, during which principal sea-level rise occurred (18,000-4,500 years B. P.), and Modern, which includes all events since about 4,500 years B. P.

Modern coastal systems are characterized by a distinctive suite of natural environments in which certain geologic processes result in deposition of unique sedimentary units. Modern deposits are similar in every respect to older sedimentary deposits of Pleistocene or Holocene age; therefore, these relict deposits can be interpreted as having originated within genetically similar ancient environments. For example, Modern river or fluvial systems are composed of levee, point-bar, and floodbasin environments, in which certain types of sediment are deposited by specific geologic processes. Similarly, levee, point-bar, and floodbasin deposits of Pleistocene or Holocene age can be interpreted as having been deposited in similar environments within an ancient river system.

A knowledge of processes that are active within Modern environments is critical if the environmental impact of various types of human activity is to be evaluated. Stated simply, natural environments must be properly understood if they are to be managed and protected. Just as important environmentally, but perhaps less obvious to most citizens, is an understanding of the ancient sedimentary substrates underlying the Coastal Zone. These relict deposits of ancient coastal environments determine to a great extent the suitability of coastal lands for various uses and human activities. Similarly, the sedimentary deposits of these older Pleistocene and Holocene systems dictate the character of soils, wildlife, vegetation, ground water, natural resources, and all manner of aspects that are important to the environmental quality of the region. For these reasons, it is critical that the nature of the environments, processes, and sediment substrates for all *active* coastal systems and the relict sedimentary substrates for all *ancient* coastal systems be determined and mapped so that a scientific basis for environmental management can be developed.

A principal goal of the Environmental Geologic Atlas of the Texas Coastal Zone is to describe active environments and relict sedimentary deposits. An appreciation of the geologic history of this dynamic region will enable the reader to envision the sequence of geologic events that has created and shaped the present Texas Coastal Zone. The geography of the region has evolved slowly through time as climate, sea level, and other environmental factors have changed. The present Coastal Zone is, therefore, but one frame in a kaleidoscope of changing rivers, shifting beaches, and subsiding plains. Past geologic events and current geologic processes join in characterizing the nature of the *total* coastal environment and in pointing to inevitable future changes that man must learn to understand, predict, and manage. In short, the Coastal Zone is characterized by natural change; man's activities may significantly affect the rates and directions of these changes.

PLEISTOCENE HISTORY

The Pleistocene ice age encompassed more than a million years of complex glacial and interglacial climate and sea-level changes (fig. 5A). It consisted of at least four principal glacial episodes separated by warmer interglacial periods; many minor warming periods or interstadial events complicated the history of each major glacial episode. Sea levels during maximum glaciation were 300 to 450 feet lower than during warm interglacial periods because a large volume of the world's water was trapped as thick continental ice sheets (Curray, 1960; Bernard and LeBlanc, 1965).

During interglacial stages of the Pleistocene, while glaciation had diminished and sea level was approximately at the present level, large rivers transported vast amounts of suspended mud and bed-load sand from remote areas of Texas to deltas within broad embayments along the ancient Gulf shoreline. As sediment passed through these ancient rivers, sandy point bars were deposited in shifting meander loops, and levees were built along vegetated riverbanks. During flood stages, the rivers overflowed their banks, and sediment was introduced into adjacent floodbasin depressions, in part as sandy crevasse splays, but mostly as mud and silt floodplain deposits.

In the course of thousands of years, the shifting, meandering rivers deposited meanderbelt sediment composed primarily of point-bar sand, but local pockets of floodplain mud and silt were preserved within the dominantly sandy river sediment. Pleistocene meanderbelt sand and various floodplain mud deposits are presently exposed over about 285 square miles of the inland part of the Corpus Christi map area (fig. 4). These ancient river deposits are restricted to an area north of Sinton and west of Copano Bay; U. S. Highway 181 marks the southern boundary of the area, and U. S. Highway 77 crosses the eastern part of the Pleistocene fluvial deposits between Sinton and Woodsboro. Pleistocene river sands form elongate deposits oriented in an east to southeast direction; continuity of these sand bodies is broken by Aransas and Mission Rivers and Sous and Medio Creeks. The Pleistocene fluvial system that is exposed in the Corpus Christi map area comprises the southeastern part of the ancient Guadalupe-San Antonio river system which is widely distributed in the adjacent Port Lavaca map area. Associated with Pleistocene fluvial sands are patches of overbank mud and mud-veneered sands. Mud-filled channels and lakes also occur within the fluvial system.

Pleistocene meandering streams changed coastward into slightly sinuous delta distributary courses that extended across broad, low deltaic plains (fig. 4). Sand and mud deposited at the mouth of distributaries slowly extended delta lobes, building land at the expense of the ancient Gulf embayments. Currents redistributed some of the deltaic sand and mud, but most of these sediments compacted and subsided beneath the advancing delta lobe.

Along the distributary channels, overbank flooding added mud, silt, and some sand to broad interdistributary embayments; lower or coastward parts of the embayments were occupied by small marine to brackish bays and lagoons fringed with salt marsh. Farther inland, the bays gave way to brackish- and fresh-water lakes and marsh and eventually to floodbasin swamps. As delta lobes built farther into the marine embayment, they became overextended. Sudden upstream shifts of rivers sent water and sediment pouring into the bay along shorter, more direct, and higher gradient courses. Distributaries were thus abandoned and later reoccupied repeatedly as the embayments filled with deltaic sediment.

Many coastward-trending segments of ancient delta distributaries are still exposed at the surface within the coastal upland prairies of the Corpus Christi map area (fig. 4). Most of the channel-mouth bar sands and prodelta mud deposits are now buried beneath younger floodbasin mud and silt. Locally, marine-reworked delta-front sand and silt are exposed in the Port Bay area and along the western shore of Laguna Larga; these deposits are commonly veneered by younger Pleistocene or Holocene lagoonal or lacustrine muds. The delta-front deposits extend beneath younger deposits as far eastward as the inner shelf area of the Gulf of Mexico.

Distributary channel sand bodies are slowly subsiding into the underlying delta mud, so that some segments are discontinuous and have been partially covered by later deposits. The courses of relict distributary streams are marked principally by higher levee deposits that still stand a few feet above the old deltaic plain. Abandoned, mud-filled river meanders, called oxbow lakes, represent relict streams that supplied the prograding delta distributary courses. Mud-filled lakes occupy some interdistributary areas. About 1,150 square miles, or 50 percent of the map area (fig. 4), are underlain by a variety of Pleistocene interdistributary and floodbasin mud and sandy distributary deposits. Fertile soils have developed on these delta deposits and presently support extensive agricultural development.

Most of the ancient deltaic deposits exposed on the flat, gently sloping coastal plain within the Corpus Christi area are part of the late Pleistocene Nueces system (fig. 4). South of the Modern Nueces River, relict Nueces distributaries generally trend eastward or southeastward across the coastal plain; north of the Nueces River in the Gregory-Taft-Sinton area, distributary deposits trend northward. The Pleistocene delta plain is slightly elevated for 2 or 3 miles along the north and south sides of the Modern Nueces River valley. This relief, along with the trends of relict distributary channels, indicates that a major distributary channel extended gulfward along the present site of the Nueces valley and that this ancient river channel eroded the delta plain when sea level began to decline at the end of Sangamon time. Pleistocene distributary deposits in the area bounded by the Modern Nueces River, U. S. Highway 181, and U. S. Highway 77 northwest of Sinton may be part of a relict San Antonio delta lobe and may be the oldest Pleistocene deltaic sediments exposed in the Corpus Christi map area. Pleistocene delta deposits between Bayside and Woodsboro are also related to the Pleistocene San Antonio-Guadalupe fluvial system. Other distributary sands originate west of the Corpus Christi map area.

Pleistocene deltaic deposits exposed in the Corpus Christi map area are probably of Sangamon interglacial age (fig. 5A, B) according to studies by Wilkinson and others (1975). At least some of the marine-reworked delta-front sand and silt deposits in the Laguna Larga and Port Bay areas were produced by waves and currents which eroded and redeposited the deltaic sediment following abandonment of each delta lobe. Marine transgression associated with the next late Wisconsin interstadial stage probably further modified the deposits. Subsequently, waves and currents within lakes and lagoons landward of late Pleistocene marine sand bodies (Live Oak Ridge and Live Oak and Encinal Peninsulas) further eroded and redeposited the Sangamon deltaic sands. A soil was developed over the abandoned Sangamon delta plain during post-Sangamon (Wisconsin) glaciation.

Late Pleistocene shoreline deposits that overlie Sangamon deltaic deposits apparently formed during a late Wisconsin interstadial period. Almost 100 square miles of these marine sand deposits are exposed in a 3-mile-wide belt parallel to and inland of the present Gulf shoreline along Encinal and Live Oak Peninsulas and Live Oak Ridge. The exposed sand bodies rise to 25 feet above MSL along the mainland shoreline in northern Laguna Madre, Redfish Bay, and part of Aransas Bay. Price (1933) referred to these sands as the "Live Oak mature offshore bar"; later, Price (1958) used the name "Ingleside barrier."

Spoil that has been dredged from Redfish Bay near the Port Aransas Causeway contains Pleistocene inner shelf and lower shoreface shells and beach rock which are part of this relict Ingleside system.

Relict lake and lagoonal sediments landward of the Ingleside sand in the Laguna Larga and Port Bay areas rest on a surface that was eroded into Pleistocene delta-front and marine-reworked deposits. Price (1933) called this surface, which occurs at elevations between 8 and 25 feet MSL, the "Ingleside terrace." The terrace and its thin Pleistocene and perhaps Holocene mud veneer lie just inland of the Ingleside sand body and extend southward from Laguna Larga along the northwestern shore of Alazan Bay (Kingsville map area). North of the Port Bay area, the Ingleside terrace correlates with genetically similar features in the St. Charles Bay and Powderhorn Lake areas (Port Lavaca map area). Headward erosion by late Pleistocene and Holocene streams subsequently eroded parts of the Ingleside terrace and produced the small valleys presently occupied by Oso, Port, and Alazan Bays. Laguna Larga occupies a closed depression (about 10 feet above MSL) within the relict lagoon-lake area that has not been pirated by younger streams. Almost 20 square miles of relict eolian dune sands and storm-washover fans cover the saline, muddy sediment of the Ingleside terrace in the Corpus Christi area.

Many geologists believe that the Ingleside sand body is a relict barrier island similar to the Modern barrier islands of Texas; this sand body, sometimes called an offshore bar, formed along the Pleistocene shoreline (for example, *see* Price, 1933, and Bernard and LeBlanc, 1965). Supporters of an Ingleside barrier island interpretation suggest that extensive lagoons existed landward of the Ingleside sands and that the shoreline sands transgressed over the lagoonal deposits to their present position as a result of wave attack.

Other geologists believe that the Ingleside deposit may represent a strandplain (Wilkinson and others, 1975). Unlike barrier islands, strandplains are shoreline deposits that are attached to the mainland without the occurrence of an extensive or continuous lagoon, although small lagoons, lakes, and marshes are commonly associated with strandplains. Interpreting the Ingleside as a strandplain implies that the sand body formed along the shoreline in its present position, followed by gulfward progradation of the strandplain as a result of sand deposition in large quantities along the beach and shoreface.

Several lines of evidence suggest that the Ingleside is, in part, a strandplain, including: (1) the presence of well-developed beach ridge-and-swale topography, which precludes a transgressive origin and requires a significant, continuous supply of sand; (2) direct superposition of Ingleside sands on Pleistocene delta-plain sediments; and (3) extensive development of Ingleside shoreface and beach sands offshore and beneath the Modern barrier islands showing an unusual degree of shoreline progradation for independent barrier island systems, such as the Modern barriers along the Texas coast. Beach ridge-and-swale topography, indicative of an accretionary origin, is prominently developed on Ingleside sand bodies on Blackjack Peninsula and in the Seadrift-Port O'Connor area (Port Lavaca map area). The absence of well-developed beach ridge-and-swale topography in the Corpus Christi area is due to extensive eolian modification. Lagoonal or lake muds and muddy sands of Pleistocene or Holocene age, or both, apparently are restricted to small areas just inland of the Ingleside deposit and most likely represent small lakes and lagoons that were not part of an extensive, continuous lagoon system. Wilkinson and others (1975) and Munson (1975) demonstrated that the Ingleside sands extend at least as far seaward as the Modern barrier islands and rest on a paleosoil developed on Pleistocene (Beaumont) delta-plain sediments. The inferred history of the Ingleside suggests that a strandplain developed along the shoreline adjacent to older Pleistocene (perhaps Sangamon) delta deposits during a subsequent high sea-level stand; the strandplain prograded gulfward for several miles (at least 12 miles in the Matagorda Island area).

Price (1958) reported the presence of lagoonal clay containing foraminifers and marine molluscs below +5 feet MSL in the lower part of the Tedford pit near Ingleside. This clay is, in turn, overlain by pond deposits containing vertebrate bones of probable Wisconsin (post-Sangamon) age (Lundelius, 1972). A lagoonal origin for the Tedford invertebrate fauna is not conclusive, as *Chione cancellata* inhabit Modern bay margins and inlet-influenced areas (Andrews, 1971), *Donax tumidus* live in the Gulf surf (beach) zone (Andrews, 1971), and *Arca transversa* occupy a shelf environment (Morris, 1950). An evaluation of the environmental significance of this assemblage is needed before it can serve as conclusive evidence of Ingleside lagoonal environments. A post-Sangamon age for the Ingleside system exposed at Tedford pit (Lundelius, 1972) is in accordance with the inferred Sangamon age of the subjacent Beaumont deltaic deposits.

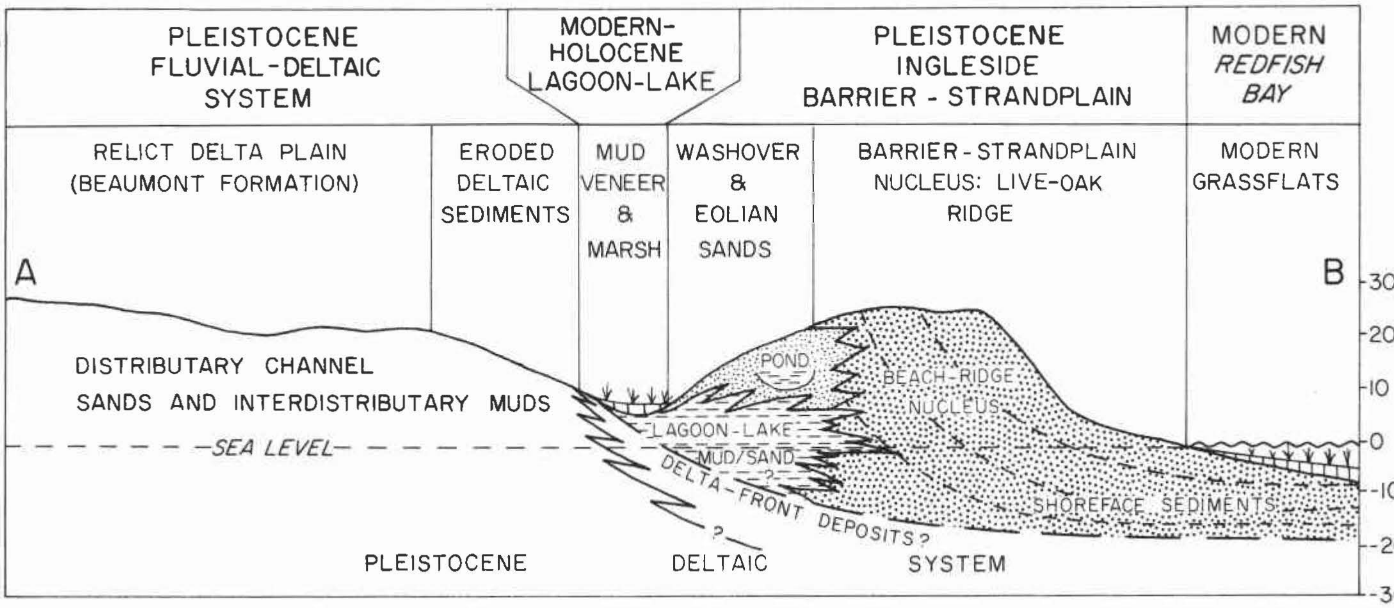
Mapping completed for the Environmental Geologic Atlas of the Texas Coastal Zone series shows no evidence of extensive, continuous lagoonal deposits exposed landward of the Ingleside sands; the Tedford pit deposits (if lagoonal in origin) may be more closely analogous to the lakes, lagoons, and marshes associated with the Modern Brazos delta (Bay City-Freeport map area). Price (1933) suggested that a series of discontinuous lakes probably existed landward of the mature offshore bar (Ingleside). Modern Laguna Larga-Oso Bay and Port Bay generally coincide respectively with the locations of late Pleistocene Lake Baffin and Lake Copano; these lakes developed between the relict Pleistocene Nueces delta plain and the Ingleside sand body and were first recognized by Price in 1933 (fig. 6). Eastern margins of the Pleistocene Nueces delta, adjacent to Port Bay and Laguna Larga-Alazan Bay, were eroded by waves and currents within the late Pleistocene lakes or brackish lagoons; spits were deposited near Spears Lake as a result of sedimentation along the shoreline of Lake Copano. Thin muds and muddy sands were deposited within the center of the lakes and lagoons. Remnants of these late Pleistocene muddy sands are now exposed over about 50 square miles; the relict lake and lagoonal sediments comprise the Ingleside terrace—a series of small, relict, discontinuous lagoons, bays, marshes, and lakes that formed within depressions situated between the Ingleside system and the eroded Pleistocene headlands.

Price's original interpretation of the origin of the Ingleside sand in the Corpus Christi area (1933) agrees in part with the results of this study, but the strong evidence of gulfward accretion would seem to preclude a transgressive barrier origin. Wilkinson and others (1975) infer that the Ingleside system accreted under the influence of a significant local fluvial sediment supply and that the strandplain is not analogous to Modern barrier islands. In the Corpus Christi map area, the Nueces River may have supplied sediment to a sandy delta which built gulfward along the axis of Modern Corpus Christi Bay. A cuspate delta (wave-dominated) is partially preserved within the Pleistocene barrier-strandplain system in the Beaumont-Port Arthur map area (Fisher and others, 1973). It may be postulated that a similar wave-dominated Nueces delta supplied sand to an Ingleside strandplain, as Gulf waves and longshore currents redistributed the deltaic sands along adjacent coastlines (fig. 6). The Ingleside sand body is herein referred to as a barrier-strandplain system.

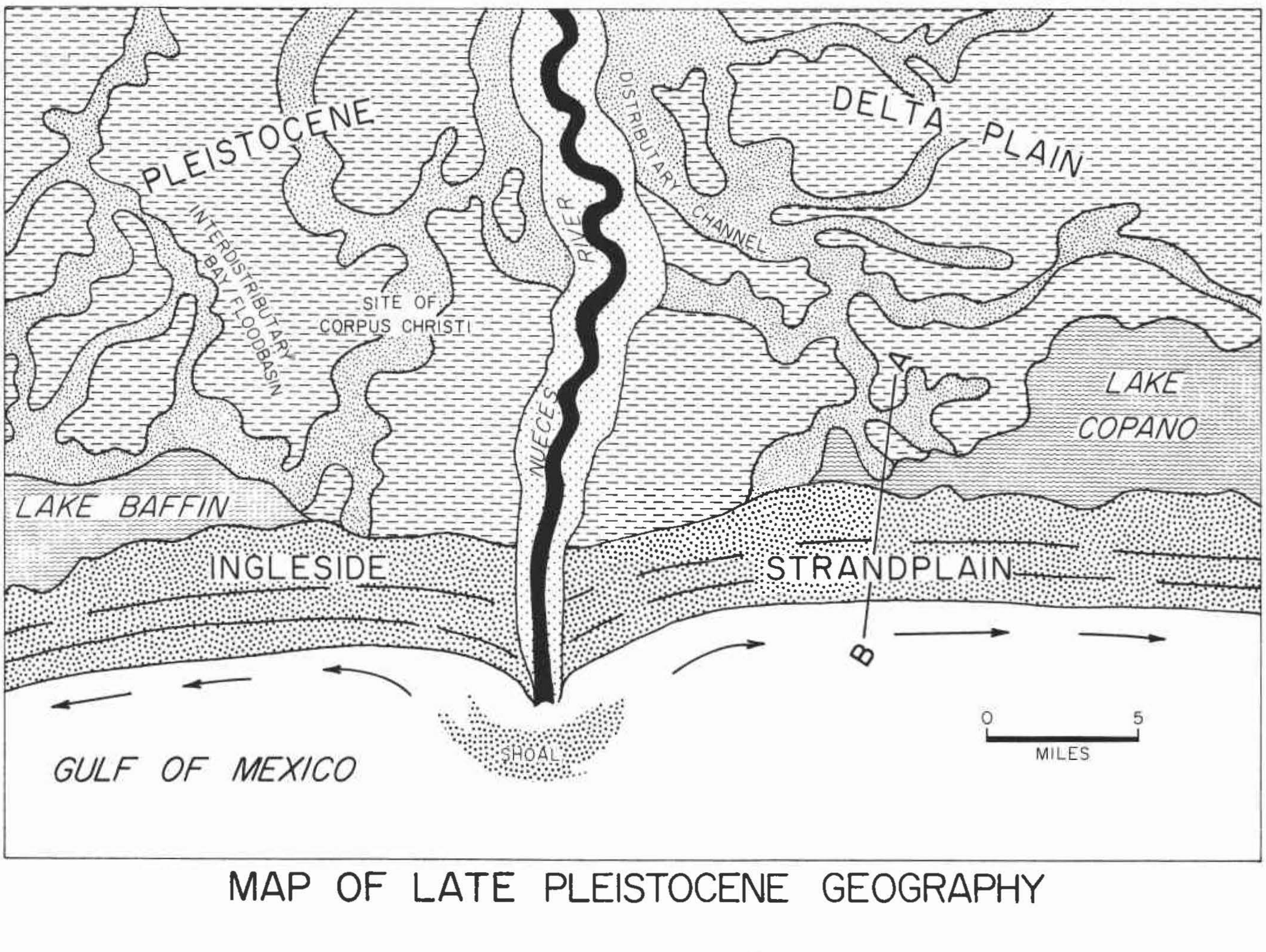
Beginning about 50,000 to 60,000 years B. P., sea level began dropping in response to final episodes of Wisconsin glaciation, and rivers along the Texas coast, as well as throughout the world, could no longer shift from their courses. Dropping sea level caused extensive downcutting of streams into older, underlying fluvial and deltaic deposits (fig. 5B). By the time sea level had dropped more than 400 feet and rivers were building a new shoreline scores of miles gulfward of the present shoreline, deep valleys were being cut across the earlier Pleistocene river, delta, and strandplain deposits. The present incised valleys of the lower Nueces, Aransas, and Mission Rivers record this event. The lower reaches of many headward-eroding creeks—Petronila, Chiltipin, and Sous Creeks—also originated at this time. Port, Oso, Copano, and Nueces-Corpus Christi Bays occupy partially filled valleys that were eroded during this period of time. The buried late Pleistocene Nueces valley extends coastward beneath present Nueces and Corpus Christi Bays and southern Mustang Island and underlies the adjacent continental shelf. The combined late Pleistocene Aransas-Mission valley now lies buried beneath Copano and Aransas Bays and extends eastward beneath St. Joseph Island and the adjacent continental shelf. The axes of these buried valleys are about 90 to 125 feet below MSL, but accurate maps of the buried valleys have not been published. These major river systems, which flowed through entrenched valleys across the continental shelf, discharged their sediment load at a late Wisconsin shoreline about 50 nautical miles seaward of the Modern Gulf shoreline.

HOLOCENE HISTORY

As final glacial episodes diminished about 18,000 years B. P. and meltwater began to reach the oceans, sea level began its last rise (fig. 5C). As sea level rose between 18,000 and about 4,500 years B. P. and rivers continued to meander within their incised valleys, point-bar sand bodies and overbank muds were deposited. The lower reaches of these river valleys, however, filled slowly with brackish to marine water. These extensive bay-estuary systems occupied submerged valleys that now lie beneath parts of Nueces, Corpus Christi, Oso, Port, Copano, and Aransas Bays. The deepest remaining unfilled river valley is the Nueces, but the Aransas and Mission river valleys are also prominent. Relict meander scars are common along the valley walls of these rivers. Various elevated river



SCHEMATIC CROSS SECTION



MAP OF LATE PLEISTOCENE GEOGRAPHY

Figure 6. Inferred relationship between Pleistocene fluvial-deltaic system and younger Pleistocene (Ingleside) barrier-strandplain system, Live Oak Ridge near Ingleside, Corpus Christi map area. The presence of lagoonal deposits is based on studies by Price (1958) and Lundelius (1972). The Ingleside system was probably a strandplain associated with numerous, discontinuous brackish bays and lagoons and not an offshore bar, with extensive lagoons similar to Modern barrier islands such as Mustang and Padre Islands.

terraces of late Pleistocene or early Holocene age, called "Deweyville" by some geologists (Bernard and LeBlanc, 1965), represent older alluvial surfaces within the valley system.

Sea level did not rise at a steady rate but at varying rates and with several pauses, resulting from fluctuations in glacial activity (fig. 5C). Pauses and minor reversals in sea-level rise are evidenced by submerged shoreline sands that occur on the shelf far from the present shoreline; these sands were deposited as barrier islands that mark temporary positions of the Holocene strandline (Frazier, 1974).

Estuaries received sediment from their respective fluvial systems and from the Gulf of Mexico. Holocene deposits which have partly filled the drowned river valleys and now underlie the present bay bottom consist of terrigenous sand and mud associated with a variety of depositional environments. Bayhead deltas developed at the upper ends of the estuaries, and tidal deposits formed near the Gulf. The valley fill is dominated by marine and estuarine sediment deposited under transgressive conditions. Frazier (1974) has established that during the Holocene transgression there were four periods of stillstand: (1) at 48 fathoms (18,500-15,000 years B. P.), (2) at 29 fathoms (13,500-12,000 years B. P.), (3) at 23 fathoms (11,000-10,500 years B. P.), and (4) at 9 fathoms (10,000-7,500 years B. P.). The two youngest stillstands probably affected sedimentation in parts of the Nueces and Aransas-Mission systems. During the stillstand at 9 fathoms, Gulf water probably extended many miles up the deep estuaries from the present Gulf shoreline. With renewed rise in sea level (about 7,500 years B. P.), the valleys were definitely inundated by the Gulf of Mexico. At the end of the Holocene sea-level rise, the Nueces valley was filled with estuarine waters at least as far inland as the present-day Interstate 37 bridge. Wave-reworked bars and berms have been recognized in the vicinity of the junction of Interstate 37 and U. S. Highway 77 on the north side of Nueces River. Similarly, the Aransas and Mission valleys formed estuaries inland from Modern deltas for about 3 and 5 miles, respectively. The present shape of the bays has resulted from Modern wave erosion of valley walls. By late Holocene time, increasingly arid winds from the Gulf had probably initiated eolian erosion of the Ingleside sand body along the Encinal and Live Oak Peninsulas. Blowout dunes migrated northwestward into Port Bay and Laguna Larga.

Subbottom profiling, washdown drilling, and core data from Nueces, Corpus Christi, Copano, and Aransas Bays are needed to determine the configuration of the Pleistocene erosional surface on which Holocene and Modern bay sediment has accumulated. The Pleistocene surface underlying the bays in the Corpus Christi area is undoubtedly characterized by many valleys and drainage divides.

Shoreline features similar to Modern ones were constructed in the Gulf of Mexico when there was a stillstand at about 9 fathoms between 10,000 and 7,500 years B. P. (Frazier, 1974). A relatively thick sand body that probably represents a relict barrier or peninsula occurs some 3 miles seaward of St. Joseph Island and up to 6 miles seaward of Matagorda Island (Port Lavaca map area). The stillstand at 9 fathoms probably lasted some 2,500 years (comparable to the age of the Modern shoreline).

MODERN HISTORY

During approximately the past 4,500 years, compaction of sediment, slow subsidence of the Gulf coast basin, and minor glacial fluctuations have resulted in relative changes in sea level of probably less than 15 feet (fig. 5C). Since about 2,800 to 2,500 years B. P., the Coastal Zone has gradually evolved to its present conditions by erosion, deposition, compaction, and subsidence—processes still important and operating today.

When sea level reached its approximate present level, 2,800 to 2,500 years B. P., several natural changes began along the mainland and Gulf shoreline of the Corpus Christi area: (1) deeper parts of the Nueces and Aransas-Mission estuaries continued to fill with sediment eroded from the walls of the drowned valleys, with deltaic sediment supplied by rivers and streams, with oyster reefs, and with sediment derived from the Gulf of Mexico and transported into the bays through tidal passes; (2) headward-eroding streams continued to erode the coastal plain, especially within relict Pleistocene interdistributary areas where significant mud compaction was occurring; (3) northern Laguna Madre, Corpus Christi Bay, and Redfish-Aransas Bays were gradually restricted behind northern Padre, Mustang, and St. Joseph Islands as offshore shoals slowly coalesced into a chain of gulfward-accreting barrier islands; (4) salt-water marshes, subaqueous marine grassflats, and wind-tidal flats developed over flood-tidal deltas and washover fans associated with the barrier islands, while brackish to fresh (locally ephemeral) marshes and minor swamps encroached delta plains, river valleys, and the margins of small, restricted bays; and (5) eolian erosion and deposition continued to modify the sandy, emergent Modern barrier islands and the relict Ingleside (Pleistocene) barrier-strandplain and thin loess deposits originating from the South Texas eolian system (Kingsville map area) in the southwestern part of the map area near Bishop.

Estuarine Erosion and Deposition

At the end of the Pleistocene, the Aransas-Mission river valley (confluence located between Shellbank and Copano Reefs near the center of Modern Copano Bay) and the Nueces River valley extended eastward across the continental shelf. During the subsequent Holocene sea-level rise, these valleys were progressively filled by river deposits, estuarine sediments, and open Gulf deposits. At about 2,500 years B. P., the lower Nueces, Aransas, and Mission river valleys were estuaries which extended inland from present river mouths for about 10, 3, and 5 miles, respectively.

The shapes of these relict valleys have been modified by erosion of valley walls from wind-generated waves within the estuaries. Eroded sediments were transported by currents and deposited throughout the estuarine system. Nevertheless, relict meander scars are still recognizable along valley walls such as along the south side of the Nueces River east of Calallen.

The present configuration of Corpus Christi and Copano Bays is the result of extensive wave erosion by persistent southeasterly winds and short-lived but severe northerly winds. The shape of the northwestern shoreline of Corpus Christi Bay in the Portland area has resulted from southeasterly, wind-generated waves. Similarly, the shoreline bounding Ward Island has been significantly straightened by waves approaching from the north. Longshore currents generated by the waves have redistributed eroded sediment along the shorelines to produce spits such as Shamrock Island. Storm waves and longshore currents have combined to produce Indian Point Peninsula and to bury Long Reef beneath shoreline sands. The straight shoreline along the northwestern shore of Copano Bay is also the product of waves driven by southeasterly winds. Northerly winds have eroded the Copano Bay shoreline between Egery Island and Rattlesnake Point. A number of smaller bays such as Port, Mission, and Oso Bays have been partially cut off from the estuarine system by spit accretion and deposition of shell berms and beaches; Indian Point Peninsula similarly has almost isolated Nueces Bay from Corpus Christi Bay.

Late in the Holocene marine transgression, the submerged valleys of the Nueces and Aransas-Mission Rivers, which are now buried beneath Corpus Christi and Copano-Aransas Bays, respectively, received tidally transported sediment from the open Gulf of Mexico. Tidal sediment, combined with sediment eroded from the submerged valley walls and estuarine deltas, had essentially filled the deeper parts of the entrenched river valleys by about 2,500 years B. P. when sea level reached its present position (fig. 5C). Shallow seismic profiles indicate that numerous relict oyster reefs are buried within late Holocene-early Modern estuarine deposits.

A variety of Modern bay-estuarine environments have developed since sea level became stationary about 2,500 years B. P. Oyster reefs, interreef areas, marginal sand shoals, grassflats, and bay-center environments, among others, mark the diversity of this depositional system.

Estuarine deltas of the Nueces, Aransas, and Mission Rivers began building into the upper ends of their respective estuaries about 2,500 years B. P. As previously mentioned, the Nueces delta has prograded for almost 10 miles, while the Aransas and Mission deltas have built into their estuaries approximately 3 and 5 miles, respectively. These estuarine deltas have extended the rivers across the shallow upper estuaries by depositing thin prodelta mud (suspension) deposits and localized sandy channel-mouth bars (bed-load deposits). Because the prodelta and channel-mouth bars are thin, the prograding river erodes through these subaqueous delta deposits into underlying estuarine sediments. Deltaic sediments are generally deposited at or in the immediate vicinity of the river mouth, except during severe flooding when suspended sediment is carried far into the estuary. Active and abandoned distributary channels are characterized by well-developed levees that are covered by trees in proximal areas, by grasses in medial areas, and by marsh near the distal part of the delta. Interdistributary bays are gradually filled by floodbasin and crevasse splay deposits as the deltas build into the estuary; marsh growth blankets the emerging delta plain.

Discharge from the Modern Nueces, Aransas, and Mission river systems is significantly less than during the Pleistocene and early Holocene. These underfit Modern rivers have, therefore, exhibited only limited meandering (and, consequently, limited point-bar accretion) during the past several thousand years. The underfit rivers flow through broad valleys that are partially filled with large relict point-bar sand bodies of late Pleistocene and Holocene age. During floods, the Modern rivers discharge large volumes of overbank mud into floodbasins that have gradually developed upon these late Holocene fluvial deposits.

Headward-Eroding Streams

About 30 square miles of the coastal plain in the Corpus Christi map area are occupied by small, commonly ephemeral, headward-eroding streams, called "consequent streams" by Price (1933). Most of these streams are eroding Pleistocene interdistributary areas where compacting muds localize subsidence. Streams such as San Fernando, Petronila, and Oso Creeks, and the upper reaches of Chocolate Swale and Chiltipin, Papalote, and Sous Creeks are now actively eroding Pleistocene sediments. The streams are fed principally by excessive rainfall runoff from highly to moderately impermeable mud substrates. Erosion of the lower parts of these river systems began during late Pleistocene and early Holocene; the streams originated as small, high-gradient tributaries of major rivers when sea level was lowered by glaciation. Headward erosion has continued during Holocene and Modern times and will persist until the systems reach equilibrium. Some alluvium occurs within the streams, especially in the lower parts of the drainage systems. For the most part, however, the upper reaches of the small streams are actively eroding banks cut into Pleistocene mud and sand.

Barrier Island Accretion

When sea level approached its present level, sands eroded from Pleistocene headlands and from submerged Pleistocene deposits on the inner shelf were moved along the coast by longshore currents and onshore by storm waves to produce shoals and bars just offshore of the headlands. By about 2,500 years B. P., the shoals became emergent and a chain of incipient islands was established principally upon Pleistocene deposits along drainage divides between the various estuaries that occupied drowned Pleistocene and Holocene river valleys. Longshore drift and spit accretion slowly extended the islands until the nuclei of St. Joseph, Mustang, and northern Padre Islands were established. Broad tidal passes continued to exist between the discontinuous islands, especially in the vicinity of the relict river valleys; spit accretion eventually closed or restricted the tidal openings between the Gulf and a landward bay-estuary-lagoon system.

In the Corpus Christi area, emerging barrier islands were supplied with sediment by onshore transport of relict Pleistocene deposits exposed nearby on the inner shelf and by longshore currents supplied with sediment from the Brazos River and from erosion of Pleistocene headlands. This sediment supply permitted gulfward accretion of beach ridges and shoreface deposits. Beach ridges are well exposed on northern St. Joseph Island, but eolian erosion has obscured the accretionary ridges on southern St. Joseph, Mustang, and Padre Islands.

Relict flood-tidal deltas occur locally on the landward side of the barrier islands and mark the position of earlier tidal passes. These tidal passes shifted, were abandoned, and reestablished many times during their history. Harbor Island is an active flood-tidal delta associated with Aransas Pass/Lydia Ann Channel. Northernmost Laguna Madre is underlain by a flood-tidal delta associated with relict Packery, Newport, and Corpus Christi Passes. Abandoned tidal passes are commonly the sites of washover channels which are opened during hurricanes and severe tropical storms. Eroded sediment is transported through the washover channels and deposited within the bay-lagoon forming a washover fan. Several active washover fans occur along the back side of St. Joseph Island, and relict washover-fan deposits are locally exposed along the back side of Mustang Island. Hurricanes have been important processes in shaping the barrier islands of the Corpus Christi area during the past 2,000 years.

How far the Modern barrier islands may have accreted gulfward during the past 2,000 years is uncertain, but there are signs that during the past 125 years, parts of the islands have gradually entered an erosional phase. Historical monitoring of shoreline changes (Brown and others, 1974; Morton and Pieper, 1976; Morton and Pieper, in press) since the 1850's shows that local segments of the Gulf shoreline along northern Padre, Mustang, and St. Joseph Islands have experienced erosion up to 10 feet per year, although each of these areas has also experienced short-term periods of accretion since the 1850's. The long-term trend, nevertheless, is erosional, indicating that the volume of sediment being supplied to the barriers in the Corpus Christi map area has reached a critical deficiency. See discussion of shoreline processes under *Active Processes Map.*

Marshes, Grassflats, and Tidal Flats

Extensive marshlands that typify the humid upper Texas coast change southwestward into sparse marshlands, extensive wind-tidal flats, and subaqueous grassflats which characterize the arid lower Texas coast. This transition occurs within the Corpus Christi map area. The Nueces, Aransas, and Mission delta plains are occupied by salt-, brackish-, and fresh-water marshes; small swamps are associated with Nueces River floodbasins. A variety of marsh types occur in the Port Bay area, where marginal, ephemeral, fresh-water marshes first appear southward along the Texas coast. These ephemeral marshes are typically developed in the Kingsville map area and occur around Laguna Larga and other areas of depressed relief on the "Ingleside terrace" within the Corpus Christi map area. Apparently controlled by climatic cycles, these ephemeral marshes are repeatedly occupied by nonmarsh plants. The marshes represent the southern fringe of widespread fresh-water marshlands typical of the more humid middle and upper Texas coast.

Salt-water marsh covers large areas of Harbor Island (tidal delta) and the landward side of St. Joseph and Mustang Islands (relict washover-fan deposits). However, the environmental niche occupied by salt marsh environments is replaced southward by extensive wind-tidal flats. This shift from salt marsh to wind-tidal flats coincides with decreased barrier island vegetation and, consequently, increased eolian erosion. The broad wind-tidal flats that occupy large areas of Laguna Madre in the Kingsville map area are produced by windblown sand deposited in the shallow lagoon. Alternating subaerial and subaqueous conditions preclude the growth of extensive coastal marshes.

Although subaqueous grassflats occur throughout the upper Texas Coastal Zone, the most widespread marine grasses in Texas occur in Laguna Madre and Redfish Bay where broad, bay-lagoon flats occur at water depths less than 3 feet. Extensive grassflats mark a mature phase in the history of lagoonal deposition prior to development of marshes and tidal flats that signal the final stages of lagoon filling.

Eolian Erosion and Deposition

The Coastal Bend and South Texas regions probably became progressively arid during the Holocene as glaciation exerted less control on the climate of North America. Increasing aridity and the persistence of the southeasterly wind regime probably began to affect the southern Texas Coastal Zone significantly during the late Holocene. Several lines of evidence indicate that the Corpus Christi area is transitional between the humid, well-vegetated upper coastal area and the arid, poorly vegetated lower coastal region. For example, stabilizing vegetation has preserved the accretionary beach ridges along Blackjack Peninsula (Pleistocene Ingleside barrier strandplain) north of Aransas Bay in the Port Lavaca map area, but less than 10 miles to the south, on Live Oak Peninsula in the Corpus Christi map area, southeasterly winds have destroyed the ridge-and-swale topography. Relict blowout dunes, blowout depressions (commonly water filled), and eolian sand sheets characterize both the Live Oak and Encinal sand bodies. Southward in the Kingsville map area, this same Pleistocene sand body has been severely eroded by the southeasterly wind.

The Modern barrier islands exhibit evidence of similar wind erosion. Well-developed beach ridges on Matagorda Island disappear southward near Cedar Bayou where large eolian blowouts destroy the ridge-and-swale topography. Small patches of beach ridges still exist on northern St. Joseph Island, but the ridges and swales disappear about 9 miles north of Aransas Pass; from this point southward, St. Joseph, Mustang, and Padre Islands have been severely eroded by the wind. The southward disappearance of Modern barrier island ridge-and-swale topography coincides with the disappearance of Pleistocene beach ridges. Certainly, increasing aridity and diminishing vegetational stability have permitted this increasing impact of eolian processes.

The highest and best developed fore-island dune ridges occur along Mustang and northern Padre Islands where sufficient moisture is available for the growth of some stabilizing plants but where eolian processes have been sufficiently dominant to produce the eolian dune ridge. Southward, blowouts in the fore-island dune ridge increase as vegetative cover diminishes. The blowouts supply sand that nourishes back-island dune fields which first appear on northern Padre Island. In the Kingsville area to the south, fore-island dunes disappear, and washover channels and fan deposits increase in number as Padre Island becomes sparsely vegetated.

HISTORICAL SUMMARY

The coastal prairies of the Corpus Christi area are underlain by Pleistocene (ice age) river, delta, and shoreline sediments deposited more than 30,000 years ago during one or more interglacial periods. River-fed deltas built gulfward across marine embayments where coastal prairies now occur. A relict shoreline deposit that lies along the mainland shore of Laguna Madre and Redfish-Aransas Bays marks the position of the youngest Pleistocene shoreline in the Corpus Christi area.

About 30,000 years B. P., sea level declined again in response to continental glaciation, resulting in the erosion of deep valleys by the Nueces, Aransas, and Mission Rivers; lesser headward-eroding streams eroded valleys beneath Oso and Port Bays. When sea level reached its lowest point, rivers flowed down these deep valleys to a shoreline situated many miles across exposed continental shelf.

By 18,000 years B. P., sea level began its final but irregular rise marking the beginning of the Holocene. During sea-level rise, river valleys that extended across the continental shelf were slowly filled, first with estuarine sediments and finally with marine sediments. Sea level reached its approximate present position between 3,000 and 2,500 years B. P., marking the end of Holocene sea-level rise and the beginning of Modern geologic processes that have created the present Texas shoreline features.

Modern geologic processes have partly filled the bays and estuaries with sediment supplied by (1) rivers and headwardly eroding streams, (2) tidal currents, and (3) wave erosion of valley walls. Between 3,000 and 2,500 years B. P., small barrier islands developed in the area of St. Joseph, Mustang, and Padre Islands. These islands coalesced by spit accretion and by filling of tidal passes to form the Modern barrier island system. Except for tidal passes, the Nueces-Corpus Christi bay-estuary system and Copano-northern Aransas bay-estuary system were separated from the open Gulf. Laguna Madre and Redfish-southern Aransas Bays were isolated landward of the barrier islands. Initial accretion of Modern barrier islands has shifted in some areas toward erosion because of a net deficiency of sand. Marshes, wind-tidal flats, and shallow marine grassflats have developed in areas where bays, estuaries, and lagoons have filled or are almost emergent. Eolian processes have modified both Pleistocene and Modern shoreline sand deposits. The Texas Coastal Zone will continue to change in response to the processes of erosion, deposition, compaction, and subsidence now operating in this dynamic region.

HUMAN IMPACT ON COASTAL GEOLOGY

During the past 100 years, man has significantly modified the Texas Coastal Zone. Man's principal effect on coastal geology has been the extensive dredging of channels and passes with resulting discharge of sediment into bays and modification of natural circulation patterns. Sediment supplied by human activities during the past few decades has far surpassed the volume of sediment supplied by natural erosion; about 27 square miles of bay-bottom spoil in the area is presently being redistributed, while nearly 15 square miles of spoil is piled above sea level and is now undergoing erosion and being introduced into the bay and marsh systems.

The transport of sediment into bays by headward-eroding streams is accelerating, principally due to increased cultivation, construction of irrigation and drainage canals, and urban paving on the broad uplands. Straightening and lining of stream courses are becoming important factors in flash flooding. The impact on the natural drainage system by urbanization of the coastal prairies is potentially a serious problem.

Bays are adequately flushed by river flooding and hurricane storm surge to remove some industrial waste. Because tidal range is low in the Gulf of Mexico and lower still in bays and estuaries, tidal exchange alone is insufficient to flush all pollutants from the bays into the Gulf of Mexico. Upstream reservoirs diminish the volume of fresh water entering the bay-estuary-lagoon system. Hurricanes significantly aid in flushing water and some sediment from the bay system, renewing the bay water and reducing the threat of growing pollution; thus, man-made structures designed to block hurricane storm surge may severely affect this bay-flushing mechanism. Similarly, placement of oil-field sludge pits and liquid- and solid-waste disposal sites on sandy substrates is a threat to ground-water purity, while leachate from these waste disposal sites also poses a threat to surface-water systems.

A steady trend toward filling or draining of marshes and swamps and the dredging of marine grassflats poses another threat to the bay ecosystem. Elimination of seemingly unneeded wetlands and grassflats not only destroys a critical link in the production of food for bay and shelf organisms but also destroys critical spawning grounds for many species. Erosion and redeposition of spoil dredged from channels through these environments likewise eliminate vast acreages of these vital resources. Devegetation, either natural or man-induced, destroys vital stability of many subaerial coastal environments.

The underground disposal of liquid wastes, especially radioactive or toxic chemicals, must be based on a thorough understanding of the geology of the disposal reservoir—its geometry, hydrology, and geochemical character. Special care should be exercised in casing, cementing, and maintaining these kinds of disposal wells.

CONCLUSIONS

The natural environments of the Corpus Christi area are directly tied to Modern geologic processes and deposits, as well as to relict geologic deposits of the past few hundred thousand years (fig. 4). If the environmental quality of the area is to be maintained acceptably and if proper and fair use and exploitation of coastal resources are to be realized, the physical, biological, and geochemical nature of the Modern systems and relict Holocene and Pleistocene sedimentary deposits must be understood. Physical properties of sediment substrates are highly variable within the region and, therefore, environmental management must consider the nature of these geologic variations. The entire Coastal Zone has been the locus of dynamic processes and events for thousands of years, and unless these natural systems are understood and respected, man can cause irreversible change in this important area of natural resources.

Coastal geology, environments, and processes are unusually susceptible to modification by human activities, and therefore, caution will be required during coming decades to maintain a satisfactory level of environmental quality. Scientific and engineering efforts must involve a proper understanding of and compatibility with the geological substrates and active physical processes.

CLIMATE AND DYNAMIC COASTAL PROCESSES

The climate of the Texas Coastal Zone strongly dictates the relative importance of many significant geological processes. Principal factors are the direction and intensity of persistent winds that control the orientation and size of wave trains approaching the shoreline. In turn, the angle at which waves strike the coast affects the nature of longshore drift.

The direction of wind-driven currents and waves in relationship to the orientation of tidal passes may increase or diminish the magnitude of astronomical tides that coincide with the wind activity. The amount of open-bay fetch and the direction of wind-driven tides within a bay also control the effectiveness of wind-tidal activity; for example, broad fetch and persistent wind aligned with the axis of a narrow, funnel-shaped bay result in high wind tides. Similarly, the angle at which hurricanes strike the coast affects the magnitude of storm tides, especially in narrow upper bay areas. The duration and intensity of winds control the nature and direction of bay currents that erode, transport, and deposit sand and mud. Erosion or deposition by currents strongly affects bay shorelines. These shorelines tend to be smoothed by erosion and sedimentation just as longshore drift smooths the seaward side of deltaic headlands, peninsulas, and barrier islands.

Wind is important in controlling coastal processes, but the combined and interrelated effects of rainfall, evaporation, and temperature are also critical. Effective precipitation controls the type and density of coastal vegetation, which are crucial in a climatic regime where wind is a primary factor. Plants stabilize coastal sands that, if unvegetated, will be deflated by wind and transported as eolian or wind dunes. The density of vegetation is especially important in stabilizing and shielding coastal barriers and shorelines against hurricane impact. Effective rainfall and associated plant cover also stabilize inland soils.

CLIMATIC CHARACTER OF THE CORPUS CHRISTI AREA

Average annual rainfall along the coast in the Corpus Christi area ranges from 30 inches in Kleberg County to 35 inches in Aransas County. Inland, average annual rainfall ranges from about 27 inches in Kleberg County to about 30 inches in Bee County. Corpus Christi, near the center of the map area, averages about 28.5 inches of precipitation annually. The average annual rainfall from 1931 to 1960 shows a progressive increase eastward across the area from 27 inches in the southwest to 35 inches in the southeast corner of the map area (fig. 7A).

Precipitation values alone are not necessarily significant until compared with precipitation deficiency (fig. 7C). Between 1931 and 1960, the Corpus Christi area had a precipitation deficit of about 12 to 16 inches. Coupled with this deficient rainfall budget is bimodal rainfall distribution. One peak occurs in late spring and early summer with the other in the fall. The fall peak coincides with the hurricane season. Another factor that affects the precipitation deficit is the temperature range. As air temperature increases from east to south along the Texas coast, the temperature-dewpoint spread increases (Carr, 1967), indicating that air along the central and south Texas coast must be cooled more than air along the east Texas coast in order for condensation and precipitation to occur. Temperatures range from a January or average winter minimum of 44° F in Refugio and San Patricio Counties to a July or average summer maximum of 97° F in Jim Wells County. Counties along or nearer to the Gulf of Mexico, such as Aransas and Nueces Counties, registered ranges from average winter lows of 47° F to average summer highs of 92° F. Between 1931 and 1960 (fig. 7B), the average annual mean free-air temperature in the Corpus Christi area was between 70° and 72° F.

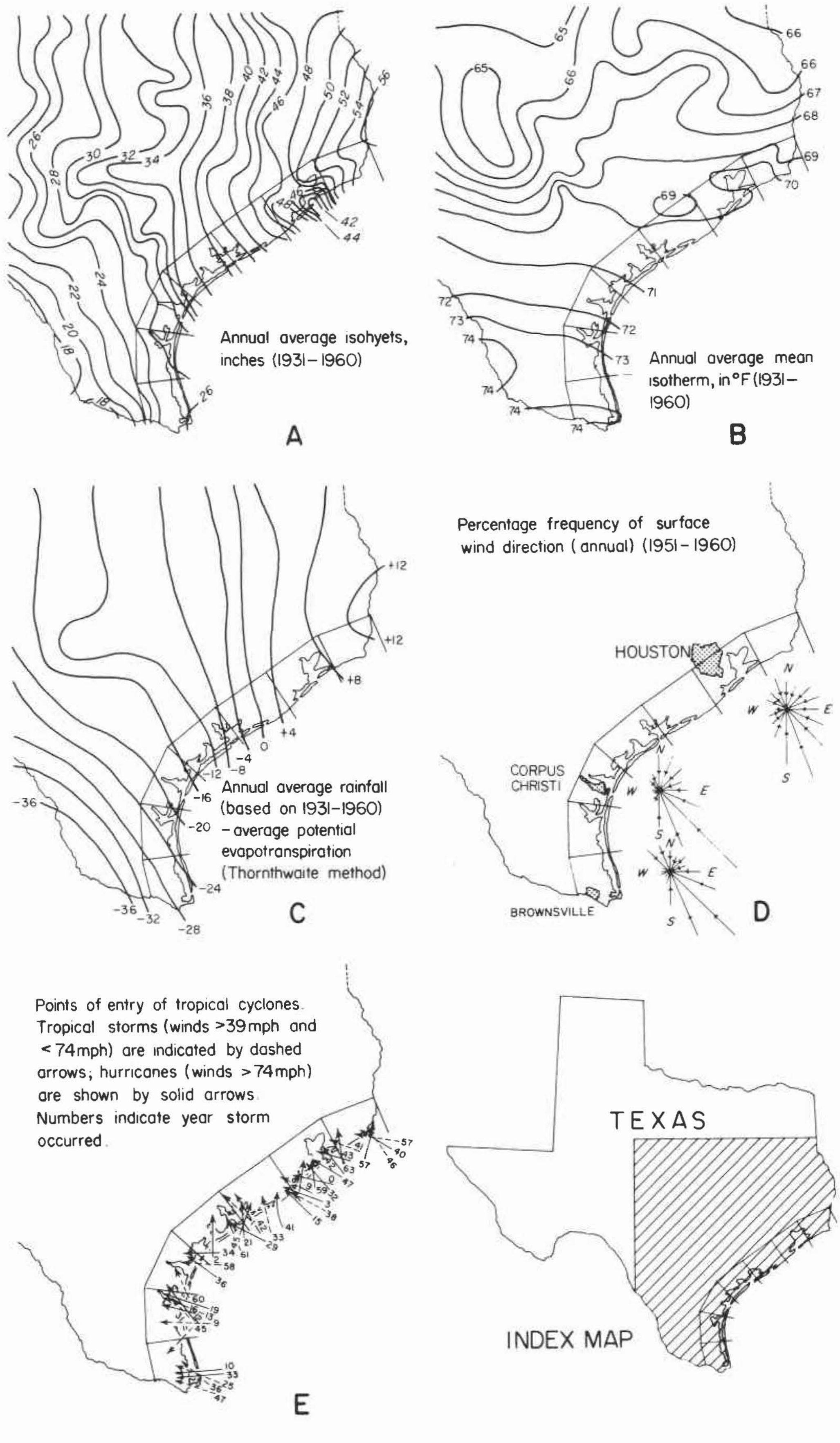


Figure 7. Regional climatic data, Texas Coastal Zone. (A) Average annual precipitation (after Carr, 1967). (B) Average annual temperature (after Carr, 1967). (C) Precipitation deficiency (after Orton, 1969). (D) Frequency of surface wind direction (after Orton, 1964). (E) Hurricane tracks across Texas coastline (after Hayes, 1967).

The significance of negative evapotranspiration values for the area is indicated by a coastal vegetation cover that is less dense than on segments of the east Texas coast. Consequently, there are more hurricane channels, blowouts, and blowout dunes, fewer wetland areas, and a greater area of wind-tidal flats in the Corpus Christi area than to the east. Fore-island dunes are continuous along St. Joseph, Mustang, and northern Padre Islands except in areas of hurricane-washover channels, man-made fish passes, and abandoned tidal inlets. Density of vegetation cover along the sandy shoreline of the Corpus Christi area is intermediate between the south and east Texas coast. Normally, ground water and soil moisture are sufficient to sustain vegetation. During droughts, dune vegetation may die and parts of the fore-island dunes may be mobilized to form blowouts and blowout dunes.

COASTAL WIND REGIMES

Two principal wind regimes dominate the Texas Coastal Zone—persistent, southeasterly winds from March through September and north-northeasterly winds from October through February (Behrens and Watson, 1973). The surface wind pattern (fig. 8) for Corpus Christi (1931-1960) illustrates the percentage frequency of various wind directions characteristic of the Corpus Christi area. Much more important than prevailing wind direction, however, is the dominance of the wind as defined by duration and velocity. If wind duration is multiplied by the average hourly velocity of the winds, the dominance of winds from the southeastern quadrant and from the winter northers is even more pronounced.

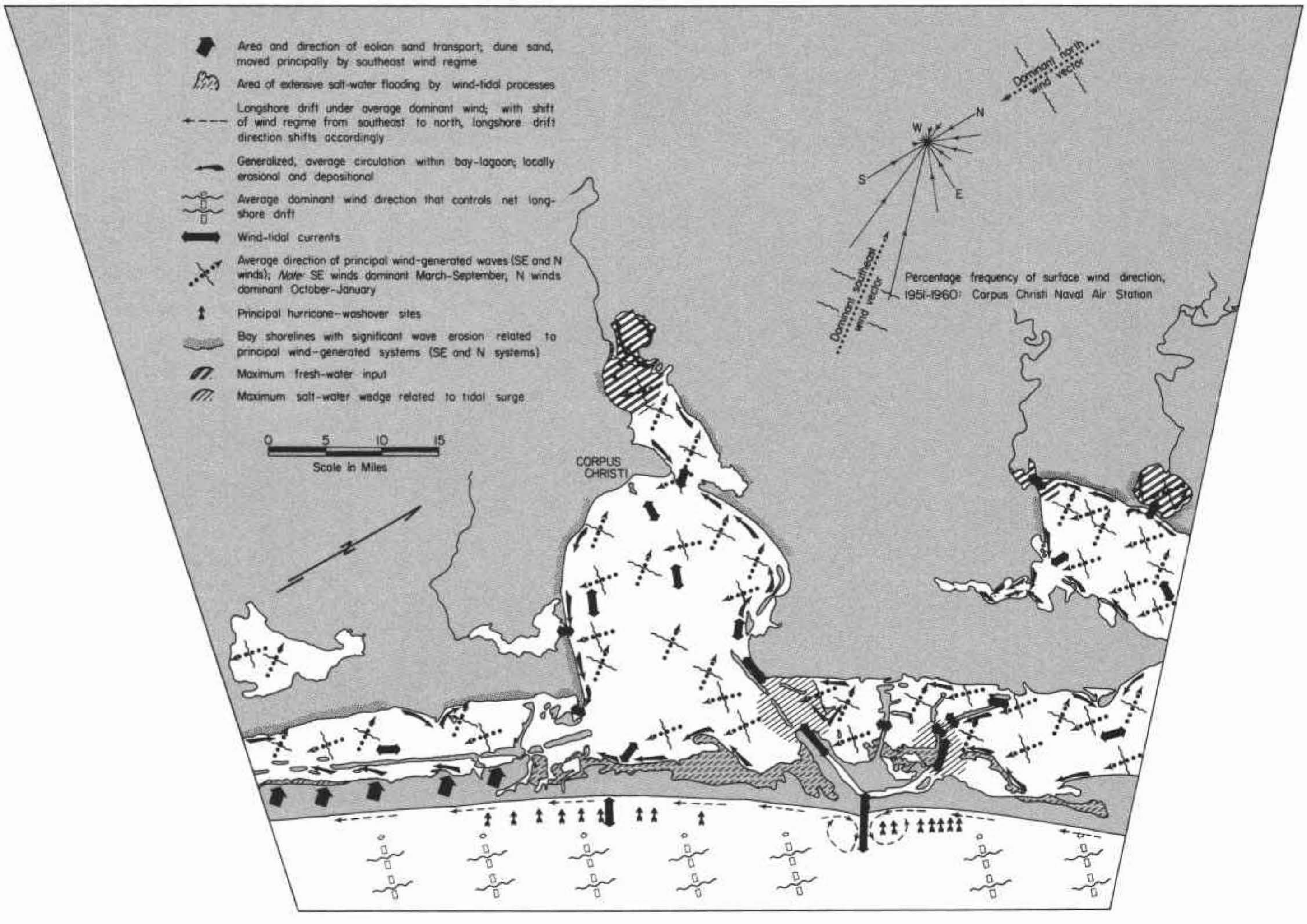


Figure 8. Circulation, waves, sediment transport, and other physical processes, bay-estuary-lagoon and offshore systems, Corpus Christi map area.

During passage of a severe polar front, for example, a north wind may blow for 24 hours at average wind velocities of perhaps 30 to 40 miles per hour. The effectiveness or dominance of the wind is duration (D) x velocity (V), or 24 hours x 30 miles per hour = 720 units. In contrast, a weak wind from the southwest may blow for long periods with less effectiveness; for example, D = 100 hours, V = 5 miles per hour, and D x V = 500 units. Along the Texas coast, the most effective or dominant winds are persistent, moderate to strong winds with a southeast vector and short-lived but intensive winds from the north. Other winds add their impact on the Coastal Zone, but they are significantly less effective in generating waves, currents, and wind tides.

Persistent Southeasterly Winds

Prevailing winds from the southeast develop wave trains that are transformed into extensive breakers as the waves contact the bottom of the smooth, gently sloping inner shelf and shoreface (fig. 8). These wave trains result in secondary waves and currents that control deposition and erosion along barrier island beaches. Wave crests oriented northwest-southeast move onshore where they strike the coastline at very low angles to the north and south along the coastal bend (fig. 8). Waves may break and re-form three or four times across the broad shoreface, resulting in three or four lines of breakers and associated breaker-point bars of shell and sand that change size and shift position as wave size varies.

Because wave trains, generated by the prevailing southeast winds, cross the shoreface and strike the concave shoreline at low angles, net longshore drift occurs. Within the Corpus Christi area, two opposing drift directions occur during the summer months (fig. 9). Along the south shoreline, drift is generally to the north, whereas along the northeastern part of the area, drift is southward. Waves approach the shoreline

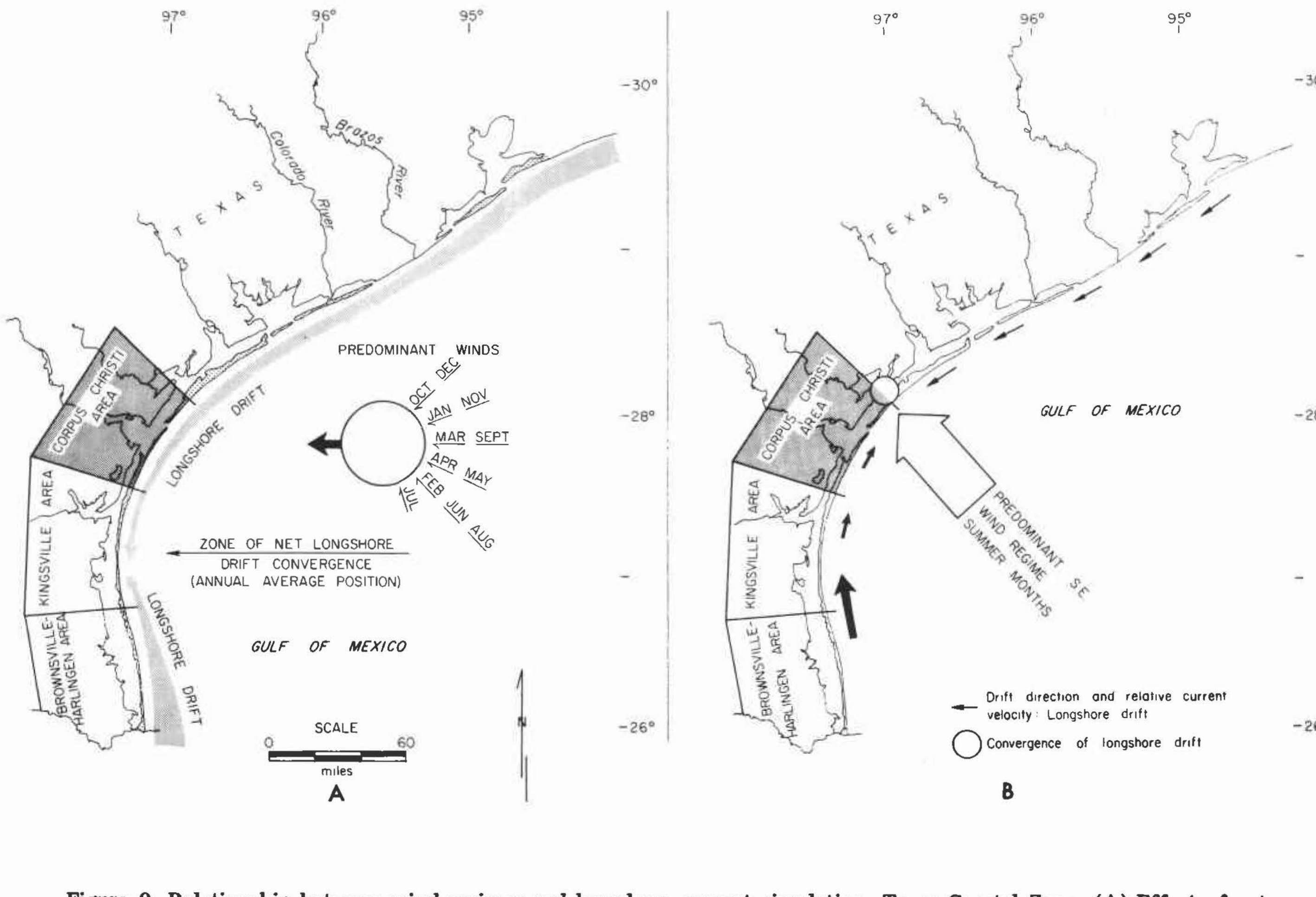


Figure 9. Relationship between wind regimes and longshore current circulation, Texas Coastal Zone. (A) Effect of net annual predominant winds on convergence of longshore drift. (B) Longshore drift convergence during typical summer months. Modified from Lohse (1952).

almost at right angles in the region just north of Aransas Pass. In this area, there is virtually no longshore drift component; this is the area of longshore drift convergence (fig. 9). Within the area of longshore drift convergence, there is sediment accumulation and short-term shoreline accretion or equilibrium. Longshore drift direction shifts in compliance with the wind regime, and the net result of the interaction of the wind regime in the Gulf of Mexico with the orientation of the Texas shoreline is a net longshore drift convergence along the south Texas coast in the vicinity of latitude 27°N within the Kingsville area (fig. 9). Under the southeasterly wind regime, sediment is continually moved onshore to the beach where swash removes fine particles that are returned to deeper waters of the shoreface and inner shelf. Storms may also push large volumes of sand high onto the beach to produce storm berms, either to be eroded and redistributed or to be stabilized as beach ridges by vegetation.

If a significant sand supply is available from rivers located farther to the northeast and south along the shoreline and from the sea floor sources on the nearby inner continental shelf, the sandy beach and shoreface will slowly build seaward. If sand is in short supply, perhaps because little is available from rivers or from offshore, beaches will become sand starved and will be composed predominantly of broken shell and rock fragments which constitute the dominant available sediment. Therefore, active shelly beaches are sand starved and normally shift landward during their development, in the absence of sufficient sand nourishment. Such active beaches are termed *erosional*. If there is sufficient sand available for net outbuilding of an active beach and shoreface, the beach is termed *depositional*. If neither net erosion nor deposition is occurring along an active beach, it is considered to be *in equilibrium*.

Southeasterly winds have a significant fetch across parts of Copano, Aransas, Redfish, Corpus Christi, and Nueces Bays, and Laguna Madre. Shorelines of all bays in the Corpus Christi area are affected by waves and longshore currents resulting from the prevailing southeast wind. Waves generated by the southeast wind severely erode shorelines that face into the wind and transport sediment westward and northward. Wind stress on the water surface causes a general lowering of water level along the bayside of barrier islands and flooding of low-lying mainland shorelines. This raising or lowering of water level is commonly known as wind tide. Wind tides may raise water level 1 to 2 feet above normal high tide.

In summary, southeasterly winds and resulting waves and currents are principally responsible for generating northeasterly and southwesterly longshore drift that converges along the Gulf shoreface in the central Texas Coastal Zone. Where sediment budget is low, the Gulf shoreline is either stationary (in equilibrium) or retreating (erosional); some erosional shorelines can be recognized by increased shell content. Since about 3,000 years ago, the Gulf shoreline in the Corpus Christi area has been chiefly accretionary. Currently, the Gulf shoreline of St. Joseph Island is chiefly erosional, and Mustang and Padre Islands are chiefly in an equilibrium state, though low rates (1-3 feet per year) of erosion have been documented for the past 100 years. Sediment from which St. Joseph, Mustang, and northern Padre Islands were constructed was derived mostly from the older Pleistocene strandplain sand (McGowen and Garner, 1972; McGowen and Scott, 1975). Sediment supply has diminished over the past few years for all the Gulf shorelines in the map area. Dams on major rivers to the east and south and jetties at Fish Pass and Aransas Pass intercept sand that would normally be delivered to Gulf beaches. Recently, the Gulf shoreline of St. Joseph Island has begun to erode, and other Gulf shorelines in the map area are also experiencing low rates of erosion.

Northerly Winds

During December, January, and February, 15 to 20 northers (rapidly moving polar fronts) pass through the coastal area (Hayes, 1965). Rain and winds up to 50 miles per hour accompany these sudden 24- to 36-hour storms. North winds generate intense wave activity in the larger bays (fig. 8). Waves erode the south and west bay shorelines. West- and south-flowing longshore currents are generated within the bays by waves approaching the shorelines from the north. Waves generated by the north wind resuspend some of the bay mud, part of which is moved through Aransas Pass and Fish Pass. Resuspended mud in Aransas Bay is transported toward the south bay shore and southward and eastward through Lydia Ann Channel and Aransas Pass.

Wind stress on the water surface during northers causes a lowering of water level along the north bay shore and a rise in water level along the south bay shore. At this time, water level may be lowered as much as 2 feet below mean low tide in northern parts of bays. Parts of the southeast bay shores (baysides of St. Joseph, Mustang, and Padre Islands) are inundated by wind tides created by northers, and wind-tidal flats are progressively better developed southward.

Coincident with the rise in water level along the southeast bay shores is a lowering of water level in the

Gulf of Mexico. One result of this situation (high water in the bay and low water in the Gulf of Mexico) is the generation of excessively high-velocity ebb currents through tidal inlets. Lydia Ann Channel and Packery Channel (a former tidal channel) are oriented north-south. This orientation is controlled, in part, by the strong ebb currents operating during northers that scour the channel and transport sediment seaward.

Along Gulf beaches, northers virtually eliminate breakers and the associated north winds transport sand from dune and beach areas into the Gulf of Mexico. Rains that accompany the northerly winds combine with increased river discharge to lower bay salinity.

TIDAL CURRENTS

Direction and magnitude of tidal currents and their role in sediment distribution are not known for the bays and nearshore marine environment. Current velocities and the general role of the tidal channels in sediment transport are reasonably well documented.

There were two natural tidal inlets in the Corpus Christi map area until the early 1900's; these were Aransas Pass and Corpus Christi Pass (now known as Packery Channel). The old Corpus Christi Pass was closed in 1929 as a consequence of man's activities in northern Laguna Madre and Corpus Christi Bay. Aransas Pass has been stabilized in its present position by jetties since the late 1800's. Fish Pass, also known as the Corpus Christi Water Exchange Pass (Behrens and Watson, 1973), was dredged through Mustang Island in 1972. Aransas Pass, the only major tidal pass in the Corpus Christi map area, lies between St. Joseph and Mustang Islands. Fish Pass cuts through Mustang Island approximately 13 miles to the southwest of Aransas Pass. Packery Channel separates Mustang and Padre Islands. Newport, Corpus Christi (new), and North Passes are also shown on the map; these are ephemeral channels across the barrier islands which are active only following severe storms or hurricanes.

Aransas Pass has been open continuously since historic records have been maintained. Until jetties were emplaced to fix the channel position, Aransas Pass was unstable and migrated freely in the area between North Pass and its present position. The pass migrated from northeast to southwest at rates up to 280 feet per year (Price, 1956). Channel migration was terminated when a hurricane cut a new, shorter channel across St. Joseph Island in the vicinity of North Pass; the older, longer pass was closed and the new, shorter channel became the major inlet which then began to migrate in the direction of longshore drift to the southwest. Tidal currents move freely through this pass, but sediment movement has been restricted since jetty construction. Maximum diurnal current velocities for Aransas Pass are 2.0 knots during flood and 1.9 knots during ebb (U. S. Department of Commerce, 1973). Mean tidal range at Aransas Pass is 1.7 feet (U. S. Department of Commerce, 1972). Part of the sediment that moves into the bay (the volume of bed-load material that moves into the bay under normal sea conditions is negligible) with the flood tide is returned to the Gulf by ebb-tidal currents. Some sand accumulates as an ebb-tidal delta; the remainder is entrained by longshore currents and moves to the southwest in the direction of net longshore drift. Aransas Pass is maintained by dredging at a width of 700 feet and a depth of 42 feet.

Packery Channel (formerly known as Corpus Christi Pass) was initially about 15 feet deep (Price, 1952). This natural pass migrated southwestward to the southeast part of Corpus Christi Bay. It became stabilized at this location, and the narrow southern tip of Mustang Island was repeatedly breached by waves and storm surge associated with hurricanes. The hurricane channel became the major channel and migrated southwestward to a stable north-south configuration at the southeast corner of Corpus Christi Bay. There are no hydrologic data for Packery Channel. The channel served as a means of communication between northern Laguna Madre, Corpus Christi Bay, and the Gulf of Mexico prior to its closing as a consequence of man's activities in the early 1900's (Price, 1952). Fish Pass (Corpus Christi Water Exchange Pass) was dredged to facilitate water exchange between Corpus Christi Bay and the Gulf of Mexico; this function was provided by Packery Channel (old Corpus Christi Pass) prior to its closure.

RIVER DISCHARGE

Within the Corpus Christi map area, three significant streams discharge into the bays. Mission River discharges water and sediment into Mission Bay and then into Copano Bay through a small inlet between Mission and Copano Bays. Aransas River discharges into the western part of Copano Bay. Nueces and Corpus Christi Bays receive water and sediment from the Nueces River. Bed load delivered to the bays by these streams accumulates near the point where the streams enter the bays and, consequently, virtually no sand derived from a fluvial source reaches the lower parts of the bays. Much of the fresh water and suspension load that reaches Aransas Bay is derived from the Guadalupe and San Antonio Rivers; these streams discharge into

San Antonio Bay which occurs in the Port Lavaca map area to the northeast. Fresh water and suspended load sediment derived from the above-mentioned streams reach the Gulf of Mexico primarily through Aransas Pass; some reaches the Gulf through Fish Pass and the ephemeral breaches through the barrier islands such as North, Corpus Christi, and Newport Passes, as well as Packery Channel.

River flooding changes the salinity of bay water and produces a salinity gradient during flooding. In the Copano-Aransas Bays area, salinity may range from about 4 parts per thousand ($^{\circ}/_{\circ\circ}$) in Mission Bay to about 26 $^{\circ}/_{\circ\circ}$ in the vicinity of Mud Island. A similar salinity gradient exists in the Nueces-Corpus Christi bay system with salinity being near 0 $^{\circ}/_{\circ\circ}$ in Nueces Bay and increasing steadily through Corpus Christi Bay to a high of 10-11 $^{\circ}/_{\circ\circ}$ near Harbor Island. Northern Laguna Madre is also characterized by a salinity gradient during flooding with a low of about 11 $^{\circ}/_{\circ\circ}$ existing near Crane Islands and a high of about 16 $^{\circ}/_{\circ\circ}$ occurring near the southern map boundary.

EFFECTS OF HURRICANE IMPACT

Hurricanes are severe tropical storms that accelerate coastal processes so that during the few hours of passage, the coastal systems experience a degree of erosion and deposition equal to months or years at the normal level of coastal activity. Most hurricanes strike the coast from the southeast, although they may veer along the coast, striking it at any angle (fig. 7). Hurricanes become a more serious problem each year because of expanding population, industry, and development along the Texas coast. These high-energy storms have a significant effect on certain coastal environments that are already overstressed by intensive use. Hurricanes are, however, the principal mechanism by which bays are flushed of pollutants, and for this reason, elimination of storm-tidal surge by artificial barriers may present serious problems of bay contamination. In addition, hurricanes transport shelf sand onto the shoreface to nourish Texas beaches; throughout the coastal systems, hurricanes tend to compensate, in part, for the problems arising from low tidal ranges and low river discharge.

Hurricanes vary in intensity and size, but several factors affect the severity of their impact upon the coast: (1) bottom slope and profile of the inner shelf and shoreface; (2) position and degree of the astronomical tide cycle at the time of approach; (3) shape and orientation of barrier islands or deltaic headlands, as well as passes and upper bay areas; (4) degree of vegetative cover in the area of impact; and (5) angle at which the storm cell strikes the coastline. These factors determine how much of the storm-tidal surge will be dissipated upon striking land and how much energy will remain to inflict damage.

Hurricanes display highly variable wind velocities and heights of storm-tidal surge, but a general hurricane model (McGowen and others, 1970) is useful in predicting storm effects along a typical stretch of Texas coastline where the hurricane moves ashore (fig. 10A).

The storm approach is marked by rising tides and increased wind velocities (fig. 10B). The longer the storm remains offshore in the Gulf, the greater will be the storm surge. Storm tides are higher in narrow, funnel-like bays than along the straight barrier or peninsular shoreline; these tides are known to reach 22 feet above sea level. Storm surge deposits sand and shell berms on beaches, pushes shelf sand onto the shoreface, erodes fore-island dunes, and may breach the barrier island or peninsula through storm or washover channels. Strong southwestward currents along the shoreface result from the counterclockwise wind circulation during storm approach.

As the storm passes over the shoreline, the counterclockwise winds generate unique currents within the bays (fig. 10C). On the left or south side of the eye, water and sediment are flushed from the bays through tidal passes and storm channels; on the right or north side of the eye, water is stacked in bays, and bay shorelines are eroded. Currents along the barrier or peninsula shoreface commonly switch to the northeast as the eye moves inland, accompanied by low atmospheric pressure and a violent shift in wind direction.

Moving inland, the storm cell becomes weak and diffused, commonly spawning numerous tornadoes (fig. 10D). Water stacked in bays during the storm approach and impact is suddenly released to drain gulfward through passes and storm channels. Heavy rains normally persist inland, causing intensive flooding along streams and poorly drained coastal prairies. Reorganized bay and Gulf circulation rapidly seals the mouth of storm breaches in the barrier, and waves begin to erode storm berms.

Hurricane Carla (1961) opened North Pass on St. Joseph Island, as well as Corpus Christi and Newport Passes and Packery Channel on Mustang Island. Fore-island dunes were eroded on St. Joseph, Mustang, and Padre Islands; on northern Mustang Island, as much as 150 feet of the fore-island dune field were eroded during the passage of Carla (Hayes, 1967). As the storm

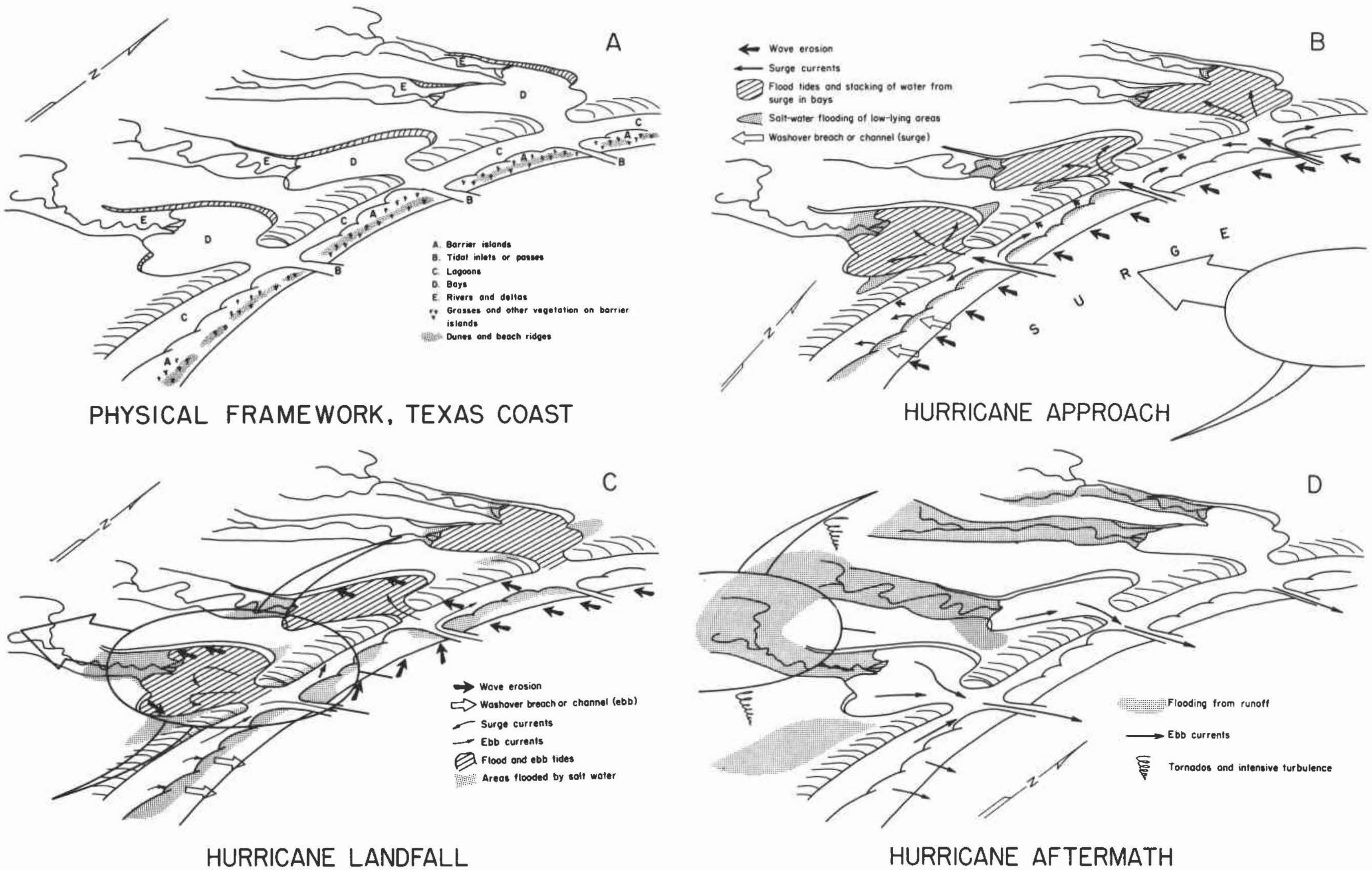


Figure 10. Schematic model of hurricane effects on the Texas Coastal Zone. (A) Physical features characterizing the Texas coast. (B) Effect of approaching hurricanes. (C) Effect of hurricanes upon impact with the coast. (D) Aftermath effects of hurricanes. After McGowen and others, 1970.

moved inland, low-lying areas were extensively flooded. For example, storm surge flooded the Aransas River valley a distance of about 8 miles from the head of Copano Bay. Total area inundated by Hurricane Carla storm surge in the Corpus Christi map area was 200 square miles. Storm-surge flooding may kill vegetation that is not salt-water tolerant; extensive flooding of St. Joseph Island during Hurricane Carla killed much of the vegetation (P. R. Bass, personal communication, 1974).

Rainfall that accompanies some storms may exceed 30 inches over a period of 2 days or so. Because of excessive hurricane aftermath rainfall, flooding along rivers and poorly drained coastal uplands is always a possibility during the passage of a hurricane.

HOW TO USE THE ATLAS

GENERAL MAP INTERPRETATION

The Environmental Geologic Atlas of the Texas Coastal Zone contains two kinds of information: (1) an *Environmental Geology Map* and eight *Special-Use Environmental Maps* with legends; and (2) a text including description of map units, tables, illustrations, bibliography, and other pertinent material. Preparatory to using the maps of the Atlas, one should be familiar with several aspects of map reading and interpretation. The maps have been constructed to be as self-explanatory as possible, but a brief review of maps and map interpretation may be desirable.

Map Orientation

The maps in the Atlas are oriented parallel to the curving Gulf coast shoreline rather than having the standard orientation with north at the top and east and west to the right and left, respectively (fig. 1). *North-south direction* on the maps parallels *longitude lines* that can be projected across the map from values printed at the map margin: 97°15′, 97°30′, and 97°45′. The 97°15′ longitude line, for example, is 97 degrees and 15 minutes west of the Prime Meridian at Greenwich, England. In the Corpus Christi area, 1 degree of longitude equals about 62 miles, or 1 minute of longitude equals 1.03 miles. Similarly, *east-west direction* on the maps parallels *latitude lines* that also can be projected across the map from the values printed on the map margin: 27°30′, 27°45′, 28°00′, and 28°15′. The 27°30′ latitude line is 27 degrees and 30 minutes north of the Equator. One degree of latitude equals 69 miles and one minute of latitude equals 1.15 miles. When using the maps, therefore, it is important to be aware of the cardinal directions of north, south, east, and west; the small index map at the lower right of each map provides immediate visual orientation of the Corpus Christi area within the Coastal Zone.

Magnetic declination in the center of the Corpus Christi area during 1974 was approximately 9 degrees 14 minutes easterly; magnetic North Pole is thus 9 degrees 14 minutes east of the geographic North Pole in the area. This simply means that a compass will read 9 degrees 14 minutes more easterly or clockwise than true or geographic North. Nine degrees 14 minutes must be subtracted from any magnetic bearing in this area if the bearing is to be converted to true or geographic North Pole.

Map Scales

Two kinds of horizontal scales are printed near the bottom of each map: fractional and graphic. The *Environmental Geology Map* was prepared with a *fractional scale* of 1:125,000. This means that one unit on the map equals 125,000 similar units in the area mapped: for example, 1 inch on the map equals 125,000 inches on the ground, or 1 inch on the map equals approximately 2 statute miles (63,360 inches per statute mile). The fractional scale for the eight *Special-Use Environmental Maps* is 1:250,000, or 1 inch on a map equals approximately 4 miles in the Corpus Christi area.

The *graphic scale* is convenient for determining distances or areas. The *Environmental Geology Map* has three graphic scales printed below the fractional scale: statute miles (5,280 feet per mile); kilometers (0.62 of a statute mile); and nautical miles (6,076 feet per nautical mile or about 1.15 statute miles). The eight *Special-Use Environmental Maps* have graphic scales in statute miles. The selection of scales for maps of this Atlas was based on maximum utility for detailed site evaluation and regional planning and analysis. Each map is presented on a controlled base, permitting accurate location and measurement. Conversion factors enabling the reader to convert to other measurement systems are provided in tables 3 and 5.

Topography and Bathymetry

Elevation and the topographic configuration of the land surface are shown by brown *contour lines* on the *Environmental Geology Map*. These lines trace equal elevations above mean sea level; *topographic contour interval*, or vertical distance in feet between the successive contour lines, is 5 feet, as shown on the map beneath the graphic scale. Each contour line value can be identified at points along the line by a figure indicating the number of feet above the blue mean sea-level line; for example, contour lines have values of 5, 10, 15, 20, 25, and so forth. To determine the approximate elevation of any point in the map area, simply estimate the position of the point relative to the next higher and lower contour lines (a point will rarely occur directly on one of the contour lines); if a point is about midway between the 30- and 35-foot contours, the elevation is approximately 32 or 33 feet above mean sea level.

Similarly, on the *Environmental Geology Map*, the depth of bay bottom and the Gulf floor is shown by blue *bathymetric lines* tracing equal depths. *Bathymetric contour interval* is commonly 6 feet, or at 6-foot vertical intervals (1 fathom) below mean sea level (-6, -12, -18, -24 feet), but in shallow parts of bays and inlets, 3-foot bathymetric contours are locally shown. The approximate depth at any point in the bays or the Gulf can, therefore, be determined in the same manner as estimating elevations above sea level.

One of the special-use environmental maps, *Topography and Bathymetry*, has both land elevations and bay-Gulf bathymetry shown in shaded colors. Each 5-foot topographic contour interval above sea level and each 6-foot bathymetric contour interval below sea level is depicted by a distinctive color, enabling easy interpretation of the land and bay-Gulf bottom configuration.

Other General Map Information

Cities, towns, ranches, airports, lakes, rivers and streams, highways, pipelines, railroads, county lines, city limits, canals, oil tanks, and other conventional geographic information are shown by symbols on the maps. Such features are commonly labeled for easy identification. All paved highways are included on the maps, but only Texas and U. S. numbered highways are labeled. Conventional map symbols used to represent this general geographic information are not included in the map legend. Users should, however, be aware of the extensive data that can be obtained by a careful study of each map.

The base map with its contours and natural and cultural features was constructed specifically for the Environmental Geologic Atlas of the Texas Coastal Zone from U. S. Geological Survey 7.5-minute topographic maps. This base map is the most accurate available regional map of the Texas Coastal Zone.

MAP LEGEND

Each map includes a legend designed to explain briefly and concisely every map unit delineated. For convenience, legends are standardized for each of the seven map areas within the Coastal Zone. The same color and order of legend units are followed on similar maps throughout the Zone. For example, any specific map unit can be readily identified and traced throughout the Coastal Zone by its distinctive color. Standardization of map colors permits joining of maps of the seven areas into a single sheet for the entire Coastal Zone. Slight differences in the color of a specific map unit, however, may occur from one map area to another because of minor variations in printing conditions.

Legend descriptions of a specific unit may change slightly from one map area to another because of natural regional environmental variations. As long as an environmental geologic unit represents virtually the same genetic process, substrate unit, vegetational type, or man-made feature, or as long as a special-use environmental unit represents the same general properties or characteristics, the map unit carries the same name and map color or symbol. A few map units may vary in color on different special-use environmental maps within the same Atlas in order that the color will be compatible with the specialized legend and color code of the specific map.

Units on the *Environmental Geology Map* are listed under respective *natural systems*. These systems are designated either *Pleistocene* or *Modern-Holocene*. This distinction refers to the relative ages of the systems. In general, *Pleistocene* refers to older units deposited before sea level began to rise at the end of the last principal glacial episode about 18,000 years B. P. During the rise in sea level from 18,000 to 4,500 years B. P., *Holocene systems* developed. All substrate, process, vegetation, and man-made units of the past 4,500 years, since sea level reached its approximate present position, are herein called *Modern*. For convenience, Holocene and Modern units have been grouped together because some units are of both late Holocene and early Modern age. Properties and characteristics of environmental geologic units are emphasized rather than age relationships.

Some map units, such as marsh, are component parts of more than one natural system; these are denoted in the legend by an asterisk. Also, some Modern units such as marsh may occur superimposed on an older Pleistocene system; these are clearly denoted within the legend.

Legend description of units on each map is purposely brief; each unit is, however, thoroughly described and its special significance discussed within the text. Table 1 shows the page number(s) where each unit is described and the map(s) on which the unit occurs. The order of units presented in map legends and

Table 1. Index of map units, Corpus Christi map area, Texas.

In the following alphabetical list of map units used in the Corpus Christi Environmental Geologic Atlas, Roman numerals indicate the map(s) on which the units occur, and Arabic numerals indicate text page(s) where the units are described or discussed. The maps are designated as follows:

I — Environmental Geology Map
II — Physical Properties Map
III — Environments and Biologic Assemblages Map
IV — Current Land Use Map
V — Mineral and Energy Resources Map
VI — Active Processes Map
VII — Man-Made Features and Water Systems Map
VIII — Rainfall, Stream Discharge, and Surface Salinity Map
IX — Topography and Bathymetry Map

within the text is generally similar, in order to facilitate use of the text descriptions.

The areal extent of each map unit, the length of linear features, and the number of specific environmental units within the Corpus Christi map area are noted in tables 3, 5, and 7-12. For example, the area covered by fresh-water marsh and the area being used as rangeland are listed in the tables. In addition, the percentage of each unit within the Corpus Christi map area is listed. The total length of features such as pipelines, erosional shorelines, or transportation canals and channels is tabulated, as is the number of specific sites such as power-generation plants, waste disposal pits, and airports. The areal extent of units is listed in square miles; linear features are in miles. Measurement of areal data is based on point-count methods and is cross-checked by planimeter techniques. Average values proved to exhibit greater than 90-percent accuracy. Linear features were measured by map-measuring wheels, and average values display greater than 95-percent accuracy. Accuracy of quantitative data is principally limited by the scale of the maps and the nature of the polyconic map projection.

ENVIRONMENTAL RESOURCE SUBJECT GUIDE

An extensive alphabetized index of information concerning the Coastal Zone has been compiled to afford easy access to desired information (table 2). The table provides a subject guide for locating general information, as well as information not specifically included in the map legends; both map and text sources are indexed. Following is an example of how this material may be used. One may wish to determine areas with very low permeability that would serve as satisfactory solid-waste disposal sites. By referring to *permeability* on table 2, the reader is directed to the *Physical Properties Map*, to specific pages in the text, and to a table evaluating land use suitability in the Corpus Christi area (table 4). In this manner, the areas of low permeability can be located on the *Physical Properties Map*. Reference to the text and table 5 provides additional description and evaluation of landfill suitability. In addition, if the user wants to know the percentage of improperly located solid-waste disposal sites within the Corpus Christi area, he can evaluate the sites based on the properties at each location (*Physical Properties Map*) and determine the percentage. Inter-

Table 2. Environmental subject index, Corpus Christi map area, Texas.

This subject index is designed to guide the reader to maps and text description that provide additional insight into varied problems and special interests within the Texas Coastal Zone. The index points to maps, figures, tables, and text sources that can be applied to specific problems. In some cases the desired information will be obvious to the reader; in other cases the reader must use the basic data to interpret an answer to his question; and in some instances the information will prove to be supplemental and must be combined with other data before specific answers can be obtained. With innovative and perceptive use of the data within the Environmental Geologic Atlas, persons with a wide variety of interests can answer many questions about the Texas Coastal Zone.

In the following index, Roman numerals indicate map(s), and Arabic numerals indicate text page(s). The maps are designated as follows:

I — Environmental Geology Map
II — Physical Properties Map
III — Environments and Biologic Assemblages Map
IV — Current Land Use Map
V — Mineral and Energy Resources Map
VI — Active Processes Map
VII — Man-Made Features and Water Systems Map
VIII — Rainfall, Stream Discharge, and Surface Salinity Map
IX — Topography and Bathymetry Map

pretation of data in this manner will naturally depend upon the experience of the user in the subject of interest.

GENERATING ADDITIONAL DATA

For cartographic convenience and feasibility, basic data are presented on a series of nine maps. Combining information from two or more maps may provide additional insight into an area or provide a specific solution to an environmental problem. Many other special maps can be prepared by the user to present any combination of properties or characteristics necessary. For example, to evaluate an area in terms of potential for recreational parks, characteristics desirable for this particular land use must be defined. If the desired recreational land should be well drained, above hurricane-tidal effects, accessible to the bay areas, vegetated with live-oak mottes, and remote from oil fields, pipelines, power lines, and residential or populated ranching communities, then the coincidence of these several factors, obtained by overlapping the special-use environmental maps depicting the required properties, outlines areas suitable for this type of recreational development. All of the recreation requisites can be obtained from various maps of the Environmental Geologic Atlas of the Texas Coastal Zone; a map that locates and rates potential recreation sites can, thereby, be prepared by the user.

If an industrial site is desired within a region, the area can be analyzed using the Atlas. For example, the *Physical Properties Map* outlines areas with suitable foundation strength and related properties; the *Current Land Use Map* indicates the current use and approximate value of the land, as well as location of residential areas for employees; the *Mineral and Energy Resources Map* indicates availability of construction materials, pipeline facilities, railroads and highways, and principal power lines; the *Topography and Bathymetry Map* shows the slopes and land configuration which might bear on the site selection; the *Rainfall, Stream Discharge, and Surface Salinity Map* illustrates climatic data that might be critical; the *Man-Made Features and Water Systems Map* shows drainage systems, reservoirs, made land, and other related elements within the area; and the *Environments and Biologic Assemblages Map* provides information on vegetation at potential sites. In this manner, an environmental analysis may be made to evaluate a site or area for a specific potential land use, or a broad area may be analyzed in order to outline favorable sites for specific uses.

Other maps may be made from the Atlas outlining areas of positive or negative suitability for a specific use, and the entire area can be grouped into various capability or use grades from excellent to poor on the basis of the number of desirable land factors which coincide. The varieties of special-use environmental maps that can be prepared from the basic *Environmental Geology Map* and units on the eight *Special-Use Environmental Maps* are virtually unlimited. By combining maps of this Atlas with other sources of economic, planning, industrial, transportation, or sociological data, a broad spectrum of environmental problems and management goals can be solved or at least outlined and properly defined.

ENVIRONMENTAL GEOLOGY MAP

The *Environmental Geology Map* of this Atlas is designed to be a basic document and inventory of the natural resources of the Texas Coastal Zone. It is the basic map from which most of the special-use maps were derived and compiled; it serves as data source for the generation of additional special-use maps. The map is also a base on which a variety of other information can be projected. Units delineated on the *Environmental Geology Map* are of first-order significance to resource preservation and use (table 1). Four basic kinds of units are: (1) physical units, including geologic substrates, soils, and subaqueous sediments, where composition and physical properties are of principal importance; (2) biologic units, including chiefly on-land units such as salt marsh, fresh-water marsh, swamp, and upland woodlands, and some subaqueous or submerged units, where biologic activity and productivity are dominant features in potential use or environmental maintenance; (3) active-process units, such as storm channels, tidal passes, wind-tidal flats, and beaches, where specific active or potentially active physical processes are of first-order consideration; and (4) man-made features, such as spoil heaps, spoil wash, dredged channels, and made or reclaimed land, where man's activity has resulted in significant land units. The first three kinds of mapped units—physical, biologic, and process—are natural units; the fourth kind—man-made—is an artificial unit.

Two broad classes of natural units exist within the Corpus Christi area of the Texas Coastal Zone. These include: (1) natural units that are products of active processes and environments, and (2) natural units formed at various earlier periods in the geologic history of the area by processes within environments no longer active. All mapped units and systems classed as *Pleistocene* on the *Environmental Geology Map*, forming chiefly the coastal uplands of the Corpus Christi area, are relict substrates formed in previously active but currently inactive environments. The Pleistocene ice age ended about 18,000 years B. P. (fig. 5), when melting glaciers caused sea level to rise; but most *Pleistocene* deposits in the Corpus Christi area were deposited during interglacial periods prior to the beginning of the last glacial episode (Wisconsin) about 100,000 years B. P. Units classed herein as *Modern-Holocene* on the *Environmental Geology Map* include: (1) deposits and landforms developed during the last rise in sea level, about 18,000 to 4,500 years B. P. (Holocene); and (2) deposits and landforms developed during the past 4,500 years, during which time sea level has been approximately at its present position (Modern).

On the *Environmental Geology Map* of this Atlas, natural mapped units are further grouped into large-scale *natural systems*. Such grouping reflects the natural associations and origins of specific mapped environmental categories. The origins of the various natural units in the Coastal Zone determine their main features, composition, and character, and are basic to considerations of resource evaluation and use. Natural systems delineated in the Corpus Christi area (fig. 4) include: (1) fluvial-deltaic system, a series of relict Pleistocene substrates and Modern environments and substrates formed by ancient rivers and deltas and by present-day rivers and deltas; (2) barrier-strandplain system, a suite of relict Pleistocene substrates and Modern environments and substrates formed at the interface of the land and Gulf; (3) marsh-swamp system, including a variety of Modern, permanently wet, grassed and wooded lands of the low-lying coastal areas; (4) offshore system, embracing various units of the Modern barrier island shoreface and inner continental shelf developed seaward of Gulf beaches; (5) bay-estuary-lagoon system, consisting of Modern subaqueous or submerged estuarine environments (for example, Nueces, Corpus Christi, Redfish, Aransas, and Copano Bays, and Laguna Madre) occurring inland from barrier islands and peninsulas and connected with the Gulf via Aransas Pass, Lydia Ann Channel, Aransas and Corpus Christi Ship Channels, and Fish Pass on south Mustang Island; and (6) eolian system, consisting of active and inactive clay-sand dunes formed downwind of marginal wind-tidal flats and other local sediment sources and a thin, discontinuous loess sheet formed from silt carried inland from the South Texas eolian sand sheet (Kingsville map area). Certain specific environments or mapped units may occur in more than one natural system, for example, marshes and swamps which also comprise local components of other natural systems. The areal extent of these natural systems and their component map units are recorded in table 3.

PLEISTOCENE SYSTEMS

Two natural depositional systems constitute the Pleistocene of the Corpus Christi area (fig. 4). These include a fluvial-deltaic system formed prior to 100,000 years B. P. and a barrier-strandplain system formed prior to 50,000 years B. P. during various interglacial and interstadial stages (fig. 5). These older deposits of the Coastal Zone form the coastal uplands generally situated at elevations greater than 10-15 feet above present sea level. Individual units within the Pleistocene systems are distinguished largely by composition of geologic sub-

Table 3. Areal extent of environmental geologic units, Corpus Christi map area, Texas. All values are in square miles.†

System	Subsystem	ENVIRONMENTAL GEOLOGIC MAP UNITS	Aransas County°	Bee County°	Jim Wells County°	Kleberg County°	Nueces County°	Refugio County°	San Patricio County°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Corpus Christi map area (excluding offshore areas)	Percentage of Corpus Christi map area covered by map unit (excluding offshore areas)
PLEISTOCENE SYSTEMS	FLUVIAL-DELTAIC SYSTEM	Meanderbelt sand, sparsely tree-covered, little grain preserved	0	56.8	0	0	0	80.7	61.2	–	198.7	8.4
		Floodplain, overbank mud, including mud-filled abandoned channels and mud-veneered meanderbelt sand	0	6.1	0	0	0	2.0	1.9	–	10.0	0.4
		Floodplain, mud veneer over meanderbelt sand, little grain preserved, grass-covered	0	19.8	0	0	0	42.1	14.1	–	76.0	3.2
		Distributary and fluvial sand and silt, including levee and crevasse splay deposits	0.3	0.3	0.2	21.0	175.1	20.7	120.6	–	338.2	14.4
		Interdistributary mud with sand veneer, including bay and floodbasin facies	2.6	2.1	0	0	0	16.5	25.3	–	46.5	2.0
		Interdistributary mud, including bay, floodbasin, and locally abandoned channel facies	0.3	2.6	0	41.9	428.3	23.1	212.0	–	708.2	30.1
		Upland oak mottes on fluvial sand (Modern)	0	1.1	0	0	0	0	0	–	1.1	0.05
		Delta-front mud and sand, may be reworked, veneered by thin marsh-lacustrine mud or loess, locally calichified	5.5	0	0	20.4	9.4	0	4.4	–	39.7	1.7
		Delta-front mud and sand, may be reworked, lacustrine mud or loess veneer removed by erosion, locally calichified	0	0	0	4.2	3.2	0	0	–	7.4	0.3
		Mud, thick veneer distributed locally over marine deltaic sand, delta-front, and reworked delta facies	6.5	0	0	0	0	2.9	3.7	–	13.1	0.6
		Marsh, fresh-water, and poorly drained depressions, mud and sand substrate, distribution varies with climatic cycle (Modern)	3.2	0	0	*	*	*	*	–	3.2	0.1
		Abandoned channel and course, mud-filled (Pleistocene and Modern-Holocene)	0	6.6	0.1	5.2	15.6	14.3	17.3	–	59.1	2.5
		Coastal lake or pond, mud-filled (Pleistocene and Modern-Holocene)	0.5	0.3	0	12.6	2.0	0.2	0.7	–	16.3	0.7
		Tidal creek, grass-covered, mud-filled (Pleistocene-Modern)	1.3	0	0	0	0	0.7	1.2	–	3.2	0.1
		Clay-sand dunes, accretionary, active, locally sparse grass, marginal to wind-tidal flat (Modern)	0	0	0	0.2	0.5	0	0	–	0.7	0.03
		Clay-sand dune complexes, inactive, grass- or brush-covered (Holocene and Modern)	0.5	0	0	*	*	0	0.5	–	1.0	0.04
		Loess sheet, thin, stippled where discontinuous, silty, overlies calichified Pleistocene fluvial sand, brush- and grass-covered (Modern-Holocene)	0	0	*	*	*	0	0	–	*	*
	BARRIER-STRANDPLAIN SYSTEM	Barrier-strandplain sand, tree-covered	9.9	0	0	0	1.2	0	10.0	–	21.1	0.9
		Barrier-strandplain sand, grass-covered	25.5	0	0	16.3	25.7	0	7.8	–	75.3	3.2
		Swales or minor drainage courses developed in lows, grass-covered, mud-filled (Pleistocene-Modern)	0.3	0	0	0	0	0	0	–	0.3	0.01
		Tidal creek, fresh-water marsh-covered, mud-filled (Pleistocene-Modern)	1.7	0	0	0	0	0	0.2	–	1.9	0.08
		Sheet sand, locally mud-veneered, landward of Pleistocene strandplain, wind- or sheetwash-derived, sparsely grass-covered, overlies partly filled lagoon, embayment, or linear depression (Pleistocene-Modern)	9.4	0	0	0	4.9	0	3.9	–	18.2	0.8
MODERN-HOLOCENE SYSTEMS	FLUVIAL-DELTAIC SYSTEM	Small ephemeral stream, alluvial or erosional, sand, silt, mud, headward-eroding, progressively sparser vegetation southward across map	0	4.3	0	2.2	9.9	4.4	7.1	–	27.9	1.2
		Wind-tidal flat, sand and mud, firm, occurs locally in lower stream valley, transitional between bay and stream	4.4	0	0	1.2	*	2.7	3.7	–	12.0	0.5
		Point-bar sand, bare or sparsely grass-covered, along active streams	0	0	0	0	0.3	0	0.3	–	0.6	0.03
		Levee and local crevasse splay deposits, silt, mud, and sand, sparsely grass-covered	0	0	0	0	2.2	0.7	3.7	–	6.6	0.3
		Levee and local crevasse splay deposits, silt, mud, and sand, tree-covered	0	0	0	0	0.5	0	0.5	–	1.0	0.04
		Levee deposits, silt, mud, and sand, fresh-water marsh-covered	0	0	0	0	0.2	1.7	3.7	–	5.6	0.2
		Meanderbelt sand without prominent grain, tree-covered, locally overbank muds, inactive, within an entrenched valley	0	4.8	0	0	3.9	10.6	13.4	–	32.7	1.4
		Meanderbelt sand and silt, sparsely grass- and shrub-covered, inactive, within an entrenched valley	0	1.1	0	0	8.1	9.8	21.0	–	40.0	1.7
		Floodbasin, overbank mud, grass-covered, inactive, within an entrenched valley	0	0	0	0	2.2	1.7	2.9	–	6.8	0.3
		Abandoned channel and course, mud-filled	0	*	*	*	*	*	*	–	*	*
		Abandoned channel and small depressions, swamp-covered, mud-filled	0	0	0	0	0	0.2	1.3	–	1.5	0.06
		Abandoned channel and course, fresh-water marsh-covered, mud-filled	*	0	0	*	*	*	*	–	*	*
		Marsh, salt-water, mud and locally sand substrate	2.6	0	0	0	*	*	5.1	–	7.7	0.3
		Marsh, fresh- to brackish-water, mud and locally sand substrate	2.3	0	0	0	0	0	6.3	–	8.6	0.4
		Marsh, fresh-water, mud and locally sand substrate	*	0	0	*	*	5.2	7.8	–	13.0	0.6
		Berm and beach ridge, abandoned, sand and shell	*	0	0	0	0	0.2	*	–	0.2	0.01
		Prodelta mud and silt (active)	0	0	0	0	*	*	0	–	*	*
		Delta-front sand (active)	0	0	0	0	0	*	0	–	*	*
		Fan delta, sand, subaerial, along bay margin and entrenched valley walls	0	0	0	0	*	0	0.2	–	0.2	0.01

Table 3 (continued) —

MODERN-HOLOCENE SYSTEMS	BARRIER-STRANDPLAIN AND OFFSHORE SYSTEM	Shelf mud and sand with shell, mottled	–	–	–	–	–	–	–	215.8	–	–
		Shoreface, sand and muddy sand, burrowed	–	–	–	–	–	–	–	39.8	–	–
		Beach, sand and shell	1.0	0	0	1.0	1.2	0	0	–	3.2	0.1
		Fore-island dune ridge, sand	1.0	0	0	1.7	1.2	0	0	–	3.9	0.2
		Sandflats and/or coppice sand-dune fields, wind-shadow dunes common, active	1.0	0	0	0	0.7	0	0	–	1.7	0.07
		Beach ridge and barrier flat, sand and shell, grass-covered (beach ridges rare or absent south of Aransas Pass)	0.5	0	0	5.7	7.2	0	0	–	13.4	0.6
		Stabilized blowout dune complex, sand, grass-covered, hummocky, ramplike	4.7	0	0	0.2	5.2	0	0.2	–	10.3	0.4
		Marsh, salt-water, mud and locally sand substrate	*	0	0	0	*	*	*	–	*	*
		Washover channel, sand-filled, inactive	0.5	0	0	0	0.2	0	0	–	0.7	0.03
		Washover distributary channel, sand, active	2.9	0	0	0	1.2	0	0	–	4.1	0.2
		Washover fan, sand, subaerial, vegetated (mostly relict)	1.0	0	0	0	2.5	0	0	–	3.5	0.1
		Washover distal fan, sand, subaerial, barren, commonly active	2.6	0	0	0	0	0	0	–	2.6	0.1
		Fore-island blowout dunes and back-island dunes, sand, active	0.8	0	0	9.3	3.0	0	0	–	13.1	0.6
		Tidal channel, sand, active	2.1	0	0	0	1.2	0	0	–	3.3	0.1
		Flood-tidal delta, sand, subaqueous, proximal to channel	*	0	0	0	*	*	0	–	*	*
		Flood-tidal delta, mud and sand, subaqueous, distal to channel	0.5	0	0	0	0	0	0	–	0.5	0.02
		Ebb-tidal delta, sand, subaqueous	0	0	0	0	*	*	0	9.0	*	*
		Inlet-related shoal, sand	0.3	0	0	0	0.2	0	0	0.5	0.5	0.02
	MARSH-SWAMP SYSTEM	Marsh, salt-water, mud and locally sand substrate	*	0	0	0	1.5	1.5	*	–	3.0	0.1
		Marsh, fresh- to brackish-water, mud and locally sand substrate	*	0	0	0	0	0	*	–	*	*
		Marsh, fresh-water, mud and locally sand substrate, ephemeral in Port Bay and Laguna Larga areas, distribution varies with climatic cycle	*	0	0	3.4	3.0	*	*	–	6.4	0.3
		Swamp, mud and locally sand substrate, locally within entrenched river valleys	0	0	0	0	0	*	*	–	*	*
	BAY-ESTUARY-LAGOON SYSTEM	Fan and fan delta, sand, subaerial, along bay margin	0	0	0	0	0.2	0	*	–	0.2	0.01
		Berm or beach ridge, abandoned, sand and shell	0.3	0	0	0	0	*	0.5	–	0.8	0.03
		Bay-margin sand and mud, accretionary, subaerial, relict depositional grain, locally vegetated	1.0	0	0	0.2	1.5	0.2	1.0	–	3.9	0.2
		Wind-tidal flat, sand and mud, firm	*	0	0	*	14.3	*	*	–	14.3	0.6
		Wind-tidal flat, mud and sand, algal-bound mud, gypsiferous, firm	1.0	0	0	0	1.2	0	0	–	2.2	0.09
		Grassflat, muddy sand with shell	4.7	0	0	17.6	30.9	0.2	0	–	53.4	2.3
		Bay-margin sand, muddy sand and shell, bare to sparsely marine grass-covered, subaqueous	5.5	0	0	1.7	9.6	1.5	0	–	18.3	0.8
		Bay-margin sandy mud, mottled, some shell	11.4	0	0	0	3.7	0	0	–	15.1	0.6
		Delta front and channel-mouth bar, sand shoal (active)	0	0	0	0	0	0.2	0	–	0.2	0.01
		Prodelta mud and silt	0	0	0	0	0.2	0.2	0	–	0.4	0.02
		Bay and lagoon mud, mottled, some mixed shell	29.6	0	0	4.4	93.2	0.5	0.2	–	127.9	5.4
		Bay mud with shell	0	0	0	0	0.5	0	0	–	0.5	0.02
		Bay and lagoon sand, muddy, locally sparse grass	3.1	0	0	0	10.1	0	0	–	13.2	0.6
		Oyster reef, veneered by sand at Long Reef and Donnel Reef	1.0	0	0	0	1.7	0.2	0	–	2.9	0.1
		Oyster reef flank, sand or mud, abundant shell, veneered by sand at Long Reef and Donnel Reef	1.6	0	0	0	1.5	1.5	0	–	4.6	0.2
		Interreef mud with oyster shell	18.7	0	0	0	15.3	9.3	0	–	43.3	1.8
		Bay sand and muddy sand, locally with shell	8.6	0	0	0	41.7	6.1	0	–	56.4	2.4
		Tidal channel, sand, active, small bay-margin tidal channels	*	0	0	0	*	0	0	–	*	*
		Flood-tidal delta, sand, subaqueous, small bay-margin tidal deltas	0.6	0	0	0	0.2	0.7	0	–	1.5	0.06
		Ebb-tidal delta, sand, subaqueous, small bay-margin tidal deltas	0	0	0	0	0.5	0.2	0	*	0.7	0.03
	EOLIAN SYSTEM	Clay-sand dunes, accretionary, active, locally sparse grass, marginal to wind-tidal flat	0	0	0	*	*	0	0	–	*	*
		Clay-sand dune complexes, inactive, grass- or brush-covered, local sediment source	*	0	0	1.7	0.5	0	*	–	2.2	0.09
		Loess sheet, thin, stippled where discontinuous, silty, overlies calichified Pleistocene fluvial sand, brush- and grass-covered	0	0	1.0[⊕]	14.5 [9.8][⊕]	0.2[⊕]	0	0	–	25.5	1.1

Table 3 (continued) —

OTHER MAP UNITS	Point-bar (fluvial) accretion	–	–	–	–	–	–	–	–	–	–
	Longitudinal dune orientation in back-island dune field and stabilized blowouts	–	–	–	–	–	–	–	–	–	–
	Beach ridge (barrier-strandplain) and berm accretion	–	–	–	–	–	–	–	–	–	–
	Spoil heap or mound, subaerial	0.5	0	0	0.7	1.5	0	0.2	–	2.9	0.1
	Reworked spoil, subaerial	1.0	0	0	0.7	9.4	0	0.7	–	11.8	0.5
	Spoil, subaqueous	2.6	0	0	3.4	21.2	0	0	0.8	27.2	1.2
	Made land	1.8	0	0	0	11.8	0	1.0	–	14.6	0.6
TOTAL	Total land area+	97.7	105.9	1.3	174.1	759.7	242.1	565.4	–	1946.2	82.6
	Total land and water area, excluding offshore area+	195.7	106.0	1.3	214.7	1002.1	265.8	571.0	–	2356.6	100.0
	Total water area (natural and artificial) excluding bay, lagoon, and open ocean	7.0	0.1	0	13.5	9.7	3.1	5.4	–	38.8	1.6
	Total bay and lagoon area	91.0	0	0	27.1	232.7	20.6	0.2	–	371.6	15.8

†Data accuracy approximately 90 to 95 percent; determined by point-count method.
°Only part of each county lies within map area.
–Data not measured or unit not applicable.
•Map unit occurs in more than one system; data recorded in system where most abundant.
+Includes only that part of county within Corpus Christi map area.
⊕Stippled unit.

To convert square miles to other units, use the following factors:
square miles x 2.59 = square kilometers
square miles x 640 = acres
square miles x 2.49 = square leagues
square miles x 3,613,041 = square varas

strates and overlying soils, trend and distribution of sediments, and locally preserved relict landforms.

Fluvial-Deltaic System

There are 17 units that were recognized and mapped within the Pleistocene fluvial-deltaic system. These include units that are entirely Pleistocene, those that were created during the Pleistocene (for example, abandoned channel segments) and are receiving some sediment today, and Modern-Holocene features (for example, tidal creeks, beaches, and oak mottes) that modify fluvial-deltaic deposits. Pleistocene and younger associated units include: (1) meanderbelt sand, (2) floodplain, overbank mud, (3) floodplain mud veneer overlying meanderbelt sand, (4) distributary and fluvial sand and silt, (5) interdistributary mud with sand veneer, (6) interdistributary mud, (7) delta-front mud and sand with thin mud or loess veneer, (8) delta-front mud and sand with mud or loess veneer eroded, and (9) mud overlying deltaic sand. Other Pleistocene and/or Modern-Holocene units that are components of the fluvial-deltaic system include: (1) upland oak motte, (2) fresh-water marsh, (3) mud-filled abandoned channel and course, (4) mud-filled coastal lake or pond, (5) mud-filled and grass-covered tidal creek, (6) active, accretionary clay-sand dunes, (7) inactive clay-sand dunes, and (8) loess sheet covering Pleistocene fluvial sand. The principal natural systems within the Corpus Christi map area are shown in figure 4.

Pleistocene meanderbelt sands and floodbasin muds have, in part, been called Montgomery and Bentley Formations, as well as Lissie Formation. Similarly, Pleistocene deltaic units (distributary channel sand and silt and interdistributary mud) and barrier-strandplain deposits (Ingleside sand) have been termed Beaumont Formation or, in part, Prairie Formation (Aronow, 1971; Bernard and LeBlanc, 1965).

Meanderbelt sands.—Meanderbelt sands, the channel and point-bar deposits of Pleistocene meandering streams, occupy almost 200 square miles of uplands bounded on the south by U. S. Highway 181 and on the east by segments of Chiltipin and Sous Creeks, Aransas and Mission Rivers, and Chocolate Swale. Northeast of Sinton, U. S. Highway 77 traverses the eastern margin of the meanderbelt complex (figs. 11 and 12). The sands form a low-relief surface on which some primary depositional topography and grain are vaguely displayed, for example, elongate meanderbelts, filled channel segments, and oxbow lakes. Point-bar accretionary grain has been destroyed by vegetation, weathering, and local wind deflation.

The meanderbelt sands exposed in the northern part of the Corpus Christi map area, along with floodbasin muds, compose the southern part of the large Pleistocene Guadalupe and San Antonio fluvial complex (fig. 4) that is widely exposed in the Port Lavaca map area. These relict meanderbelts, which trend south and southeast, represent abandoned segments of many river courses. The rivers graded gulfward into deltas which slowly filled a large, Pleistocene embayment. Meanderbelt sands are permeable and well drained; they support mixed chaparral, post-oak, and rare live-oak vegetation. The meanderbelt sands are used principally for cattle production. Thick, sandy soils, such as the Refugio sand, are well developed on these fluvial substrates. The sands are principally fine to medium grained, but coarse-grained sand and gravel may occur within the unit at the base of individual point-bar deposits.

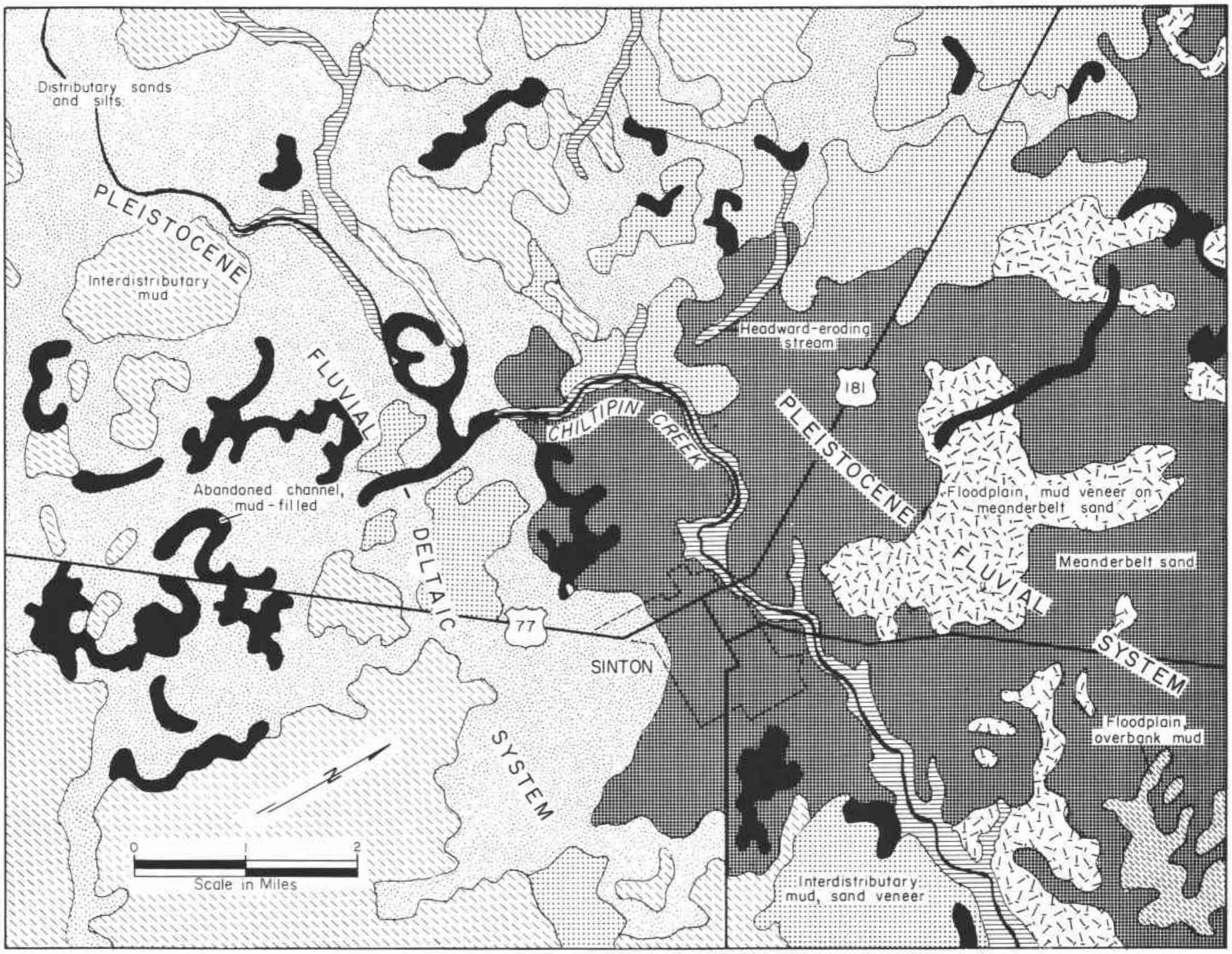


Figure 11. Pleistocene fluvial system composed of meanderbelt sands and floodbasin, overbank mud and mud veneer and Pleistocene fluvial-deltaic deposits in the vicinity of Sinton, Corpus Christi map area. Chiltipin Creek is a Modern, headwardly eroding fluvial system.

Floodplain muds.—Broad, somewhat elongate areas lying between meanderbelt sands are underlain by muddy or clayey deposits and soils. About 85 square miles of these relict, Pleistocene floodbasin deposits occur within the meanderbelt complex north of Sinton (figs. 11 and 12). Some of the areas are underlain by thick muds (10 square miles), but 75 square miles are composed principally of a mud veneer of variable thickness overlying meanderbelt sand bodies. These mud veneer deposits are overbank sediments derived from streams that occupied the associated relict meanderbelts. The Pleistocene overbank deposits form isolated prairies vegetated by grasses and scattered trees and brush. Some local silage crops are grown on the floodbasin muds, but principally the unit is used for cattle grazing. Soils that have developed on the floodbasin prairies include soils of the Victoria and Banquete series.

Distributary and fluvial sand and silt.—More than 1,000 square miles of the coastal plain in the Corpus Christi map area are underlain by Pleistocene deltaic deposits. Except for the Pleistocene meanderbelt complex north of Sinton and the Ingleside barrier-strandplain sand, most of the Corpus Christi area above an elevation of 10 feet is underlain by mud, silt, and sand deposited primarily by the relict Nueces delta (Sangamon Interglacial stage).

Elongate distributary and fluvial sands cover about 340 square miles within the Corpus Christi map area.

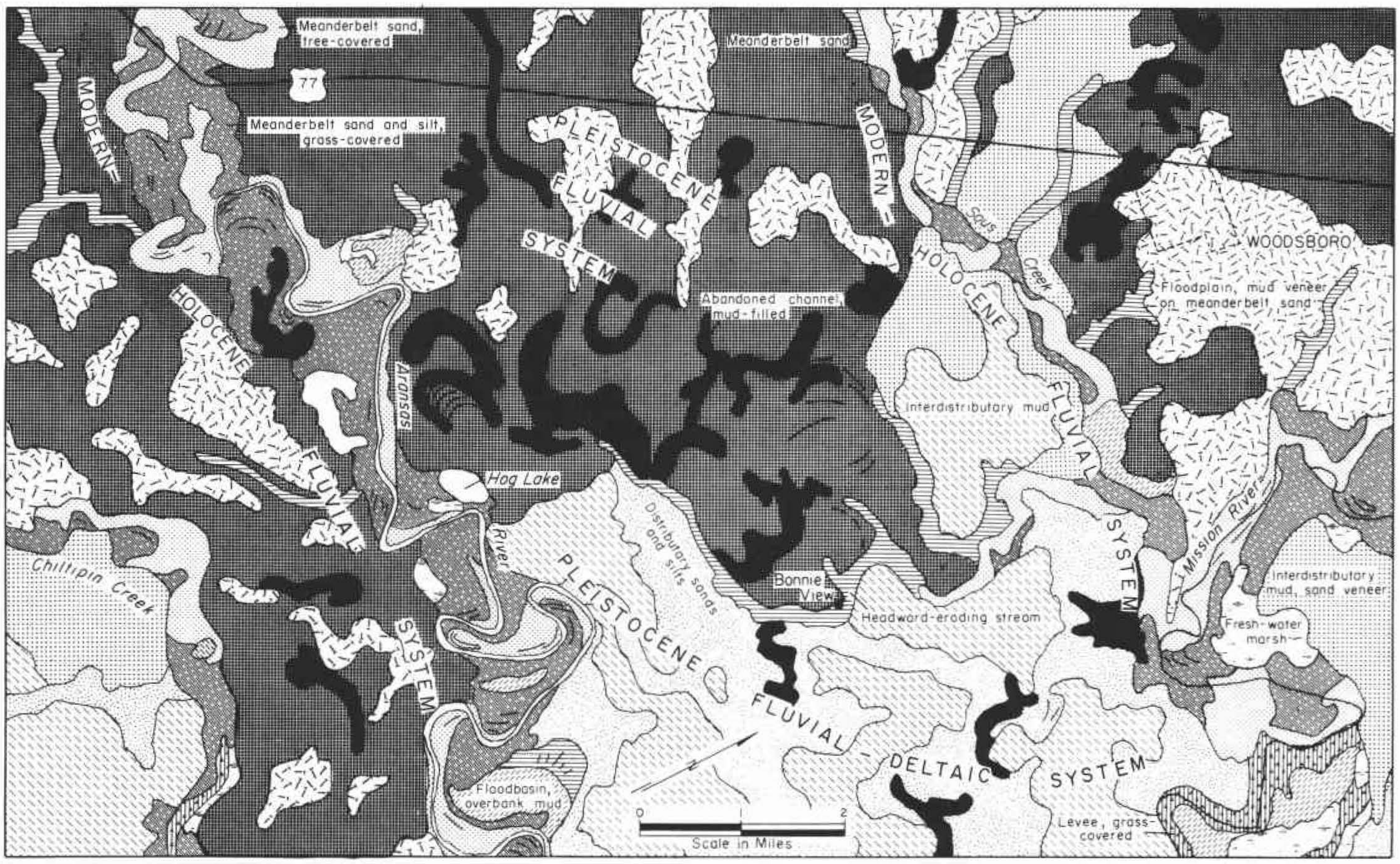


Figure 12. Pleistocene fluvial deposits (meanderbelt sands and floodbasin, overbank mud and mud veneer) and Pleistocene fluvial-deltaic system in the vicinity of Woodsboro, Corpus Christi map area. The Modern Aransas River flows over Holocene meanderbelt sand deposits.

South of the Nueces River, these elongate sand and silt deposits generally trend southward across the broad coastal plain; north of the river, the sands trend northward (fig. 4). The sands and silts were deposited within distributary channels, on flanking levees, and as crevasse splays on broad, late Pleistocene delta plains. Individual sand bodies are up to 30 miles long, range in width from about 0.25 mile to 4 or 5 miles, and may be up to 100 feet thick (fig. 13). They are composed of very fine- to fine-grained sands with admixtures of silt and clay. Locally the sands have been partially replaced by caliche. Soils associated with the distributary deposits include Orelia, Miguel, and Willacy fine sandy loams and Clareville loam; abandoned channels and crevasse splays are commonly covered by Banquete and Victoria clays.

Areas underlain by the channel sands are slightly elevated (3 or 4 feet) above the surrounding coastal plain. Most of the exposed channel units are composed of levee deposits; channel-fill sands commonly lie below the surface of the slowly subsiding sedimentary bodies. Silty, crevasse splay deposits are preserved within the adjacent interdistributary basins flanking many of the younger channels (see, for example, the channel segments between Robstown and the Chapman and Laureles ranches). Channel bodies are characterized by distributary branching patterns and abandoned channel loops and courses. The channel loops were abandoned during the Pleistocene, though infilling continues to the present. The abandoned channel segments and loops are largely filled with mud in contrast to the sand on which they are commonly superimposed. Most of the loops are filled and have been obscured by ploughing and cultivation. Following heavy rains, some channel segments pond water. Boundaries between fluvial sand and finer grained silt and mud may be delineated more precisely on infrared aerial photographs than on the black-and-white photographs used in this study.

Distributary channel deposits generally trend coastward within the Corpus Christi map area. During late

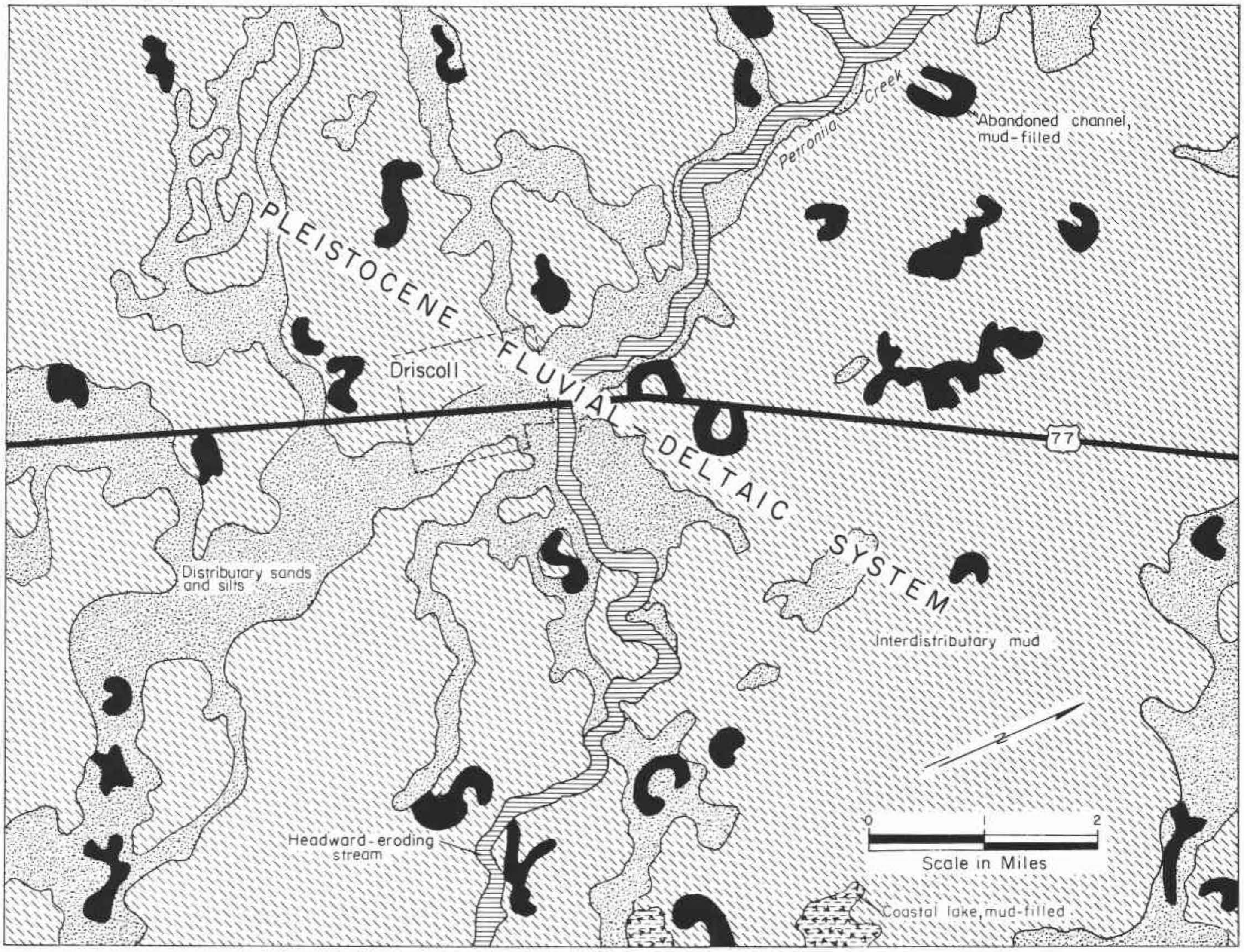


Figure 13. Delta-plain deposits of the late Pleistocene fluvial-deltaic system near Driscoll, Corpus Christi map area. Petronila Creek has eroded headwardly across the surface of the relict delta system.

Pleistocene, a major, elevated distributary lay along the present course of the Nueces River; several distributaries branch northward and southeastward from this relict channel trend. Near Sinton (fig. 11) and between Copano Bay and U. S. Highway 77 (fig. 12), distributaries appear to have originated from the late Pleistocene Guadalupe-San Antonio meanderbelt complex.

Map patterns indicate that Pleistocene meanderbelt deposits (Lissie Formation) and Pleistocene deltaic deposits (Beaumont Formation) may intertongue throughout much of the coastal plain. For example, in the Woodsboro area, meanderbelt sand deposits appear to grade coastward into deltaic distributary channel deposits. Gulfward in the Laguna Larga and Port Bay areas, the distributaries grade into sheet sands and muds of delta-front and marine environments (fig. 14). Pleistocene deltaic deposits extend gulfward beneath the Ingleside barrier-strandplain sand body (fig. 6).

Interdistributary mud.—Extensive areas of the Pleistocene coastal uplands between distributary channels (fig. 4) are composed of broad, flat to slightly depressed areas of mud and clay substrates, mud with sand veneers, and associated soils (figs. 11-15). These fine-grained muddy and clayey sediments represent floodbasin or overbank deposition on the Pleistocene delta plain. This is the most extensive map unit in the Corpus Christi area, covering over 750 square miles. The Victoria clay soil that has developed on most of the

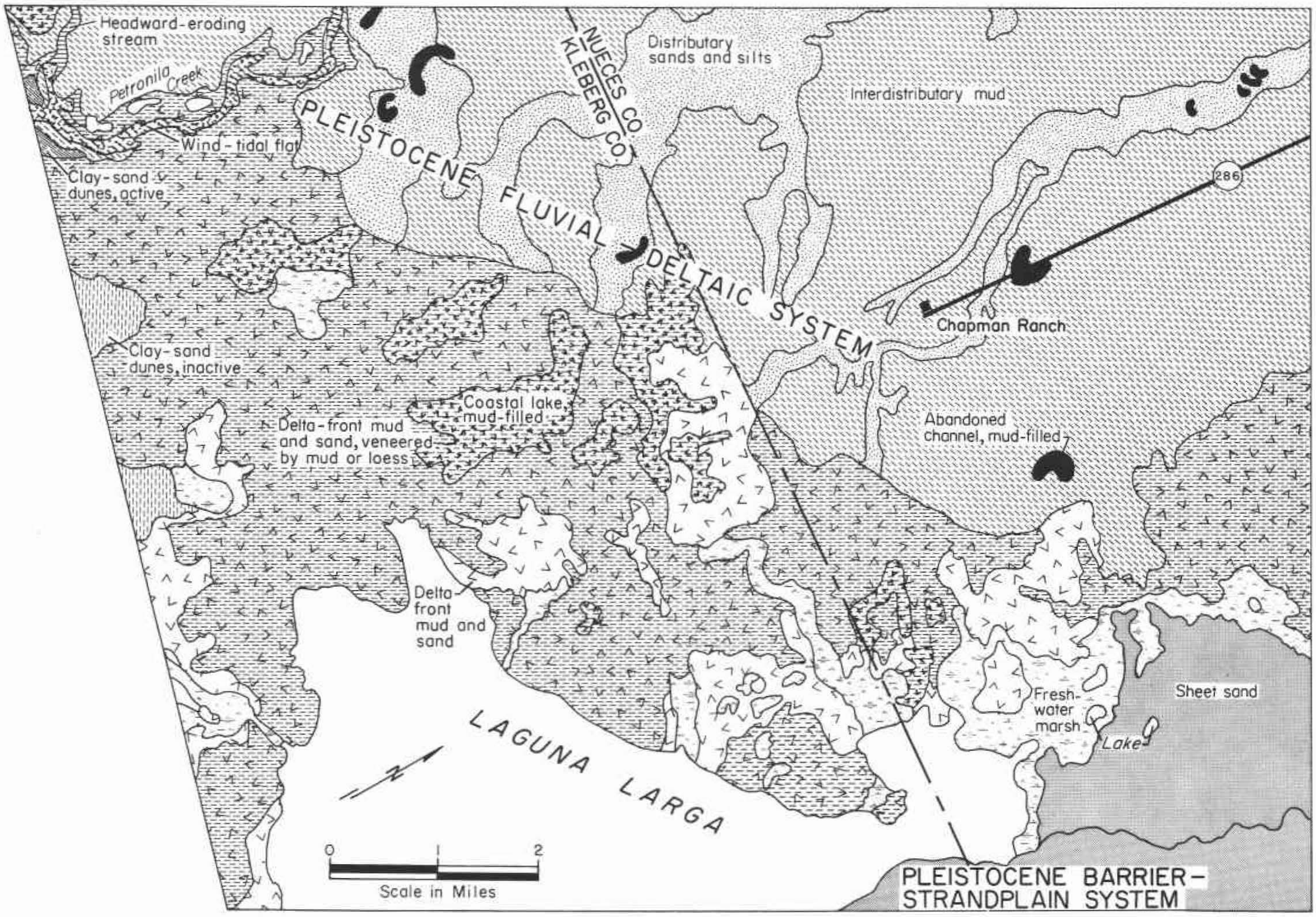


Figure 14. Pleistocene fluvial-deltaic system grading gulfward into delta-front mud and sand deposits in the vicinity of Laguna Larga, Corpus Christi map area. Younger Pleistocene barrier-strandplain sands overlap the deltaic deposits. Laguna Larga occupies a remnant of a Pleistocene brackish bay or lagoon.

Pleistocene interdistributary deposits is a dark, fertile, highly productive agricultural soil. Cultivated lands within the region are almost entirely restricted to the interdistributary Victoria clay and Orelia, Miguel, Willacy, Clareville, and Banquete soils that have developed on the associated distributary deposits of the relict delta plain.

Delta-front mud and sand.—Some distributary channel sands of probable Sangamon age terminate gulfward in broad sand sheets (fig. 14) composed of delta-front sediments. After the delta was abandoned, there was subsequent reworking by marine currents. The deltaic sands and silts also may have been eroded and reworked during minor Wisconsin interglacial stages. Approximately 60 square miles of marine sheet sand are exposed west of Laguna Larga and adjacent to Port Bay (figs. 14 and 15). All but about 7 square miles of the marine deposit is veneered by Pleistocene or Holocene lagoonal, lacustrine, and loessic sediments. Near Port Bay, about 13 square miles of the marine deltaic deposits are obscured by a thick veneer of muddy sediments. Sandy areas are covered by Mustang and Nueces fine sand soils that grade into Orelia and Clareville soils of the distributary units. Muds are overlain by Banquete, saline Lomalta, and some Orelia soils. In the outcrop area, these marine deposits may be principally reworked sands that rest upon eroded, distal delta-plain sediments.

Upland oak motte.—A single, large oak motte, covering about 1 square mile, occurs on floodbasin mud along Medio Creek in the northernmost part of the map area.

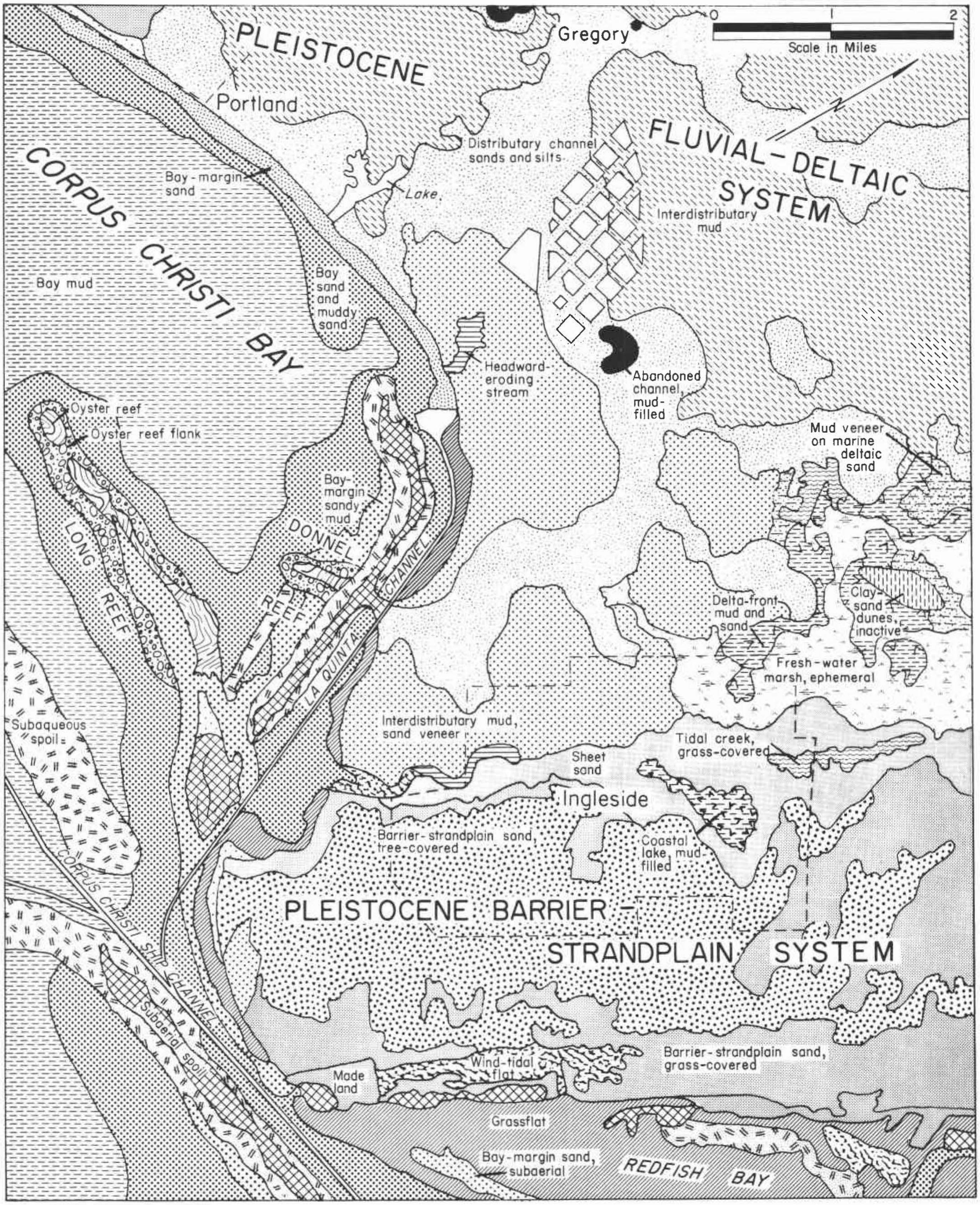


Figure 15. Pleistocene fluvial-deltaic system overlapped by younger Pleistocene Ingleside barrier-strandplain sands in the vicinity of Ingleside, Corpus Christi map area. Long Reef has been buried by sand reworked from subaqueous spoil deposits. Ephemeral marsh north of Ingleside represents a remnant of Port Bay.

Marsh and poorly drained depressions.—Patches of fresh-water marsh and other hydrophytes occupy poorly drained depressions that have developed on Pleistocene marine deltaic sands and Holocene mud veneer in the Port Bay area and adjacent to Laguna Larga (figs. 14 and 15). Occupying only about 3 square miles, these depressions periodically pond water. During drought years, the marsh environment is destroyed, but marsh may reoccupy the depression during subsequent periods of higher rainfall. Soils include Banquete and perhaps some Lomalta clays.

Abandoned channel and course.—Rivers frequently alter their courses in response to changes in flow characteristics of the stream system. Evidence of channel changes in a meandering river are meander cutoffs which subsequently become oxbow lakes. Channels that are abandoned slowly fill with mud and plant debris. Pleistocene meander cutoffs are common throughout the Pleistocene fluvial-deltaic system (figs. 11-13). The oxbow lakes are filled with Pleistocene and Modern-Holocene sediment. Cultivation has significantly obscured the filled oxbow lakes in the Corpus Christi map area. Some filled oxbows pond water following severe rains, but the deficient rainfall budget in the coastal bend areas precludes development of fresh-water marshes that commonly occupy abandoned channels in the more humid upper Texas coastal area. Almost 60 square miles of filled meander channels have been mapped. Use of infrared aerial photographs will permit more precise mapping of the cutoffs because of thermal differences exhibited by the mud-filled channel and adjacent sands.

Coastal lake or pond.—Most coastal lakes or ponds in the Pleistocene fluvial-deltaic system of the Corpus Christi area are mud filled. About 16 square miles of mud-filled lakes and ponds are located within interdistributary depressions and poorly drained delta-front areas in the southern part of the map area (figs. 13 and 14). Banquete and Victoria clay soils have developed on most of these poorly drained depressions. The low permeability of the clay substrates and soils permits retention of moisture for several days following normal rainfall. The areas are characterized by dark tones on black-and-white aerial photographs; moisture variations should allow more precise mapping using infrared aerial photographs. Insufficient ponding of water has precluded the development of fresh-water marsh, but high-moisture hydrophytes occupy the depressions during extended periods of higher rainfall.

A few mud-filled ponds and lakes occur within relict floodbasin areas near Medio Creek in Bee County. Large lakes such as those north and northeast of Refugio (Port Lavaca map area) do not occur in the Corpus Christi area.

Tidal creeks.—In the Port Bay area, Modern tidal creeks have eroded Pleistocene marine delta-front deposits. Many of the creeks are still active or have been covered by fresh or fresh to brackish marsh (fig. 16). Other tidal creeks are relict mud-filled and grass-covered units (fig. 15). Tidal creeks occupy about 3 square miles of the Corpus Christi area. Lomalta-type saline soils are common on the channel-fill deposits.

Clay-sand dunes.—Some active and inactive clay-sand dunes occur near Port Bay and McCampbell Slough, along the margin of Oso Bay and Oso Creek, and southwest of Laguna Larga (figs. 14 and 15). Except for active dunes located on the northern and western margins of wind-tidal flats within the lower reaches of Oso Creek, all of the clay-sand dunes in the Corpus Christi map area are currently inactive. These dunes occur on Pleistocene delta-front deposits near Port Bay and Laguna Larga and along Oso Creek which is headwardly eroding the Pleistocene delta sediments.

The active dunes within lower Oso Creek are forming by accretion of saline clay pellets deflated from the surface of the wind-tidal flats. Wind deflation near Laguna Larga and Port Bay is presently inactive; these dunes were deposited on the Ingleside terrace principally by deflation of sand and silt from Pleistocene delta-front deposits. Other inactive clay-sand dunes are associated with the South Texas eolian system west of Bishop and San Fernando Creek. Inactive dunes are well vegetated by brush and grasses; active dunes are sparsely grass covered. Only 0.7 square mile of clay-sand dunes is currently active and 1 square mile of inactive dunes exists within the Corpus Christi area.

Loess-covered fluvial deposits.—Within the Corpus Christi map area west of Bishop, about 25 square miles of Pleistocene fluvial deposits (meanderbelt sand and floodbasin mud) are covered by a thin veneer of loess derived from wind deflation in the South Texas eolian system near Baffin Bay (Kingsville map area). This map unit is a component of the eolian system.

Barrier-Strandplain System

Most of the Texas coast is characterized by a series of Modern barrier islands that formed seaward of extensive bay and lagoon systems by the gulfward accretion of beach ridges and shoreface sediments. A series of relict marine sand bodies preserved inland of the present coastline throughout much of the Texas

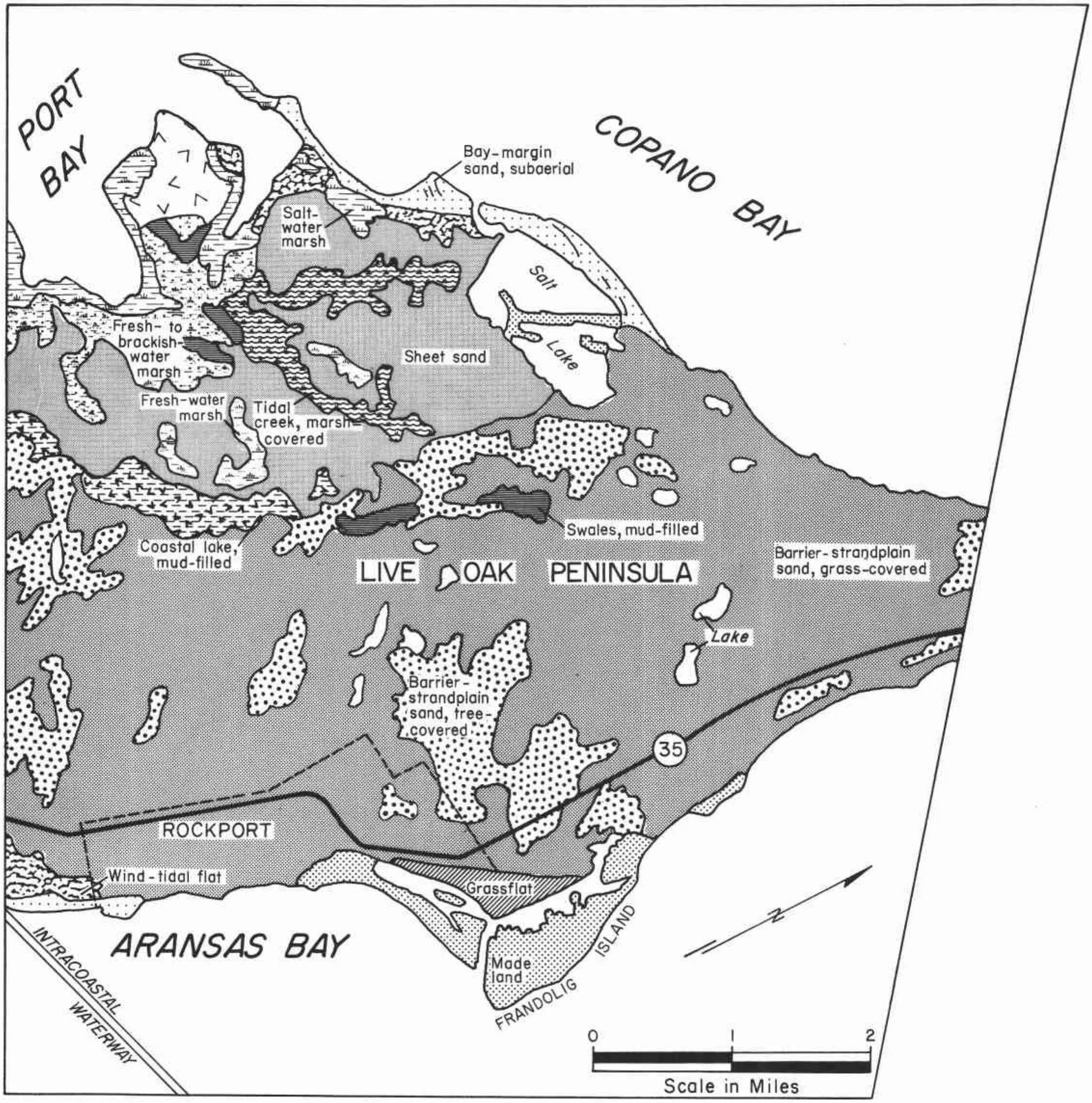


Figure 16. Pleistocene Ingleside barrier-strandplain system near Rockport, Corpus Christi map area. Eolian and storm-washover sheet sands partially fill Port Bay. Berms along Copano Bay were produced by Modern processes.

Coastal Zone has been considered by many geologists (Price, 1933, 1958; Bernard and LeBlanc, 1965; and others) to represent a Pleistocene counterpart of the Modern barrier islands. Many of these sand deposits, which are called Ingleside sands (Price, 1933), may, in fact, have formed within strandplain environments along ancient Gulf shorelines that were supplied with sediment by local deltas and by erosion of older Pleistocene coastal headlands. Wilkinson and others (1975) infer a strandplain origin for Ingleside deposits in the Port Lavaca area and suggest that the sand was supplied locally by rivers such as the late Pleistocene Guadalupe-San Antonio system. Similarly, Ingleside sands in the Corpus Christi area may have formed as strandplains associated with a wave-dominated Nueces delta of late Pleistocene age. Because of the uncertainty of the precise origins of the various Ingleside sands of the Texas coast, the unit herein is called a "barrier-strandplain system." Based on the interpretation of vertebrate fossils from the Tedford pit near Ingleside, Lundelius (1972) infers a Wisconsin age for the Ingleside sand in the Corpus Christi area.

A strandplain origin for the Ingleside system does not require a continuous late Pleistocene lagoonal system landward of the sand body. In fact, the "Ingleside terrace" that occurs landward of the Ingleside sands (Price, 1933, 1958) probably represents a series of discontinuous lagoons and lakes that were associated with the strandplain system. Based upon environmental geologic mapping for this Atlas, the Ingleside sand body rests upon eroded late Pleistocene (Sangamon?) deltaic deposits (figs. 6 and 15). The precise relationship between the Ingleside sand body and the mud deposits that Price (1958) interpreted to be Ingleside lagoonal deposits, can be clarified only by additional subsurface analysis. Based on the fact that Ingleside sands in the adjacent Port Lavaca area accreted gulfward for more than 16 miles (Wilkinson, 1973; Wilkinson and others, 1975) and that strong, accretionary, beach ridge topography has been preserved, it is very unlikely that the Ingleside sand was of transgressive origin. If extensive Ingleside lagoonal muds do exist, they must underlie eolian sheet sands, mud veneers, and marsh deposits in the Port Bay-McCampbell Slough and Laguna Larga-Oso Bay areas (figs. 14-16). Other aspects about the origin of the Ingleside deposits have been described in the previous chapter, Geology and Geologic History.

In the Corpus Christi map area, the Ingleside barrier-strandplain system is composed of five units based on vegetation, morphology, and substrate composition: (1) tree-covered barrier-strandplain sand; (2) grass-covered barrier-strandplain sand; (3) mud-filled, grass-covered swales; (4) mud-filled, marsh-covered tidal creeks; and (5) wind or sheetwash sand. The system covers about 100 square miles of the map area. Principal soils developed on the Ingleside deposits are Galveston and Mustang fine sands.

Barrier-strandplain sand.—The ancient barrier-strandplain sands are moderately well preserved, but eolian deflation has obscured the relict beach ridge-and-swale topography that characterizes the unit to the north in the Port Lavaca map area. Barrier-strandplain sands are both grass covered (75 square miles) and tree covered (21 square miles). The sands form an elongate body from 2 to 4 miles wide that is exposed for about 40 miles along the mainland adjacent to Laguna Madre and Redfish and Aransas Bays (figs. 15 and 16). The sand body is approximately parallel to the Modern Gulf shoreline (fig. 4); it underlies the entire length of Encinal Peninsula, Live Oak Ridge, and Live Oak Peninsula. The barrier strandplain, which is probably about 30 feet thick in most places, rises to an elevation of 20 to 25 feet MSL (fig. 6).

Ingleside sands overlie and are bounded landward by Pleistocene deltaic deposits; the presence of extensive Ingleside lagoon muds beneath and landward of the sand body has not been verified. The barrier-strandplain sands are local, perched aquifers. The Ingleside exhibits a few indistinct swales northwest of Rockport; southeasterly winds have eroded depressions in the sand body and blowout dunes are aligned northwest-southeast (fig. 16). Consequently, beach and upper shoreface sands are buried beneath eolian sand dunes and sheet deposits. Since the Ingleside system built gulfward by shoreface accretion, the basal contact of the sand body gradationally overlies shelf deposits, especially near its eastern margin. Lower shoreface and inner shelf invertebrate shells of Pleistocene age underlie Modern-Holocene sediments in Redfish Bay; similarly, shoreface and shelf sediments probably underlie Modern-Holocene lagoonal sediments in Laguna Madre.

Mud-filled swales and tidal channels.—These minor elements of the Ingleside system occupy only 1.2 square miles (fig. 16). The swales are mud-filled depressions that are probably the result of sheetwash and local erosion along the landward side of the sand body. A great number of similar features occur on Blackjack Peninsula north of Aransas Bay (Port Lavaca map area).

Mud-filled tidal channels that have eroded Ingleside sheet sands are irregular depressions occupied by freshwater marsh. The marshes occupy the upper reaches of channels that communicate with Port Bay.

Sheet sand deposits.—Eighteen square miles of sheet sands blanket the landward margin of the Ingleside system (figs. 14-16). These sheet deposits are composed of sand deflated from the barrier strandplain and blown into the Port Bay and Laguna Larga depressions and sand transported to the depression by sheetwash down the landward side of the Encinal and Live Oak Ridges. The grass-covered sands may overlie both Pleistocene and Modern-Holocene lacustrine, bay, and marsh deposits of the Ingleside terrace. The sand is muddy to well sorted and very fine grained; it is highly to moderately permeable.

MODERN-HOLOCENE SYSTEMS

Three major and two minor natural systems are currently active in the Corpus Christi area (fig. 4). For the most part, these systems have existed during the past 2,500-3,000 years since sea level reached its approximate present position (fig. 5C). Deposition began in some of these systems, however, during the Holocene. Major Modern-Holocene natural systems include a fluvial-deltaic system, barrier-strandplain and offshore systems, and bay-estuary-lagoon and lake systems. Minor systems include a marsh-swamp system and an eolian system. Fifty-five distinctive environments are delineated and mapped within these natural systems (see *Environmental Geology Map*). Specific environments are recognized by floral and faunal assemblages, physiographic expression, depositional grain and morphology, dominant active processes, and sediment-soil composition.

Fluvial-Deltaic System

The principal Modern-Holocene fluvial systems of the Corpus Christi area include the Nueces, Aransas, and Mission Rivers, and Chiltipin, Sous, and Medio Creeks. San Fernando, Petronila, Oso, and Papalote Creeks and Chocolate Swale are minor streams in the area. All flow within entrenched valleys. The principal fluvial systems in the Corpus Christi area are fine-grained meanderbelt streams (at least in the lower reaches) which flow within meandering valleys that were eroded during the final Pleistocene glacial stage and partially filled during Holocene sea-level rise. The Modern rivers are generally underfit streams with considerably less discharge than during late Pleistocene and early Holocene times. The streams are characterized by sinuous courses, some active point bars, meander cutoffs (some of which support swamps and marshes), relatively high mud loads, and flat to slightly depressed floodplains.

Minor streams in the Corpus Christi area are all headward-eroding systems, as are most tributaries of the principal streams. Headward-eroding streams are not in adjustment and are actively cutting small valleys, especially in their upper reaches. Valleys are generally wooded in the northern part of the area but south of the Nueces River, the headward-eroding streams support only sparse tree vegetation along their courses.

The Nueces, Aransas-Chiltipin, and Mission systems are each constructing bayhead deltas. The Nueces River is actively prograding its delta into Nueces Bay, but the Aransas-Chiltipin and Mission deltas exhibit limited progradation. Nineteen natural environments compose the Modern-Holocene fluvial-deltaic system. Several environments occur in more than one system. Because the fluvial and deltaic environments are transitional, it is impossible to draw a sharp boundary between them. For convenience in the following description, the 19 specific environments are grouped into a lesser number of general categories.

Fluvial Environments

Within the Corpus Christi area, Modern-Holocene fluvial environments are grouped into five principal categories: meanderbelt sands, floodbasin muds, levee deposits, abandoned channel-fill deposits, and headward-eroding streams. A few active point bars along the Nueces River near the western edge of the Corpus Christi map area are large enough to map as independent environments. Except for headward-eroding streams, all Modern-Holocene environments within the Corpus Christi area occur within entrenched, partially filled valleys. The sloping walls of these valleys, which were eroded when sea level dropped during late Pleistocene, are now covered with a sandy veneer resulting from Modern gully erosion and slopewash.

The discharge of streams along the Texas Coastal Plain has diminished during late Holocene and Modern times. Modern-Holocene streams generally are underfit and flood their valleys infrequently. Levees are still occasionally active environments along the river courses, although some levees are essentially relict. Floodbasin deposition occurs following infrequent floods. Abandoned channels are still slowly filling with mud and marsh or swamp deposits. Headward-eroding streams are, however, very active and continue to erode the Pleistocene uplands.

Several fluvial environments have been subdivided based principally on the nature of vegetative cover. Both tree-covered and grass- or shrub-covered meanderbelt sands and tree- and grass-covered levees have been separately delineated within the Modern-Holocene fluvial system. Abandoned channel environments are subdivided into those characterized by mud fill, swamp, and marsh.

Meanderbelt sands.—Two types of environments are recognized on meanderbelt sands in the Corpus Christi area: (1) tree-covered sands without prominent grain, and (2) sparsely grass- and shrub-covered sand and silt. Tree-covered meanderbelt environments occupy about 33 square miles within the entrenched valleys of the major streams in the Corpus Christi map area; 40 square miles of grass- or shrub-covered meanderbelt sands also flank the Modern streams. These meanderbelt sands are products principally of relict Holocene systems; nevertheless, some meanderbelt (point-bar) deposition continues to occur along the Modern underfit streams such as the Nueces, Aransas-Chiltipin, and Mission-Sous systems (figs. 12, 17, and 18).

Relict Holocene meanderbelt deposits occur as terraces at various elevations above the Modern rivers. The higher terraces have been called "Deweyville" by earlier workers (Bernard and LeBlanc, 1965). These higher Holocene (and late Pleistocene?) terraces are well developed along the Nueces River, for example, immediately southeast of Odem (fig. 18). The walls along the entrenched, partially filled valleys of the Nueces, Aransas, and Mission Rivers and the lower Sous and Chiltipin Creeks exhibit relict meander scars (figs. 12 and 17). Most of the Modern-Holocene meanderbelt sands are preserved as low terraces along the rivers which are flooded during periods of high discharge. The valleys, which are partially filled with fluvial deposits, grade coastward into deltaic and estuarine sediments (fig. 18).

Meanderbelt sand terranes are relatively flat with minor relief resulting from original depositional topography. Some are marked by accretionary (point-bar) grain and by meander cutoffs or scrolls. Some meanderbelt deposits are covered by dense stands of water-tolerant hardwoods; others are grass covered and may be locally veneered by thin floodbasin mud deposits. The deposits vary from moderate- to well-sorted sands; gravel occurs at the base of most meanderbelt deposits. Buried, clay-filled abandoned channels may occur within the sand belt. Water table is generally high, and "Deweyville" terrace deposits may serve as perched aquifers. Meanderbelt sand bodies are lenticular in geometry.

Floodbasin muds.—Associated with the Modern-Holocene meanderbelt sands are small, grass-covered areas underlain by mud and clay deposits (figs. 12 and 17). These areas occupy about 7 square miles of the Corpus Christi area and are sites of overbank deposition within entrenched valleys. Some of the floodbasin deposits are now generally isolated from the present stream, but other floodbasins flank the active stream channels and are repeatedly flooded. Active floodbasins may grade into fresh-water marsh. The overbank muds are thin, blanketlike deposits which veneer buried meanderbelt sand bodies. Relict floodbasin muds are interstratified with lenticular meanderbelt sand bodies within the buried Modern-Holocene valley-fill deposits (fig. 18).

Levee deposits.—Streams subject to frequent overbank flooding deposit fine sand, silt, and mud levees adjacent to their channels (figs. 17 and 18). Levees are prominent along the lower reaches of the Nueces, Aransas, and Mission Rivers and Chiltipin Creek. Levees also occur in upstream areas but because of less relief and areal extent, they are mapped as part of the meanderbelt sand deposit (fig. 17).

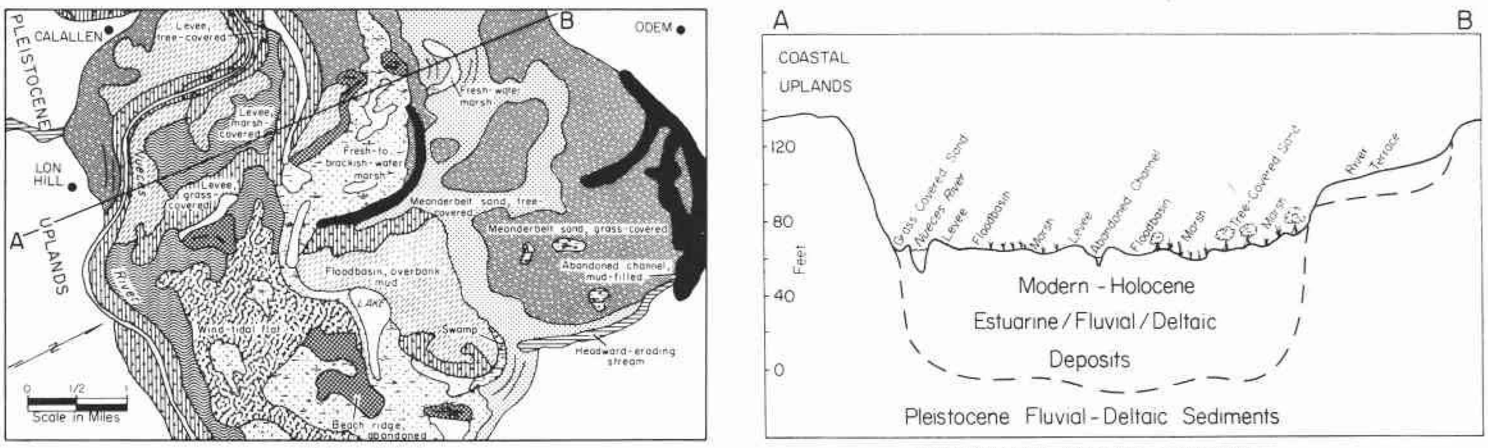


Figure 17. Incised valley of the Nueces River, southwest of Odem, Corpus Christi map area. Valley was eroded into Pleistocene fluvial-deltaic deposits during final glacial stage (late Pleistocene) and subsequently filled with Modern-Holocene fluvial deposits. Present Nueces River is an underfit stream.

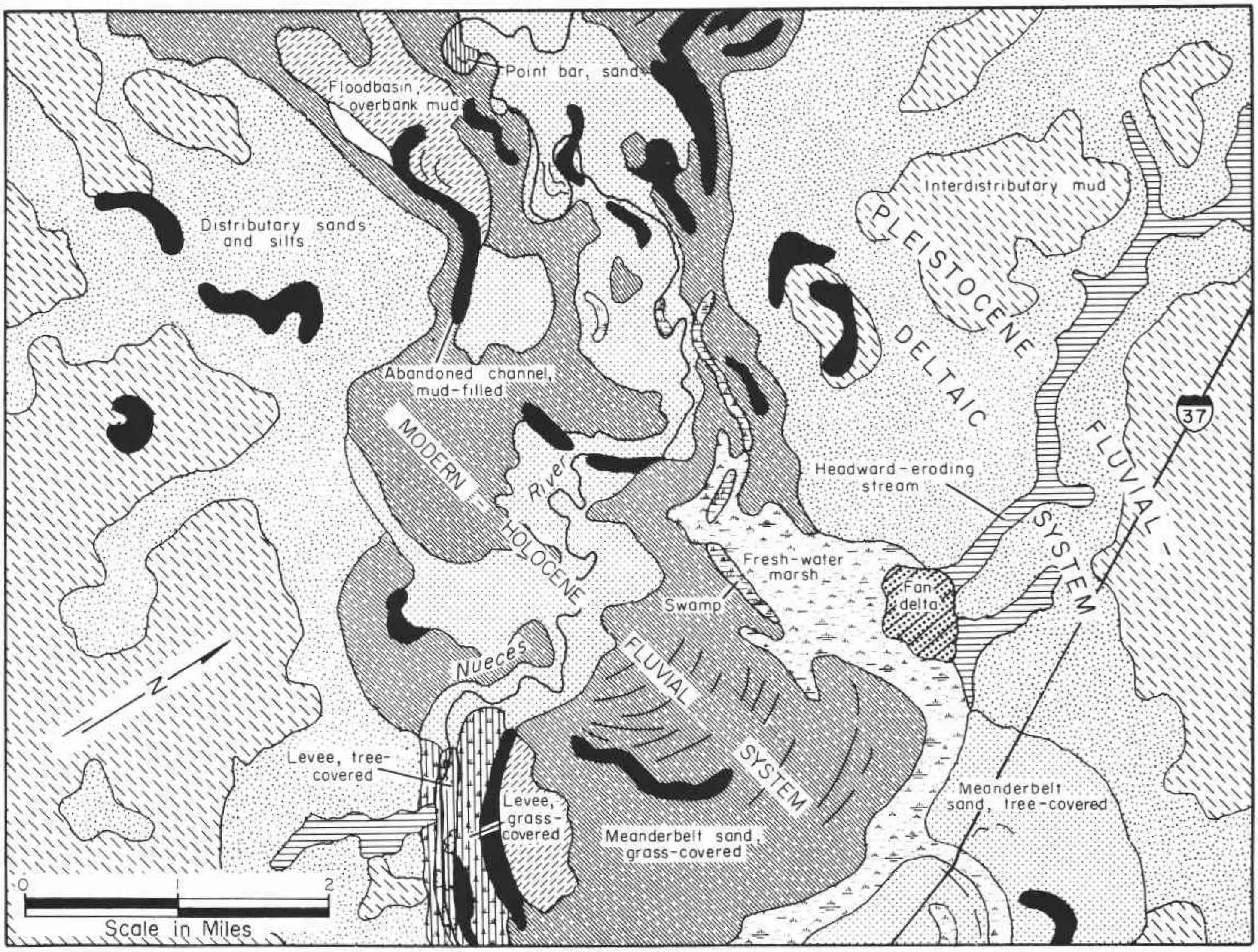


Figure 18. Transition between late Modern-Holocene Nueces fluvial deposits and the Modern Nueces delta, Corpus Christi map area. The wide valley was occupied by the upper part of Nueces Bay before the estuarine delta began prograding into the bay about 3,000 years B. P. at the end of Holocene sea-level rise.

Two types of levees have been delineated within the fluvial systems of the Corpus Christi area: tree covered and grass covered. Approximately 1 square mile of tree-covered levees has been mapped along the Nueces and Mission Rivers. Almost 7 square miles of prominent grass-covered levees occur in the area, but some of these levees are also part of the associated delta systems. About 4 square miles of marsh-covered levees occur along lower reaches of the streams within the deltaic system.

Levees are thickest and exhibit maximum topographic relief immediately adjacent to the river channel. They thin and slope away from the channel into flanking floodbasins, marshes, and swamps (fig. 18). Older, less active levees are generally covered by willows, cottonwoods, and cane; younger levees are more sparsely covered by grasses and locally by marsh plants.

Abandoned channels.—Within the entrenched valleys of the Corpus Christi area, remnants of former river courses are slowly filling with mud and organic matter. Abandoned channels filled with water are called oxbow lakes; along the lower reaches of the Nueces River, these lakes contain marsh or swamp vegetation (figs. 17 and 18). Approximately 13 square miles of fresh-water marsh fill abandoned channels and other depressed areas within the fluvial system. Other abandoned channels have filled with mud from overbanking floodwaters and slopewash and are sparsely vegetated with grass. These relict channels are mostly semicircular loops that reflect the original meandering courses of the rivers and creeks.

Active point bars.—Meandering stream channels are unstable features that simultaneously migrate laterally and downstream. As the meanders migrate, erosion occurs along the outer (concave) bank and deposition occurs along the inner (convex) bank. Point bars are the depositional features formed along the convex bank. Former positions of the river are shown by accretionary grain, consisting of curved, alternating ridges and swales that develop on the point bar. Point bars are gravelly at the base and sandy toward the top; the sands are moderately sorted. Except near the western edge of the map area, active point bars are too small to map separately. Most active point bars have been combined with the Modern-Holocene meanderbelt sands, which are large sand bodies composed of many coalescing and overlapping individual point-bar deposits.

Headward-eroding streams.—About 28 square miles of Pleistocene coastal uplands in the Corpus Christi area have been dissected by small, headward-eroding, consequent streams (figs. 11-13). These streams have developed principally within topographically depressed, interdistributary areas on the relict Pleistocene delta plains. The relatively impermeable substrates in these areas promote extensive runoff, thus propagating the headward erosion. Examples include San Fernando Creek, Petronila-Pintas-Agua Dulce Creeks, Oso Creek, upper Chiltipin Creek, Chocolate Swale, Mullens Bayou, and tributaries of Sous and Medio Creeks. Small, high-gradient streams have developed along the margin of Nueces and Oso Bays, as well as along the steep walls of the Nueces River valley (fig. 17). Small fan deltas and alluvial fans form at the terminus of several small headward-eroding streams along the Nueces valley, Nueces Bay, and Oso Bay. These features are described in another section, Bay-Estuary-Lagoon System.

Along middle and lower courses of the headward-eroding streams, steep-sided channels are common. In the upper reaches of headward-eroding streams, tributaries commonly flow through shallow swales which slowly erode Pleistocene deltaic mud and sand. The tributaries gradually move inland, subjecting more and more of the coastal plain to slopewash and channel erosion. North of the Nueces valley, these slope sediments and the soils they support are well drained and may be vegetated with hardwoods. South of the Nueces valley, trees are sparse along headward-eroding channels.

Deltaic Environments

Three delta systems—Nueces, Aransas-Chiltipin, and Mission—occur within the Corpus Christi map area (fig. 4). These deltas are called bayhead or estuarine deltas. With rise in sea level beginning about 18,000 years B. P., the entrenched river valleys were inundated, forming estuaries. During the past three thousand years, the upper ends of the estuaries have been filled by prograding bayhead deltas. The deltas in the Corpus Christi area have not been studied extensively, but their composition, history, and general character are similar to the Guadalupe bayhead delta (Port Lavaca map area) studied by Donaldson and others (1970).

Along the Nueces, Aransas, and Mission Rivers, there is a transition from chiefly fluvial to deltaic environments. These environments occur about 10, 3, and 5 miles upstream from their respective river mouths. The subaerial parts of deltas (delta plains) are occupied principally by marsh, lake, wind-tidal flat, channel, and levee environments. Submerged parts of the deltas include prodelta and delta-front environments. The nature and distribution of deltaic environments are well exhibited by the Nueces delta (fig. 19).

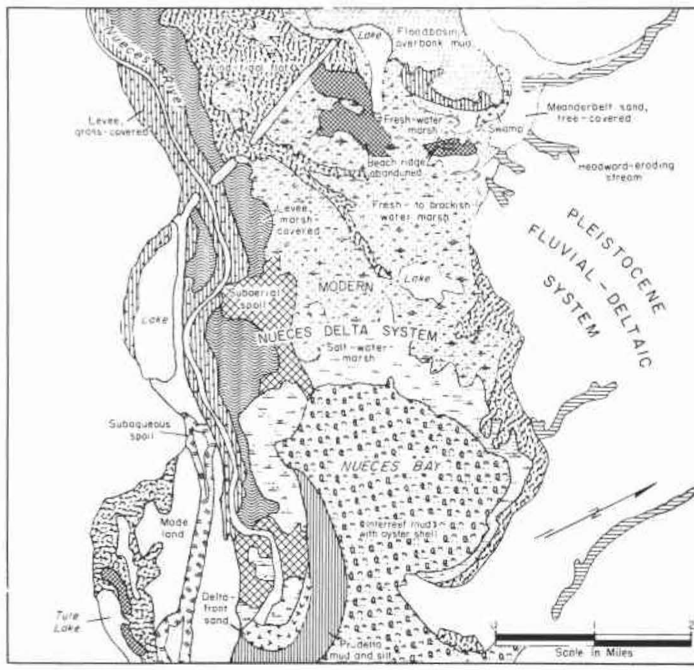


Figure 19. The Modern Nueces delta system, Corpus Christi map area. The estuarine delta plain is occupied by broad marshes, tidal creeks, and abandoned levees. Local beach-ridge deposits mark the position of relict shorelines. The delta has filled about 8 miles of the upper estuary.

Deposition of bed-load sand at the river mouth produces a channel-mouth bar that is subsequently redistributed by waves and currents to form a delta-front sand deposit. Suspended, muddy sediment settles to the bay bottom farther from the river mouth to produce a prodelta mud deposit. Repeated deposition at the river mouth progressively builds the delta farther into the bay—a process of outbuilding called progradation. Inland from the channel mouth, the subaerial delta plain is built up during periods of high discharge chiefly by deposition within the river channels, along the adjacent levees, and within flanking marshes and bays (interdistributary environments). Deposition on the delta plain results in upbuilding or aggradation.

In the Corpus Christi area, the Nueces, Chiltipin-Aransas, and Mission deltas began to build into their respective bays about 2,500 years ago. All deltaic environments were created during this period of bayward progradation. The rate of delta construction has been controlled by various factors including volume of sediment discharge and depth of bay waters. Estuarine deltas in Texas are low discharge systems that build into shallow bays; thus, construction of thick, areally extensive deltas does not occur.

Only bayhead or estuarine deltas occur within the Corpus Christi map area. In fact, the Brazos River, Colorado River, and Rio Grande are the only fluvial systems in Texas that discharge directly into the Gulf of Mexico. The many specific environments that compose bayhead deltas in the Corpus Christi area can be grouped into seven categories. These areas are characterized by a variety of active and relict environments: prodelta, delta front, levee, marsh, wind-tidal flat, abandoned channel, and berm and beach ridge. Several minor alluvial fans and fan deltas are also described.

Prodelta mud and silt.—During periods of high discharge, suspended mud and silt carried by the flooding coastal rivers of the Corpus Christi area enter their respective bays or estuaries within turbid fresh-water plumes. These plumes move away from the channel mouths over the denser, saline bay waters. The suspended plumes mix with the underlying bay waters, resulting in flocculation of clay particles into larger aggregates that settle to the bay bottom. Consequently, prodelta deposits are broad, arcuate- to fan-shaped blankets of mud and silt (fig. 19) which overlie and grade bayward into bay sediments. As a river mouth builds slowly into a bay, the prodelta environment correspondingly shifts bayward and displaces various bay environments. The prodelta environment is, in turn, displaced by the advancing delta-front environment; thus the delta-front sands prograde bayward over prodelta muds and silts.

Prodelta deposits are water-saturated mud and silt that commonly undergo extreme compaction. Because the Texas bays are very shallow, prodelta sediments deposited in bays are thin—generally less than 2 feet thick. Older prodelta deposits beneath the delta plain may be thicker because bays were deeper during early stages of delta building. When a stream is not actively discharging, the prodelta environment may be invaded by invertebrate organisms, resulting in burrowing and mixing of prodelta and bay deposits.

Prodelta environments (0.4 square mile) were mapped within the Nueces and Mission deltas, but the boundaries are transitional and shift with variations in river discharge; environments are active only during periods of significant stream discharge. A discrete prodelta environment was not shown for the Chiltipin-Aransas delta because of exceedingly low discharge.

Delta-front sand.—Rivers discharging into Texas bays transport bed-load sand to the river mouth, where diminishing velocity results in the deposition of a channel-mouth bar at the terminus of the fresh-water wedge. During periods of reduced discharge when bay waters encroach the lower part of the river channel, waves and currents within the bay system erode and redistribute the sand into an arcuate shoal (fig. 19).

The delta-front sand body is lenticular and generally less than 4 feet thick. As the river mouth moves bayward, the river channel erodes the delta front and subjacent prodelta deposits and rests upon older bay deposits; channel-fill sand and perhaps mud eventually fill the eroded channel. Flanking the river channel, uneroded delta-front sands rest upon older prodelta mud and silt, which in turn, overlie older bay deposits.

The delta-front deposit is composed of moderate- to well-sorted, fine- to medium-grained sand that exhibits ripple crossbeds. The sand body may be highly burrowed, especially in the upper part of the deposit. Small delta-front shoals (0.2 square mile) were mapped at the mouth of the Nueces and Mission Rivers.

Abandoned channels and flanking levees.—Channel-fill sand and mud deposits are not exposed within the estuarine deltas, but flanking levees are preserved and unfilled parts of the channels are commonly occupied by an elongate lake or marsh. River channels on a delta plain, called *distributary channels*, normally bifurcate bayward; overextended channels are commonly abandoned and subsequently filled with mud and marshy organic deposits. Areas between or beside distributary channels or delta lobes are occupied by *interdistributary* *bays* or *delta-flank bays*, respectively. These bays merge landward with delta-plain marshes and tidal flats; further up the delta, the environments merge with fluvial floodbasins that are occupied by marsh, swamp, or grass. As the delta progrades bayward, these interdistributary and flanking environments correspondingly shift bayward.

The distribution of abandoned channels provides insight into the history of delta development. For example, the Nueces delta began its bayward progradation about 2,500 years ago near the present town of Calallen, where U. S. Interstate Highway 37 now crosses the Nueces River (fig. 18). An abandoned, water-filled distributary channel (outlined by grass-covered levees) indicates that the river flowed into Nueces Bay just east of the point where the Missouri Pacific Railroad tracks (Odem and Corpus Christi branch) cross the abandoned slough, about 4 miles southeast of Odem (*Environmental Geology Map*). This distributary channel ultimately extended about 6 miles eastward before it was abandoned (fig. 19), and while active, a small delta-flank bay existed along the southern shore of the estuary near Lon Hill. Subsequently, another distributary channel extended along the southern side of the estuary to a point north of Lon Hill. Here several minor distributaries branched into the bay flanking the older abandoned delta lobe. The elevated levees along one of these abandoned channels are now occupied by tidal flats near the Odem-Corpus Christi branch of the Missouri Pacific Railroad tracks, 0.5 mile east of the railroad bridge over the present Nueces River. Unless man intervenes, the present Nueces Channel, which has built far into the bay along the southern shoreline, will eventually be abandoned in favor of a new channel that probably will branch about 1 mile east of the Missouri Pacific Railroad bridge. This channel will enter the upper part of Nueces Bay (a delta-flank bay) near the mouth of a dredged channel that has been cut into the delta-plain marsh.

The Chiltipin-Aransas delta presently discharges through two channels. An older delta lobe is still exposed along the Aransas River, about 3 miles upstream from the present river mouth.

As previously mentioned, elevated natural *levees* are prominent features along active and inactive distributary channels of the delta system (figs. 18 and 19). Levees are composed of muddy and silty sediment that is deposited from suspension when overbanking floodwater loses velocity as it flows into adjacent floodbasins, marshes, or interdistributary bays. The grain size of levee sediment decreases away from the channel, except where deep breaches in the levee, called *crevasses*, permit coarser bed-load sand to leave the channel and enter the bay or floodbasin; the resulting deposit is a sandy and silty *crevasse splay*. Older levees within the associated fluvial systems are commonly tree or grass covered; on the delta plain, older grass-covered levees generally grade bayward to younger marsh-covered levees near the channel mouth (figs. 18 and 19). Almost 6 square miles of marsh-covered levees (and some crevasse splays) occur within the Nueces, Chiltipin-Aransas, and Mission deltas.

Delta-plain marsh.—As estuarine deltas prograde bayward, interdistributary and delta-flank bays are slowly filled with fine-grained sediment supplied by adjacent distributary channels, crevasse splays, and overbanking floodwaters. These shallow basins are subsequently covered by a variety of marsh assemblages grading from salt-water marsh along the bay margin to fresh-water marsh higher on the delta plain and along natural levees. The delta-plain marshes are transitional with marshes and swamps of the fluvial system (fig. 20). In the Corpus Christi area, salt-water marsh and fresh- to brackish-water marsh occupy approximately 16 square miles of the estuarine delta plains; fresh- to brackish-water marshes are principally restricted to the Nueces delta. About 13 square miles of fresh-water marsh occur within the various Modern fluvial-deltaic systems.

Abundant lakes and tidal channels occur within the delta-plain marsh (fig. 19). Mission Lake and the lake at the confluence of Melon Creek and Mission River occupy small, relict delta-flank embayments. In the Corpus Christi area, estuarine delta-plain marshes commonly grade upslope into barren wind-tidal flats.

Wind-tidal flats.—During severe storms or long periods of persistent easterly winds, bay water is pumped through the delta-plain marsh environments to wind-tidal flats via tidal creeks and small tidal passes (fig. 19). Wind-tidal flats associated with the estuarine deltas of the Corpus Christi area are developed upon crevasse splays, abandoned levees, relict meanderbelt sands, and slopewash-alluvial fans along valley walls. Twelve square miles of wind-tidal flats occur as components of Modern deltaic and fluvial systems in the Corpus Christi map area.

Wind-tidal flats lie between mean sea level and an elevation of approximately 2 feet above MSL. Lower tidal flats may be flooded by normal astronomical tides (about 0.5 foot), but the middle and upper flats are flooded mainly when winds are aligned to blow directly along the axis of an estuary. Some algal mats may occur on the ponded flats; thin clay laminations are intercalated with the sandy tidal-flat sediments. Upper wind-tidal flats may be sparsely covered with salt-tolerant grasses. Slopewash and small alluvial fans supply some of the higher marginal tidal flats with sandy sediment eroded from valley walls; similarly, crevasse splays may supply sediment to the flats adjacent to the levees of active distributary channels.

The valleys along the lower reaches of Petronila and Oso Creeks are occupied by sandy wind-tidal flats which extend downstream to Alazan Bay (Kingsville map area) and Oso Bay, respectively. These flats are developed upon fluvial sand deposits derived by the headward-eroding drainage systems. Deposition occurs principally within braided channels and associated fan deltas which prograde into the shallow upper ends of Alazan and Oso Bays. Wind tides flood these sandflats only during storms. The nature of stream deposition along the lower reaches of these types of systems is described in the "Environmental Geologic Atlas of the Texas Coastal Zone—Kingsville Area" (Brown and others, in preparation).

Abandoned berms and beach ridges.—A very distinctive but minor (0.2 square mile) element of estuarine deltas in the Corpus Christi area are well-defined beach ridges and storm berms. These features are relict deposits formed principally by storm tides impinging upon the margins of the delta plain. Alternating ridges and marsh-covered or mud-filled swales are prominent elements on the Mission delta (*Environmental Geology Map*). The ridges are aligned on the downwind (northwestern) side of Mission Lake, showing that the lake has filled progressively due to beach ridge accretion. Similar relict ridges have been built along the northwest side of Mission Bay; a berm is currently being constructed at the shoreline. An elongate feature on the northwest side of a lake at the mouth of Melon Creek may be a remnant of a beach ridge and swale, although the feature is referred to as an abandoned channel segment on the *Environmental Geology Map*.

A number of features on the Modern Nueces delta plain have been classed as relict berms and sand shoals. These features formed along the shoreline of relict interdistributary and delta-flank bays when storm waves and currents redistributed meanderbelt sand, crevasse splay deposits, and bay sediments (figs. 18 and 19). Further investigation is needed to verify the origin of these features. Similarly, several features mapped as grass-covered abandoned levees along either side of the Missouri Pacific Railroad tracks southeast of Odem may be, in part, composed of relict beach ridges and sand shoals. Beach ridges also occur on the northwest shore of Tule Lake. Two relict beach ridges or berms along the margin of the Pleistocene delta plain near Spears Lake and McCampbell Slough were previously thought to have formed on the shoreline of Lake Copano, a late Pleistocene (Ingleside) or early Holocene lake that existed in the Port Bay area (Price, 1933).

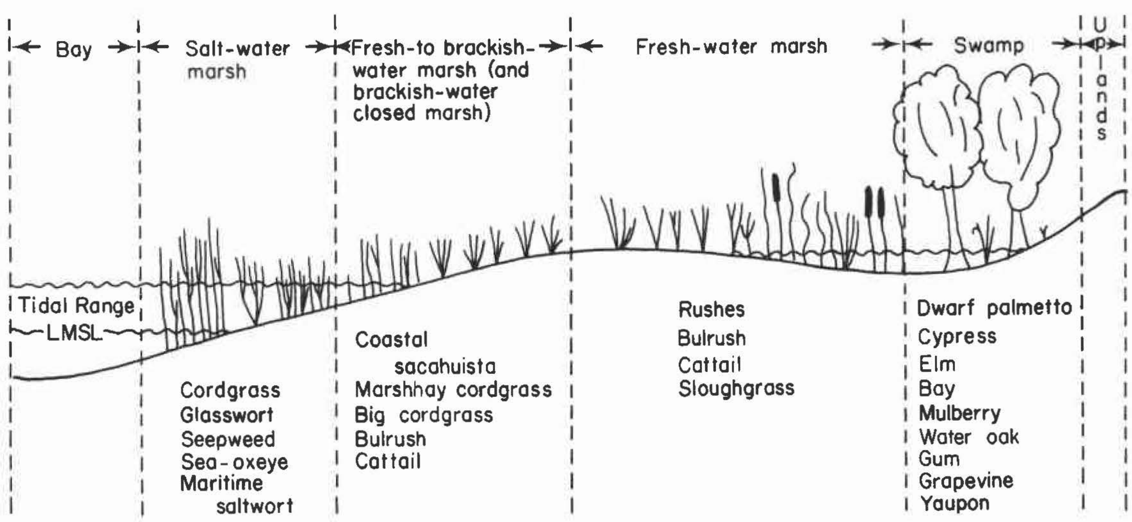


Figure 20. Schematic profile of the Modern marsh-swamp system that occupies large areas within the lower parts of the Nueces, Aransas, and Mission river systems and within the upper Port Bay area. Large areas of salt-water marsh occur on tidal deltas and along bay shorelines. Fresh-water marsh is delicately balanced and is principally ephemeral; swamps are rare.

Barrier-Strandplain and Offshore Systems

An important natural system within the Corpus Christi area is the Modern barrier-strandplain system. The suite of environments that compose this system forms at the interface of the land and ocean. Also included is the adjacent offshore area constituting the barrier shoreface and the inner part of the continental shelf (figs. 4 and 21).

The seaward extension of the barrier-strandplain system is called the shoreface. In the Corpus Christi area, the shoreface averages about 1 mile wide and extends from mean sea level to a depth offshore of about 5 fathoms. At mean sea level, the sediment at the top of the shoreface (the beach) is sand. At a depth of 5 fathoms, shoreface sediment is mud and muddy sand; here, the shoreface merges with the inner part of the continental shelf, which is predominantly mud.

From the Gulf of Mexico across the barriers and into the bays, environmental components of the barrier-strandplain and offshore systems are associated with shelf mud and sand, shoreface sand and muddy sand, beach sand and shell, fore-island dune ridge sand, active and stabilized blowout dune sand, beach ridge and barrier flat sand, barren wind-tidal flat sand and mud, and salt marsh underlain by mud and sand (figs. 21-24). On the *Environmental Geology Map* of the Corpus Christi Atlas, wind-tidal flats, which are transitional between the bay-estuary-lagoon system and the Modern barrier island system, have been arbitrarily included within the former system. South of the Corpus Christi map area where marshes are uncommon, wind-tidal flats are important elements in the bay-estuary-lagoon system; north of the Corpus Christi area, however, where marshes are well developed, the wind-tidal flats are less extensive.

Other components of the Modern barrier-strandplain system are active and inactive washover channels, active and relict washover fans, and the various specific environments constituting the tidal channel, flood and ebb deltas, and inlet-related shoals.

Offshore System

The area gulfward of the present beach is included on the *Environmental Geology Map* as a part of the offshore system. Environments include the shoreface of St. Joseph, Mustang, and Padre barrier islands, the innermost part of the adjacent continental shelf, and the previously mentioned ebb-tidal deltas.

The *shelf mud and sand* environments extend seaward from about the 30-foot or 5-fathom line (figs. 21 and 22). The inner shelf is a transitional area where sands and muds of the lower shoreface and inner shelf are mixed by the activities of burrowing animals. It is also an area of considerable erosion and resedimentation during the hurricane season. The inner shelf in the Corpus Christi area may be floored locally by relict Pleistocene and Holocene deposits like the inner shelf of the Port Lavaca area (Wilkinson, 1973; McGowen and Brewton, 1975), but most of the surface shelf sediment is Modern-Holocene mud. The transitional sand-mud boundary lies about 3 miles offshore from the barrier islands.

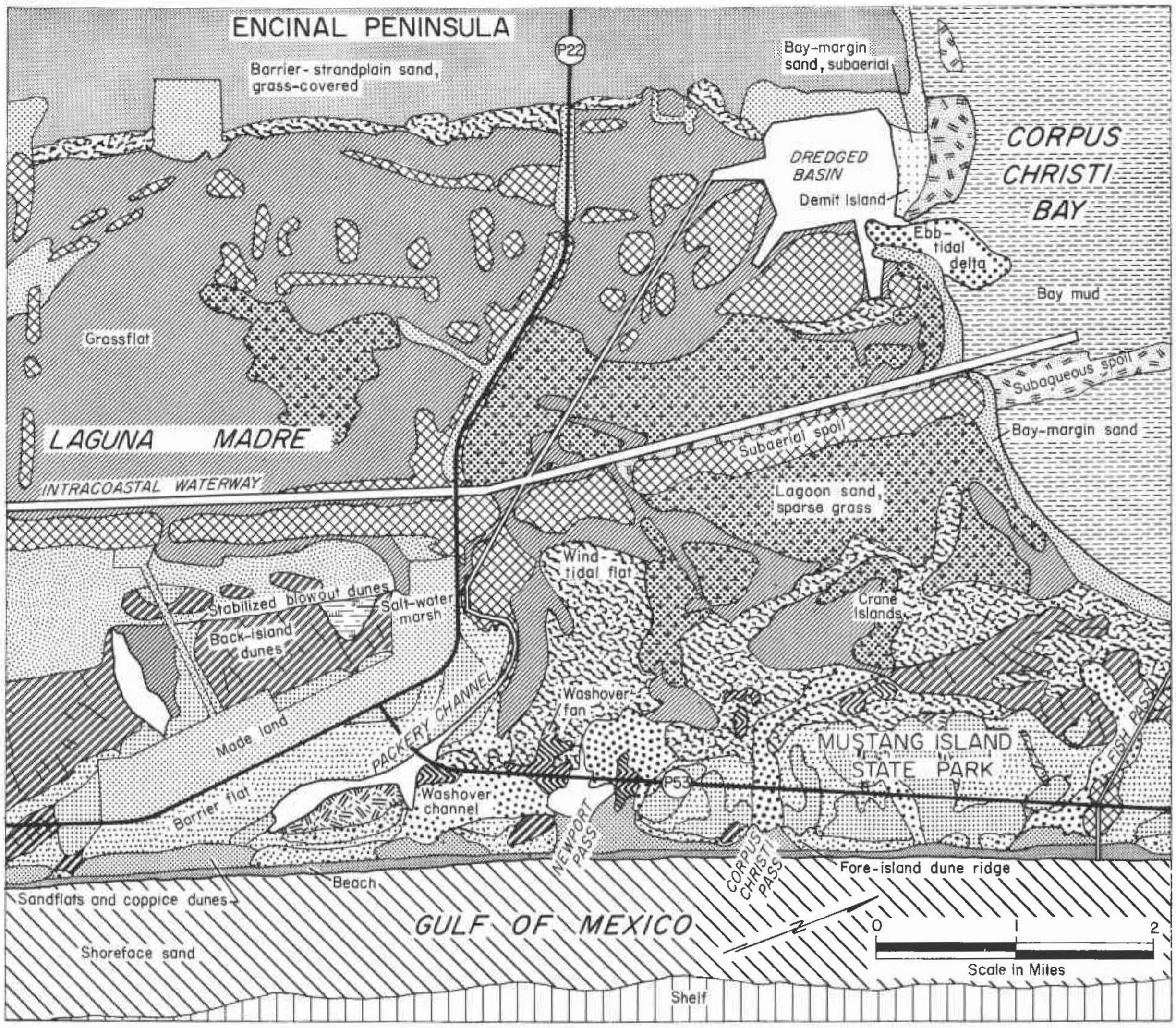
The *shoreface* is the gulfward extension of the barrier islands; it extends seaward from mean sea level to about the 5-fathom line or to the boundary with the shelf mud and sand (fig. 21). In the Corpus Christi area, width of the shoreface averages about 1.0 mile and occupies about 40 square miles. Locally only a veneer of Modern sediment rests on relict Holocene and Pleistocene deposits.

The shoreface is a zone of high physical energy, especially in the upper part where waves break (breaker and surf zones). Greatest wave intensity occurs in an area from where waves begin to feel bottom to the line along which they finally break. Waves begin to break when wave height is about 0.8 times that of water depth. Normal wind-driven waves are 2 to 4 feet high and break on the upper part of the shoreface. The absence of breaking waves and the slow rate of sedimentation on the lower shoreface result in the accumulation of finer grained sediment in that zone. Accordingly, biologic activity dominates the lower shoreface which is composed of extensively burrowed or mottled muddy sand and mud.

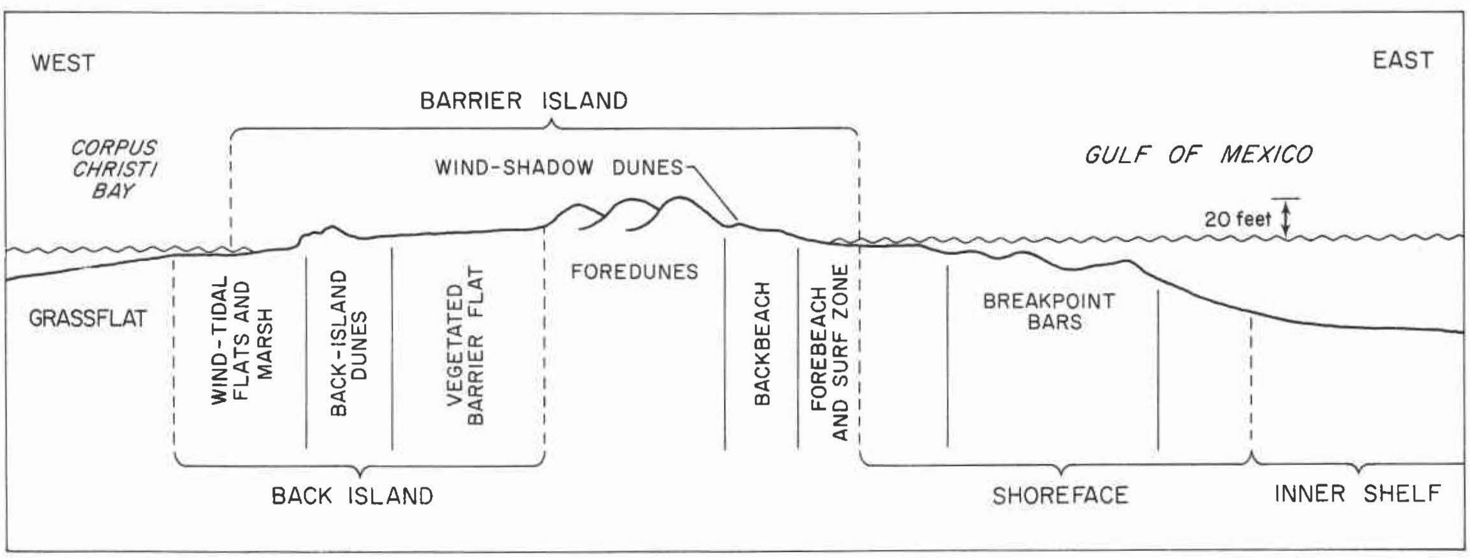
The middle part of the shoreface (about 12 to 20 feet deep) is less muddy than the lower shoreface but is also burrowed extensively. The upper shoreface, which consists predominantly of sand, extends from mean sea level to a depth of about 12 feet; it is, by contrast, the zone where normal wind-driven waves feel bottom and break. Several lines of breakers or spilling waves generally characterize the upper shoreface. These result in the formation of breaker-point bars that may trend parallel or at an angle to the shoreline. The innermost breaker-point bar is generally connected to the lower forebeach.

Barrier-Strandplain System

Beach.—About 3.2 square miles of Gulf beach occur between low tide and the first inland line of

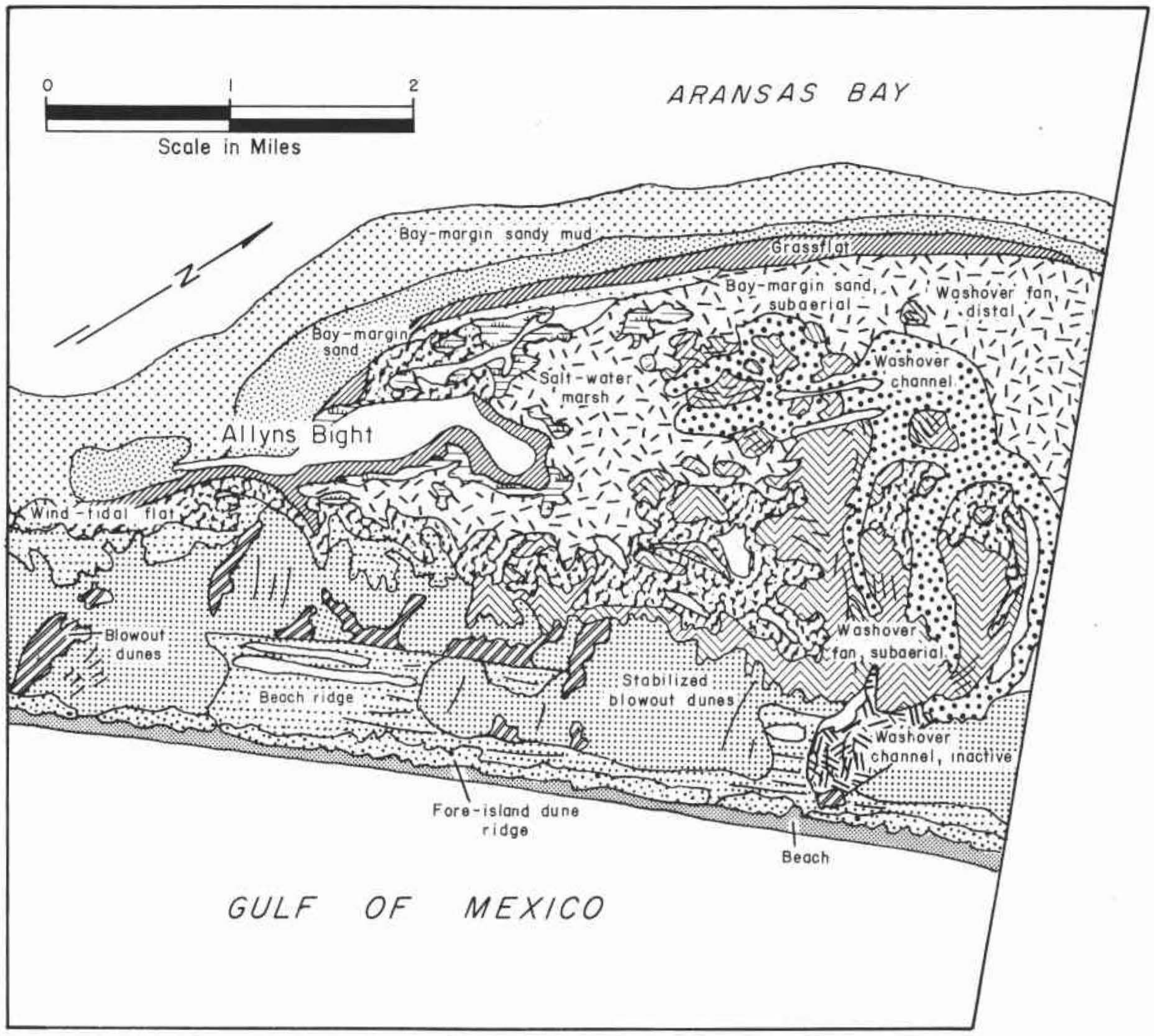


MAP VIEW

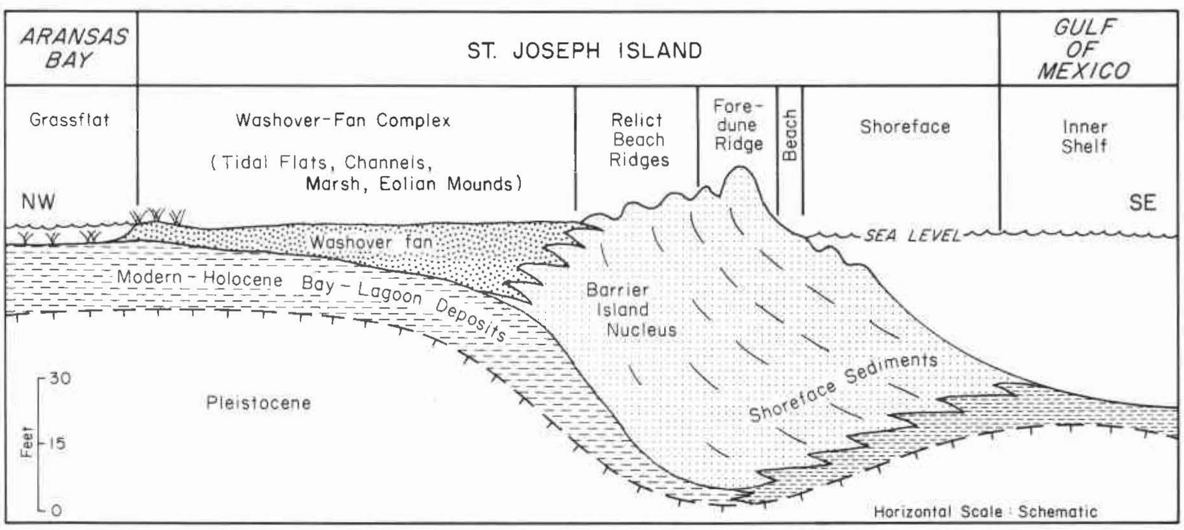


SCHEMATIC TOPOGRAPHIC PROFILE

Figure 21. Northern Padre-southern Mustang Islands, a barrier island system separating Laguna Madre and Corpus Christi Bay from the Gulf of Mexico in the Corpus Christi map area. A complex of relict tidal passes separates the two islands. Extensive vacation-home development is taking place on northern Padre Island. Laguna Madre is highly modified by dredged channels associated with oil and gas production.



MAP VIEW



SCHEMATIC CROSS SECTION

Figure 22. Washover fan complex on St. Joseph Island, Corpus Christi map area. Eolian blowouts and hurricane-washover channels have obscured most of the accretionary beach ridges. The schematic cross section illustrates the principal subsurface relationships based in part on studies by Andrews (1970).

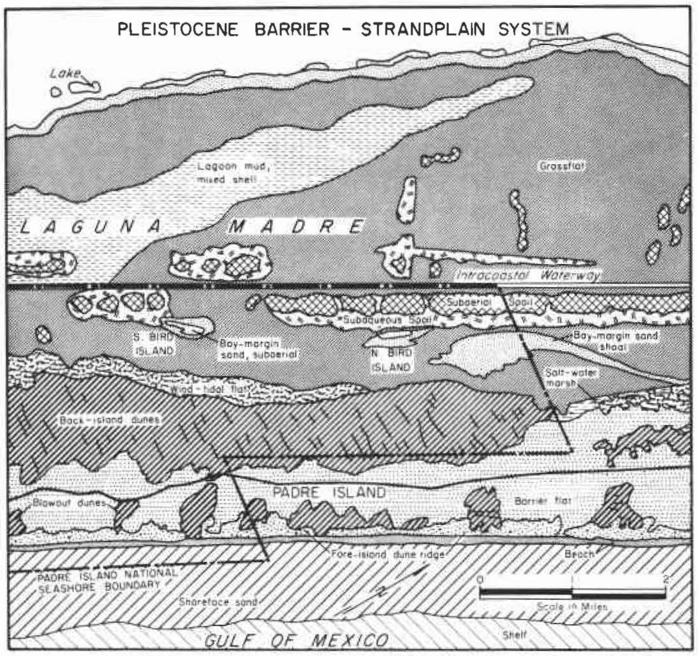


Figure 23. Padre Island barrier system and Laguna Madre lagoonal system, Corpus Christi map area. Eolian blowouts and blowout dunes supply sand to extensive back-island dune fields. Subaqueous grassflats occupy large shallow lagoonal areas.

vegetation, which is generally situated at the toe of the fore-island dunes (figs. 21-24). Beaches consist primarily of terrigenous sand with local concentrations of shell. Sand beaches exhibit two distinct zones: forebeach, the seaward-sloping smooth part of the beach that is affected daily by swash, and backbeach, which may be separated from the forebeach by a berm. The backbeach slopes gently seaward but in places may slope landward. Many of the beaches of St. Joseph, Mustang, and Padre Islands have been undergoing long-term erosion for at least 74-132 years (Brown and others, 1974). Less than 5 feet of erosion per year is common near the junction of Padre and Mustang Islands and along central Mustang Island. Central St. Joseph Island has experienced long-term erosion of less than 5 feet per year, but during the past 7-23 years, short-term erosion has exceeded 10 feet per year.

Fore-island dunes.—Fore-island dunes are well developed on Mustang and northern Padre Islands; these dunes are less developed on St. Joseph Island (figs. 21-23). Fore-island dunes commonly reach a height of 20-25 feet along northern Padre Island where there is a delicate balance between the intensity and duration of the winds and the density of stabilizing vegetation. In the Corpus Christi area, about 4 square miles of the fore-island dunes form a relatively continuous ridge except where blowouts and washover channels have developed. The ridge is composed of two or three irregular lines of dunes parallel to the Gulf shoreline. Hurricanes commonly erode the gulfward line of dunes; the dune ridge then accretes slowly back toward the beach. Establishment of small coppice or wind-shadow dunes provides a nucleus for vertical upbuilding of the gulfward ridge by wind deposition and plant stabilization. Dunes consist of very well-sorted, fine-grained sand; they are highly permeable and locally provide a source of fresh water. Average dune height in the Corpus Christi area is about 15 feet, and maximum height is about 30 feet.

Where overgrazing has not occurred, dunes are stabilized by vegetation that is zoned on the seaward side of dunes. Marshhay (*Spartina patens*), morningglory (*Ipomoea* spp.), and sea purslane (*Sesuvium portulacastrum*) generally occur at lower dune elevations, and sea-oats (*Uniola paniculata*), *Panicum*, and *Croton punctatus* occur along the middle and upper parts of dunes. Seacoast bluestem (*Andropogon scoparius littoralis*) is common on the back sides of dunes. Fore-island dunes provide a flexible defense against hurricane-tidal surge that is adjusted to the sand budget of the barrier island system; that is, the ridge retreats or accretes with erosion or accretion of the Gulf beaches. The dune ridge also stores excess sand for renourishing the beaches following severe hurricane erosion.

Sandflats or coppice sand-dune fields.—Several segments of the Gulf shoreline in the Corpus Christi map area are characterized by various sandflats and fields of low coppice dunes, which locally replace the fore-island dune ridge in the vicinity of active washover channels (figs. 21 and 24). This environment occurs gulfward of Packery Channel, Newport Pass, Corpus Christi Pass, and near Fish Pass. Similarly, the environment extends about 5 miles along southern St. Joseph Island between North Pass and Aransas Pass. A small area of sandflat occurs on the southern side of Aransas Pass along the south jetty as a result of sedimentation by counter longshore currents.

The environment develops principally along the gulfward side of washover channels during periods between hurricanes; the coppice dune field is the first stage in development of a fore-island dune ridge, but repeated storm surges limit dune ridge accretion. About 1.7 square miles of this environment have been mapped in the Corpus Christi area.

The coppice dunes develop by wind-shadow accretion around clumps of vegetation, fence posts, or large pieces of driftwood. Locally, man has modified the

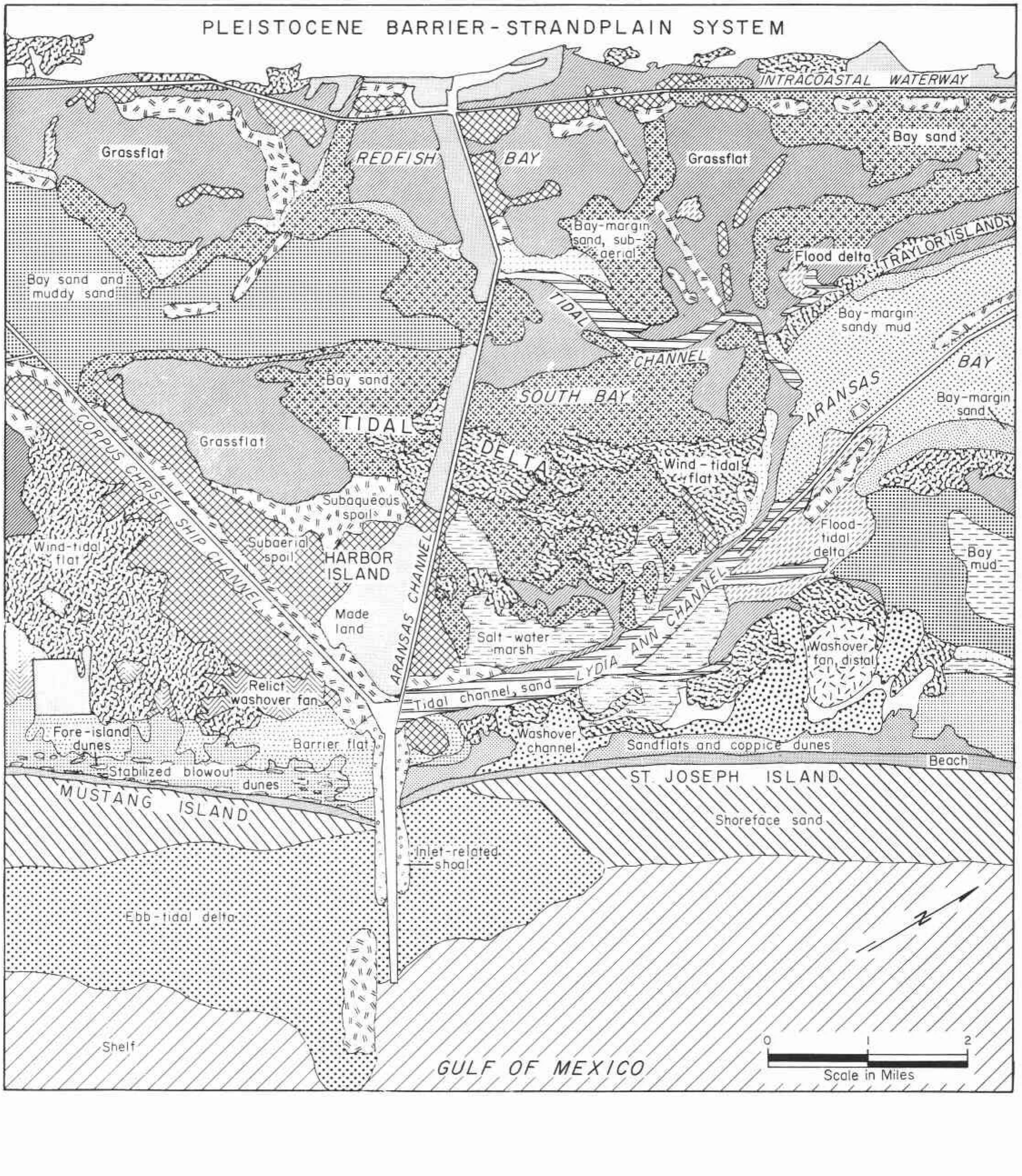


Figure 24. Harbor Island, a tidal delta complex constructed during the past 2,000 years by tidal passes separating Mustang and St. Joseph Islands, Corpus Christi map area. The large flood-tidal delta slowly became emergent and is primarily covered by marshes, grassflats, and tidal flats. Corpus Christi and Aransas Channels have modified the tidal delta processes.

coppice dunes by grading; this is apparent in Nueces County Park near Packery Channel. The dunes and flats are composed of well-sorted, clean sand derived directly from the beach by wind deflation and from the beach and upper shoreface by hurricane-tidal scour. This is a transitory environment that is subjected to intense wave and storm-surge energy.

Active and stabilized blowout dune complex.—Where vegetative cover has been damaged or removed from fore-island dunes, eolian blowouts tend to develop. Blowouts are gaps in the fore-island dune ridge that are commonly deflated to the water table (figs. 22 and 23). Sand is removed from the fore-island dune field and transported bayward as blowout dunes by the wind. Active blowout dunes (combined with back-island dunes) are present at several localities along St. Joseph, Mustang, and northern Padre Islands.

The bayward migration of blowout dunes ceases when a vegetative cover is sufficiently dense to impede movement of sand by eolian processes. Blowout dunes are stabilized chiefly by grasses. Stabilized blowout dunes (10 square miles) are present on St. Joseph Island and Mustang Island and are sparsely distributed on northernmost Padre Island. They are especially well developed on southwestern St. Joseph Island where only remnants of beach ridges are exposed within the areas of stabilized blowouts (fig. 22).

Grain-size characteristics and physical properties of stabilized blowout dunes are the same as those of fore-island dunes. Blowout dunes consist of sand derived from fore-island dune areas; they differ from stabilized dunes in that they are barren of vegetation and are free to migrate downwind.

Beach ridge and barrier flat.—The beach ridge and barrier flat comprise a major environment of the barrier system in the Corpus Christi area, totaling about 13 square miles on southern St. Joseph, Mustang, and northern Padre Islands. Relict beach ridges are absent except in small areas on southern St. Joseph Island (fig. 22); eolian activity has destroyed the beach ridge-and-swale topography that typifies barrier islands along the upper Texas coast.

The small areas of beach ridge terrane preserved on St. Joseph Island are characterized by a series of subparallel *beach ridges and swales* generally oriented parallel to the trend of the barrier island (fig. 22; *Environmental Geology Map*). Each ridge represents a position of the shoreline during earlier stages of barrier development. Swales are filled with water or fresh-water marsh. Ridge height is generally about 5 to 10 feet above mean sea level. Individual beach ridges may extend for several miles but only one mile of ridges is preserved in the Corpus Christi area. The beach ridge-and-swale unit on St. Joseph Island is considerably narrower than the unit on Matagorda Island (Port Lavaca map area).

The growth of beach ridges 5 to 10 feet above sea level is a function of several interacting coastal processes. Sand and shell, which comprise the ridges, have been moved onshore by wind-driven currents from offshore deposits (fig. 8). Under normal sea conditions, the strandline builds seaward by the accumulation of sand on the beach. Spring tides and storms raise sea level, temporarily allowing sand to accumulate as berms a few feet above mean sea level. With return to normal sea level, the berm is modified by wind and biologic processes. Subsequent spring tides or storms create another berm which is accreted to the previous one.

South of Brown Cedar Cut (Port Lavaca map area), decreased vegetation and increased wind dominance have resulted in the deflation of original beach ridge-and-swale topography to produce *vegetated barrier flats* (figs. 22 and 23). The vegetated flat is, therefore, composed of a sand veneer of variable thickness that is derived locally from underlying beach ridges; some sands are derived from fore-island blowouts. The barrier flat lies between mean sea level and 5 feet above MSL (figs. 22 and 23). The slightly hummocky surface of the barrier flat dips gently bayward. Vegetation on the flat, as on the preserved beach ridges, is predominantly grasses that are tolerant to salt spray and occasional flooding by storm-tidal surge. In the Corpus Christi map area, vegetated barrier flats occupy large parts of Mustang and northern Padre Islands.

Back-island dunes.—Extensive back-island dune fields on northern Padre Island have accumulated principally from sand supplied by fore-island blowout dunes (fig. 21; *Environmental Geology Map*). These types of dunes, which are common on central Padre Island, are described in detail in the "Environmental Geologic Atlas of the Texas Coastal Zone—Kingsville Area" (Brown and others, in preparation). Small areas of back-island dunes near Fish Pass on southern Mustang Island are being stabilized by vegetation.

The dune fields are composed of elongate but discontinuous dunes that are affected by both south-easterly and northerly winds. The dunes on northern Padre Island are migrating into Laguna Madre. Shape and areal extent of the back-island dune fields vary significantly from year to year. Thirteen square miles of back-island dunes and fore-island blowouts existed when aerial photographs used in this study were made (fig. 3).

Land development on northern Padre Island is eliminating significant acreage in the back-island dune environment. Continued westward migration of the dune fields will eventually fill northern Laguna Madre east of the Intracoastal Waterway (fig. 21).

Salt-water marsh.—Salt marshes characterized by a specific plant community occupy the bay margins of barrier islands that are inundated daily by astronomical and/or wind tides. These areas are relatively flat, increasing in elevation away from the bay margin where they grade into barren wind-tidal flats.

Thin, discontinuous bands of salt marsh occur along the bayside of St. Joseph Island and northern Mustang Island (figs. 22 and 23) in the vicinity of Allyns Bight, Mud Island, Lydia Ann Island, and Shamrock Cove. Extensive marshes occur on Harbor Island. During northers, shells of oysters and other bay species are washed into the marsh developing thin, narrow, and discontinuous beaches. With the exception of the shell beaches, sediment underlying the marshes generally becomes sandier toward the higher parts of the marsh. Sediment underlying low marshes is generally dark gray mud or muddy sand that has been intensely burrowed by worms, crustaceans, and molluscs, and mottled by penetration of plant roots. Sediment of the high marsh is reworked primarily by plant roots and fiddler crabs.

Washover channels and fans.—During hurricane surges and storms, the barrier island locally may be breached. Storm-generated currents may erode channels through the barrier and carry sand to the bayside of the barrier where it is deposited as a washover fan. Approximately 11 square miles of washover environments exist within the Corpus Christi map area. Parts of St. Joseph Island and the southern part of Mustang Island are frequently breached by hurricane storm surge (fig. 8; *Active Processes* and *Environmental Geology Maps*).

Most of northern St. Joseph Island is a washover fan (fig. 24) studied by Andrews (1970). Refer to the "Environmental Geologic Atlas of the Texas Coastal Zone—Port Lavaca Area" (McGowen and others, 1976) for a detailed description of washover channels and fans of northern St. Joseph Island. The washover complex that occurs in the Corpus Christi map area is presently inactive. Except for ponded, partly mud-filled channels, surface sediment is principally a mixture of fine sand and shell. Shell content decreases toward the bays. Several depositional features are present on the St. Joseph washover fan, including washover channel, washover distributary channel, proximal washover fan, and distal washover fan (fig. 24). Another washover complex between North Pass and Aransas Pass (fig. 24) was studied by Nordquist (1972).

During the passage of some hurricanes, *washover channels* erode as much as 10 to 15 feet below mean sea level. Following the passage of storms, washover channels may remain open for days or months. They are ultimately closed at their gulfward terminus by sediment transported onshore by waves and alongshore by longshore currents. Channels are filled with a mixture of sand and shell near the base of the channel. Shell content decreases upward in the channel and the ultimate fill is primarily very fine- to fine-grained terrigenous sand. Water stands in unfilled segments of some washover channels. Windblown sand derived from the barriers accumulates in many channels. Channels also may be closed at their bayward terminus by sand derived from the bay. Washover channels that are repeatedly flooded are considered to be active; inactive channels are currently closed and at least partially filled.

Well-developed *washover distributary channels* are located on the northeast part of St. Joseph Island, on southern St. Joseph Island, and along southern Mustang Island (figs. 21 and 24). The channels may bifurcate away from major washover channels (fig. 22), or only a single channel may be present (figs. 21 and 24). Sediment moves through the washover channels and is deposited on the landward side of the barrier island to form a large washover-fan deposit. At the proximal ends, the channels are partly filled with sand and shell. Deeper parts of the channels become ponds after the passage of hurricanes; mud accumulates within the ponded channels. A fauna consisting of oysters, *Tagelus*, *Ensis*, and other molluscs is characteristic of water-filled, inactive channels. The shallow gulfward part of the distributary channel, which is mostly sand filled, grades bayward into the washover distal fan.

Washover fans are generally composed of two principal elements: vegetated, principally relict, proximal areas and barren, active, distal areas. *Vegetated washover fan* deposits on St. Joseph Island were named "eolian mounds" by Andrews (1970). These vegetated mounds form a simple radiating pattern centered on the apex of the fan; they range from 0.05 mile to 1.6 miles long and 0.02 to 0.43 mile wide. Height of mounds above mean sea level ranges from 1 foot to 9 feet. Mounds consist of sand and are characterized by concentric accretion structure. Sand is stabilized by a dense growth of grasses and thorny shrubs. In the Corpus Christi area, these vegetated, accretionary mounds or "islands" are generally relict (currently inactive), although eolian processes may continue at times to deposit sand along their margins. Remnants of these vegetated fan deposits, which occur along the landward side of Mustang Island, are evidence of relict washover complexes that have been inactive for many years (fig. 24; *Environmental Geology Map*).

The active, commonly outer part of the washover fan, called the *washover distal fan*, is a barren, level surface that is no more than 2 feet above mean sea level. Sediment is predominantly sand that is transported into the area by storm-surge flooding. Within the bays, north winds produce wind tides that may inundate large areas of the distal fan; currently, a veneer of bay mud covers the fan surface. Subsequent desiccation and eolian activity remove most of these mud veneers. The distal fan area is alternately wet and dry, primarily as a result of wind tides, and consequently, salinity of the substrate exceeds that of normal sea water. Because of this hypersalinity, blue-green algae are common. Alternate wetting and drying produce large air holes in the sediment, giving it the appearance of "sponge cake." Walking across the washover distal fan is difficult because the sediment is soft.

Large washover fans develop on abandoned tidal deltas; the St. Joseph Island washover fan is an example. Other large, abandoned tidal deltas, which have been partly modified by washovers, lie south of Aransas Pass and in the vicinity of Corpus Christi Pass (figs. 21 and 24). These relict fans form prominent islands on the tidal flats at the landward side of Mustang Island (*Environmental Geology Map*). The inactive washover channels are filled on the seaward side of Mustang Island where they are fronted by younger barrier flats, stabilized blowout dunes, and fore-island dunes (fig. 21).

Tidal channels and tidal deltas.—Natural breaks between barrier islands and peninsulas, through which tidal exchange occurs between bay and Gulf waters, are called tidal channels or passes. Sediment moves into the bay through tidal channels with flood tides, and a part of the sediment load accumulates as fan-shaped bodies near the bay terminus of a tidal channel; these comprise flood deltas. During ebb tide, some sediment is transported from the bay seaward through the tidal pass; part of this sediment load accumulates as ebb deltas near the gulfward terminus of tidal channels. Since physical processes are more intense on the gulfside of the barriers than on the bayside, much of the ebb sediment is immediately eroded and moved in a southwestward direction by longshore currents. Accordingly, ebb deltas are poorly developed and form a simple seaward bulge with some inlet-related shoals near and within the pass.

Aransas Pass-Lydia Ann Channel is the only active natural pass in the Corpus Christi map area (fig. 24). Deposits in the deeper parts of Aransas-Lydia Ann *tidal channel* consist of a mixture of shell fragments and terrigenous sand. Before construction of jetties that stabilized the pass, the gulfward terminus tended to migrate in the direction of longshore drift. As the channel migrated, it was successively filled with sand by accretion of spits into the shifting channel.

Harbor Island *flood delta* consists of shell and sand deposited near the mouth of Aransas-Lydia Ann tidal channel; sediment generally becomes finer grained on the distal, bayward part of the delta. Flood delta sediments have been deposited near the bay terminus of Lydia Ann Channel (fig. 24); most flood delta deposits are now covered by marsh, grassflats, or wind-tidal flats. Harbor Island (fig. 24) became emergent when storms raised the water level in the bay, allowing vertical accretion of sediment. With subsidence of the storm and associated high tides, parts of the flood delta may become emergent and may be subsequently stabilized by marsh vegetation. Subaqueous parts of the tidal delta are covered by shallow marine grassflats and sparsely vegetated sandflats (see Bay-Estuary-Lagoon and Lake Systems). Wind-tidal flats are transitional between the bay and the subaerial part of the tidal delta; shell berms and beach ridges occur along the margin of the exposed tidal delta. The reader should refer to a detailed study of Harbor Island by Hoover (1968) for specific details about processes, sediment, and biology exhibited by the flood delta. Recent mapping by Casby (1975) also includes the tidal delta complex.

An *ebb delta* that is characterized by shell and sand has been constructed near the Gulf terminus of Aransas-Lydia Ann tidal channel. The subaqueous deposit becomes finer grained in the deeper waters of the Gulf. The distal part of the ebb-tidal delta is predominantly sand and muddy sand. Longshore drift has displaced the ebb delta to the south (fig. 24).

Well-sorted sand and shell-bearing sand comprise *inlet-related shoals* within the tidal pass (fig. 24); these shoals are affected by both tides and waves. This environment is strongly affected by the tidal currents confined between the Aransas Pass jetties.

A relict tidal delta lies beneath the southern part of Mustang Island and adjacent northern Laguna Madre, but it is now occupied by wind-tidal flats, washover channels and fans, and subaqueous grassflats and sandflats. Relict channels associated with the tidal delta include Corpus Christi Pass, Newport Pass, and Packery Channel. Corpus Christi Pass closed one year following the dredging of Aransas Pass in 1925 because of the reduction in tidal discharge.

Several small tidal deltas, which have been constructed at the termini of small passes between restricted segments of the bay-estuary-lagoon system, are described elsewhere in the section on that system.

Marsh-Swamp System

Within the Corpus Christi map area, the lower parts of the coastal areas and river valleys, generally at elevations less than 5 feet above mean sea level, support a marsh-swamp system (fig. 4). Although there are three significant fluvial systems and one large bayhead delta, swamps are areally restricted in the Corpus Christi area.

Vegetation in marshes and swamps requires a perennially wet substrate with a permanently high water table. Marshes and swamps develop on a variety of landforms including: (1) flood-tidal deltas, (2) barrier islands, (3) mainland shorelines, (4) bayhead deltas, (5) abandoned tidal creeks, (6) washover-channel margins, (7) floodplains of principal rivers, and (8) abandoned courses and cutoffs of Modern and ancient stream systems.

Components of the marsh-swamp system in the Corpus Christi area include: (1) salt-water marsh, (2) fresh- to brackish-water marsh, (3) fresh-water marsh, and (4) swamp (rare). In addition to a distinction based on predominance of characteristic grasses and trees, marshes are zoned by frequency and intensity of exposure to waters of varying salinity. Substrate salinity appears to be one of the major factors controlling plant distribution. Salt marshes situated on delta plains are sometimes inundated by fresh water during river overbank flooding, and fresh-water marsh on the same delta plain may be inundated by saline bay water during the passage of a hurricane. There is, then, a substrate salinity gradient from the bay margin inland across a delta plain. Salinity decreases away from the bay, and the normal succession inland is from salt marsh to swamp (fig. 20). Swamps are exclusively a fresh-water, tree-dominated environment.

Salt-water marsh.—Salt-water marsh, kept perennially wet by salt water, occupies 10.7 square miles of the Corpus Christi area. Chief occurrences are on the delta plains of bayhead deltas (7.7 square miles), on flood-tidal deltas, along bay margins, and along the back sides of barrier islands and peninsulas.

Salt marshes include low marsh and high marsh. The low salt-water marsh is characterized by pure stands of smooth cordgrass (*Spartina alterniflora*) that grow at the margin of salt-water bodies in water a few inches deep (fig. 20). The high part of the marsh is inundated almost daily by either astronomical or wind tides and is characterized by numerous salt-tolerant, largely succulent plants that show an orderly succession in types from the water margin toward the higher and more saline substrates. The water in which high and low salt-water marshes are situated varies from less than to greater than normal marine salinity (35‰). Climatological conditions are key factors in controlling salinity fluctuations normally experienced by high salt-water marsh.

Principal areas of salt marsh occur on the Nueces, Chiltipin-Aransas, and Mission deltas. These marshes extend inland from sea level along the bay margins to 1 or 2 feet above MSL on the delta plain (fig. 19). Marshes are inundated by both astronomical and wind tides; along the Texas coast, wind tides inundate larger areas. From the bay margin inland, dominant plant assemblages are: (1) *Spartina alterniflora*, (2) *Batis maritima*, *Salicornia bigelovii*, *S. perennis*, *Distichlis spicata*, (3) *Spartina spartinae*, and (4) fresh-water marsh or levee assemblages, depending upon the specific location.

Bay-margin marshes are more restricted in size than marshes on delta plains. Bay-margin marshes are composed of the same species and display the same zonation as on delta plains, but they rarely grade into fresh-water marsh except along upper Port Bay (fig. 16). The bay-margin marshes are commonly situated on substrates of mixed shell and sand. The marshes occur discontinuously along the shoreline of Copano, Mission, Port, and Nueces Bays. In many places, the salt marshes are too narrow to map at a scale of 1:24,000.

On the back sides of barrier islands, marshes display an orderly plant succession from the bay shoreline to the higher parts of the barrier island. The succession is controlled by factors such as degree of salt-water inundation, salinity of the substrate, and height of the surface above bay water level. From the bay shoreline toward the higher marsh areas, the general plant succession is: (1) *Spartina alterniflora*, (2) *Batis*, *Salicornia*, and *Distichlis*, (3) *Borrichia*, *Monanthochloe*, and *Suaeda*, and (4) sparse marsh vegetation. In the Corpus Christi area, back-island marshes are discontinuous and restricted in areal extent. These marsh sites are restricted to small areas along St. Joseph Island (figs. 23 and 24) and Mustang Island (fig. 23). Harbor Island, a flood-tidal delta, is the site of extensive areas of salt marsh (fig. 24).

Fresh- to brackish-water marsh.—Fresh- to brackish-water marsh, present at slightly higher elevations than salt marsh, is also poorly developed in the Corpus Christi area. These marshlands total approximately 8.6 square miles. They are present on the Nueces delta (fig. 19) and along some active and inactive tidal creeks and tributaries associated with Port Bay (fig. 16). Fresh water is contributed to these marshes by overbanking of minor streams during flood stage and by runoff from the adjacent Pleistocene uplands. Salt water is contributed to marsh areas from the various bay segments. The extent of inundation depends primarily upon direction, intensity, and duration of the wind.

Salinity in fresh to brackish marshes varies with climatological conditions. During prolonged dry periods, both surface and soil water have salinity in excess of 35°/₀₀, whereas during periods of excessive rainfall, surface water may be virtually fresh. Salinity of substrate water appears to have the greatest influence on the kind of vegetation which will develop in an area.

Fresh-water marsh.—Pure stands of fresh-water marsh vegetation in the Corpus Christi area are best developed on the Nueces and Mission deltas and along the Nueces, Chiltipin-Aransas, and Mission Rivers (figs. 18 and 19). During wet climatic cycles, an ephemeral, poorly developed fresh-water marsh occupies low areas adjacent to Port Bay and McCampbell Slough and along the margin of parts of Laguna Larga. Fresh-water marshes cover a total of almost 20 square miles in the Corpus Christi area, but 13 square miles are associated with bayhead deltas. The lower parts of levees within the delta systems are occupied by an additional 5.6 square miles of fresh-water marsh.

Swamp.—Swamps are relatively rare environments in the Corpus Christi area, constituting an area of only 1.5 square miles within abandoned channels of the Nueces River. They are perennially inundated by fresh water and support a tree-dominated flora. Swamp vegetation (for example, cypress, willow, swamp palmetto, and sweet gum) is intolerant of saline water. The swamp environment is one of relatively low energy; water is supplied to the area by overbanking during floods and is also transmitted to the area from the main fluvial system by seepage into point-bar sands underlying parts of the swamp. Swamps in the Corpus Christi area are nearing extinction because of the diminished discharge resulting from upstream dams and perhaps because of gradually increasing aridity.

Bay-Estuary-Lagoon and Lake Systems

An extensive network of shallow-water bays, lagoons, and estuaries comprises a major natural system throughout the Texas Coastal Zone (fig. 4). In the Corpus Christi area, this system principally includes northern Laguna Madre, Nueces, Corpus Christi, Redfish, and South Bays, and parts of Aransas and Copano Bays. Oso, Port, and Mission Bays are smaller elements of the system. These shallow submerged environments occupy over 350 square miles of the Corpus Christi map area.

Also present in the Corpus Christi map area are 26 square miles of natural lakes or ponds. These small, enclosed water bodies occur in low-lying inland areas, along floodplains of Modern river systems, and just inland of the Pleistocene barrier-strandplain sand deposits stretching from Fulton southwestward into Kleberg County.

The Texas bays, estuaries, and lagoons (figs. 15, 21-25) are relatively low-energy environments protected on the seaward side by well-developed barrier islands. Water exchange between the bays and the Gulf is normally limited to natural and artificial tidal passes through the barrier islands. During storms, Gulf waters also enter the bay through washover channels cut through the barrier islands. Fresh water is supplied to the bays and lagoons by larger river systems terminating at the bayheads and by several small streams that drain local areas of the adjacent coastal uplands.

The series of inland water bodies that comprises the bay-estuary-lagoon system was formed when rising sea level (following the last glacial period) inundated and flooded older river valleys. Arcuate shorelines, such as exhibited by Nueces Bay (fig. 19), are relict meanders of these old river valleys. Erosional meander scars have been modified in shape and enlarged through subsequent bay shoreline erosion. Where the bay shoreline impinges upon older Pleistocene sands, the local sand supply is sufficient to develop small sand beaches and spits.

The salinity of the bay complex is variable and depends on the amount of fresh-water discharge into the bays. Following intensive rains, such as occur during hurricane-aftermath storms, saline bay waters are greatly diluted by fresh water, and only slightly brackish salinities occur near river mouths. Conversely, during hot, comparatively dry summers, the salinity of the bays and lagoons is increased significantly by inflowing Gulf water, evaporation within the bays and lagoons, and the low discharge of streams. Maximum salinities in the area occur in Laguna Madre. In the central part of Corpus Christi Bay, maximum water depth is approximately 13 feet (*Environmental Geology Map*). Along the bay margins, water depths are less than 6 feet, and over large

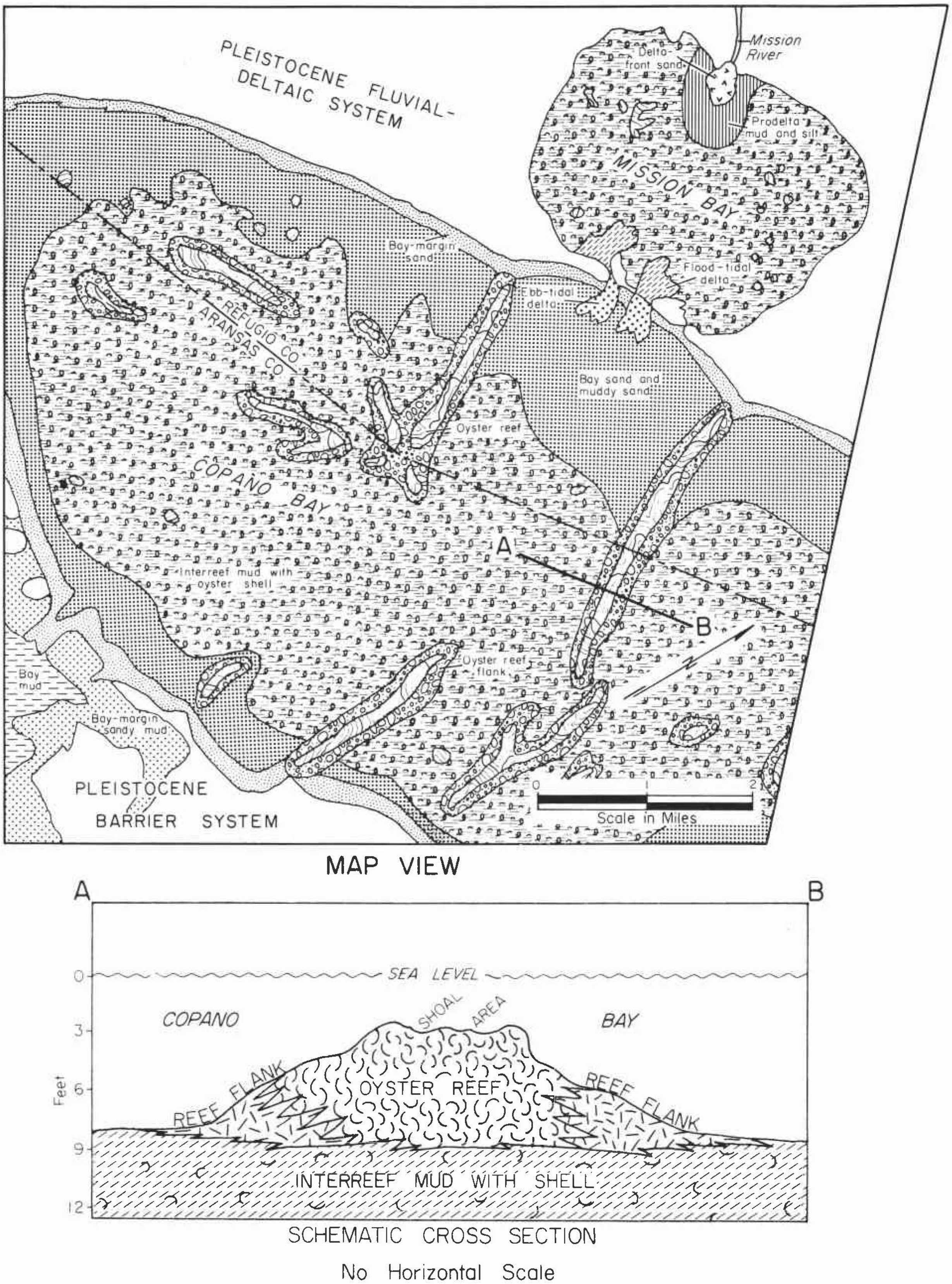


Figure 25. Copano Bay system composed of elongate oyster reefs and interreef environments. Relict reefs are buried beneath bay deposits. Living oysters and other reef-associated fauna occupy the outer surface of existing reef structures. Schematic cross section illustrates vertical and lateral relationships of reef, reef flank, and interreef deposits.

areas of some bays, average water depth is on the order of 3 feet. Tidal channels, passes, and dredged channels are greater than average depth.

Nueces Bay has been significantly altered from its natural state by extensive shell dredging and by the development of large tracts of made land in the Corpus Christi port area. Channel dredging with concomitant disposal of spoil has occurred in Laguna Madre and Aransas, Corpus Christi, and Redfish Bays. Redfish Bay and northern Laguna Madre have experienced the most intensive dredging within the bay-estuary-lagoon system. Spoil deposited in shallow water has been extensively reworked by waves and currents, modifying nearby shorelines and the bay bottoms (fig. 15). Oyster shell dredging has been intensive near the mouth of Copano Bay (Port Lavaca map area) and throughout Nueces Bay. Extensive dredging has occurred on the bayside of Mustang and northern Padre Islands.

Bay-Estuary-Lagoon Environments

The various environments composing the bay-estuary-lagoon system in the Corpus Christi area constitute four categories: (1) subaerial bay- or lagoon-margin environments; (2) subaqueous bay- or lagoon-margin environments; (3) subaqueous bay- or lagoon-flat environments; and (4) bay- or lagoon-center environments. The first two categories include subaerial and shallow-water environments developed principally as part of the shoreline complex. The third and fourth categories are subaqueous environments that have developed in shallow flats and central areas, respectively. Bay waves and currents are critical factors controlling bay-margin environments (fig. 8). Various environments of the bay-estuary-lagoon system shown on the *Environmental Geology Map* are defined by dominant physical or biologic process and composition and nature of the bay substrate.

Subaerial bay- or lagoon-margin environments.— The principal subaerial bay-margin environments of the Corpus Christi map area include about 21 square miles composed of (1) small fan deltas, (2) abandoned berms or beach ridges, (3) active accretionary bay-margin sand and mud, and (4) wind-tidal flats. Narrow unmapped beaches are poorly developed along bay shorelines; these local beaches derive their sand supply from the erosion of sandy Pleistocene deposits. Most of the bay shoreline is bounded either by an erosional escarpment cut into Pleistocene deposits or by wind-tidal flats or coastal marshes.

Small *fan deltas* have built into Nueces Bay along its northern shoreline and into Oso Bay and Laguna Vista (*Environmental Geology Map*). These fans, which are supplied with sediment from adjacent sandy Pleistocene deposits, flow along a steep gradient from the coastal plain surface to the bay margin. McGowen (1971) describes in detail the origin, characteristics, and depositional history of Gum Hollow fan delta, the largest of these features. The fan deltas are alluvial fans composed of braided stream deposits which prograde into the shallow bay where waves and currents rework and modify the distal-fan deposits. Gum Hollow fan delta is supplied with sand derived from a Pleistocene distributary deposit which has been devegetated by surficial disposal of oil-field brine. In the upper part of Nueces Bay, two of the fans are building on a wind-tidal flat. About 3.5 miles south of Edroy, a large alluvial fan at the terminus of a headward-eroding stream is building into marshlands of the Nueces fluvial system (fig. 18).

Most *abandoned berms and beach ridges* are associated with earlier Modern shorelines such as near the head of the Nueces delta (figs. 18 and 19) and in upper Port Bay adjacent to McCampbell Slough. Younger berms are associated with the northwestern shorelines of Mission Lake and Mission Bay. Other relict berms, possibly of late Pleistocene or Holocene age, occur in the vicinity of Spears Lake at elevations of about 10 to 15 feet above MSL. Sediments of the abandoned beach ridges consist of caliche nodules, pebbles, sand, and shell fragments. The relict deposits are the products of both normal and storm conditions; storm waves are capable of constructing berms several feet above MSL. Swale-fill, marsh, and mudflat deposits are commonly associated with the beach ridges.

In the Corpus Christi area, *active, accretionary bay-margin deposits* covering 4 square miles are locally well developed (figs. 16 and 24; *Environmental Geology Map*). Active beaches and berms occur on the northwest shore of Mission Bay, along the northwest shore of Copano Bay, at Egery Island and Hannibal Point on the southern shore of Copano Bay, along the margin of Harbor Island, along the margin of the shallow subaqueous shelf occupied by Redfish Bay, at Mud Island in Aransas Bay, at Indian Point, Dermit Island, Shamrock Island, and the North Beach area in Corpus Christi Bay, and at North and South Bird Islands, and Pita Island in northern Laguna Madre. These deposits normally exhibit beach- or spit-accretion grain. Some occur several feet above MSL. Shell derived from the oyster, *Crassostrea virginica*, constitutes most of the material of the beaches and berms. *Phacoides, Chione, Aequipecten,* and *Cerithium*, and other bay molluscs are also common.

Beach ridge deposits result primarily from strong waves breaking upon the mainland shoreline. Berms and spits along the bayside of barriers are commonly produced by storm waves breaking upon shallow, submerged shoals to develop emergent islands which serve as the nuclei for continued spit accretion. Similarly, storm waves breaking upon the shallow margin of Harbor Island and the shallow shelf occupied by Redfish Bay pile up berms and beaches composed of shell derived from nearby bay bottoms.

Approximately 16 square miles of the Corpus Christi map area are occupied by *wind-tidal flats*, which are barren, flat depositional surfaces occurring between sea level and 2 or 3 feet above MSL. The environment is common along the back side of barrier islands (figs. 21-23) although some wind-tidal flats occur within the Modern bayhead delta systems (fig. 19). The environment also occupies parts of the Harbor Island flood-tidal delta (fig. 24). Wind-tidal flats also occur within the lower parts of Oso Bay and Petronila Creek (see Modern-Holocene Fluvial-Deltaic System). Two varieties of wind-tidal flats occur within the map area: firm, sandy flats and muddy, algal-rich, gypsiferous flats. The latter type is restricted to the Harbor Island flood-tidal delta.

Inundation of the flats by salt water occurs a few times each year as a result of polar fronts, tropical storms, or persistent onshore winds. Since the tidal flats are flooded only a few days each year, most of the surface water evaporates, leaving a thin salt crust. Blue-green algae flourish on these flats during and shortly after flooding; otherwise, the environment is largely biologically barren. Some local salt-marsh vegetation exists, and *Uca*, the fiddler crab, commonly burrows the higher parts of the flats. Wind-tidal flat sediment is predominantly sand with interspersed thin mud layers. Refer to "Environmental Geologic Atlas of the Texas Coastal Zone—Kingsville Area" (Brown and others, in preparation) for detailed discussion of wind-tidal flat environments and processes.

Subaqueous bay- or lagoon-margin environments.— Approximately 155 square miles of the bay-estuary-lagoon system within the Corpus Christi map area are occupied by subaqueous bay-margin or shallow bay- or lagoon-flat environments (figs. 15, 21, 23, and 24). Water depths within these environments range from a few inches to about 6 feet, although water is commonly less than 3 feet deep. Distinctions between subaqueous bay-margin and deep bay-center environments are clear; differences are less distinct in shallow bays such as Nueces and Redfish Bays. Bay- or lagoon-margin environments and bay- or lagoon-flat environments are transitional and herein are arbitrarily subdivided.

Subaqueous bay-margin environments include relatively narrow, marginal bay-lagoon environments occupied principally by grassflats or underlain by substrates composed of bay-margin sand and shell, bay-margin sandy mud with some shell, bay sand and muddy sand with some shell, and local delta-front sand shoals. Within the bay- or lagoon-margin zone, the substrate is composed of sediment that has been winnowed to some extent by waves and currents (fig. 8). Pleistocene mud and sand are exposed locally along high-energy, principally erosional, mainland shorelines.

Marginal *grassflats* occur as narrow bands along the back side of Mustang and St. Joseph Islands (fig. 22), along parts of Port Bay shorelines, along the margin of Harbor Island, and along the shelf adjacent to Shellbank and Traylor Islands in Aransas Bay (fig. 24; *Environmental Geology Map*). The grassflats generally grade shoreward into salt marshes or wind-tidal flats. They are restricted to a narrow belt along the deeper bays where water depths increase rapidly from a few inches to about 3 feet; this restricted setting is in contrast to the broad shallow flats within the bays and lagoons where extensive marine grasses dominate the subaqueous environment. Substrates along bay margins that are occupied by marine grasses are normally muddy sand and shell.

Grasses consist chiefly of *Diplanthera (Halodule) wrightii. Ruppia maritima* is common along some of the bay margins, especially where salinities are less than normal. *Thalassia testudinum* is the most common marine grass in Aransas Bay (West, 1969). These bay-margin grassflats are occupied locally by migrating subaqueous sand and shell bars and shoals. The grassflats are also transitional with bay-margin sand shoal environments.

Intergradational shoal-water environments, which are underlain by *bay-margin sand and shell* and *bay-margin sandy mud with some shell*, are characterized by strong wave energy and longshore currents. These bay-margin shoal environments occupy about 33 square miles of the map area (figs. 15, 21-24). These environments are generally restricted to water depths less than 6 feet. Sediment sources for bay-margin deposits include flood-tidal deltas, washover fans, and eroded Pleistocene sediment. The high-energy shoal environments occur along the landward side of Laguna Madre (fig. 23) and along most of the bay shorelines in the Corpus Christi area (figs. 15, 21, and 22). Subaqueous bars and shallow shoals and spits are common within these high-energy areas.

In the Corpus Christi map area, about 56 square miles of *bay sand and muddy sand with local shell* occur in water depths of 9 or 10 feet. This substrate characterizes a lower energy environment than the bay-margin sandy mud environment with which it is transitional. It lies bayward of the narrow, high-energy shoals along the margin of Copano Bay, in the eastern part of Corpus Christi Bay, in the eastern part of Nueces Bay, and within Oso Bay (figs. 22, 24, and 25). In Copano and Nueces Bays, the oyster shell content is high. The bottom is intensively burrowed by bottom-dwelling organisms. Deposition is slow and the environment is gradational between the narrow, high-energy, bay-margin shoals and the bay-center environments.

Sand shoals composed of *delta-front and channel-mouth bars* occur at the mouths of the Nueces and Mission Rivers. The sand is deposited by the river during periods of high discharge; waves and currents within the bays rework the bar deposits between floods. Refer to Modern-Holocene Delta Environments for further description.

Subaqueous bay- or lagoon-flat environments.— These environments include: (1) broad grassflats, (2) bay and lagoon sand with sparse grass, and (3) small intrabay tidal channels and associated flood-ebb deltas. They occur in relatively shallow bay waters, normally less than 3 feet deep. The principal occurrences are in Redfish Bay, on the adjacent submerged parts of the Harbor Island tidal delta (fig. 24), and within northern Laguna Madre (fig. 23).

The *broad grassflats* account for most of the 53 square miles of marine grasses in the Corpus Christi area. Most of northern Laguna Madre is occupied by broad, shallow grassflats composed of *Diplanthera (Halodule) wrightii* and locally by *Ruppia maritima; Thalassia testudinum* is absent. *Diplanthera*, *Ruppia*, and *Thalassia* are locally plentiful within Redfish Bay. The marine grass communities thrive in shallow, agitated waters generally no deeper than 3 feet MSL where high photosynthesis activity is possible. A variety of molluscs (snails and clams) dominate the benthic invertebrate community. Sediments are muds and muddy sands; decaying plants produce a reducing environment characterized by the production of hydrogen sulfide. Seasonal changes occur in the productivity of the grassflats. Refer to the "Environmental Geologic Atlas of the Texas Coastal Zone—Kingsville Area" (Brown and others, in preparation) for additional description of the grassflat environments.

Shallow-water environments of *bay and lagoon sand with sparse grass* are transitional with broad marine grassflats of northern Laguna Madre and the Redfish Bay-Harbor Island area. This environment is a sparsely grass-covered sandflat that occurs at water depths less than 3 feet and is created when sediment eroded from spoil deposits is transported onto marine grassflats by storm-generated waves and currents. Sediment may completely bury a large area of marine grass to produce a barren to sparsely vegetated subaqueous sandflat. Marine grasses may gradually reinhabit the area. Seasonal variations in salinity and turbidity may also affect the density of marine grasses. The distribution of this environment is, therefore, very ephemeral within Redfish Bay and northern Laguna Madre.

Several *small intrabay tidal channels and tidal deltas* exist at points where tidal exchange occurs between various restricted segments of the bay-estuary-lagoon system. For example, tidal deltas have developed at small passes between Oso Bay and Corpus Christi Bay, between Laguna Madre and Corpus Christi Bay, between Redfish Bay and Aransas Bay, and between Mission Bay and Copano Bay (figs. 21 and 24). Tidal flow may be caused by both astronomical and wind-generated tides. Generally, the tidal exchange occurs between an open, deep bay and a shallow, restricted bay.

Bay- or lagoon-center environments.—Most of the submerged bay-estuary-lagoon environments in the Corpus Christi map area (180 square miles) occupy the central parts of bays or lagoons (figs. 15, 21, and 23-25). These environments include those associated with oyster reefs and those without oyster reef development. In Corpus Christi, Aransas, and Copano Bays, bay-center environments occur in water depths generally greater than 6 feet below MSL; exceptions are the smaller bays and lagoons, such as Mission, Port, and Nueces Bays, and Laguna Madre. The deeper bays, particularly, are subjected to continuous wave motion, but breaking waves and strong bottom currents are uncommon within most of the bay- and lagoon-center environments. Within the shallower bays, water depths preclude the generation of relatively large waves except during periods of elevated sea level associated with hurricane-tidal surge. The sediments and benthic faunas in bay-center environments, therefore, are characteristic of lower physical energy. Exceptions are the oyster reef and reef-flank environments subjected to intensive wave energy because of greater bathymetric relief.

Environments included in the bay- and lagoon-center category are floored by substrates composed of: (1) mottled bay and lagoon mud with some shell, (2) bay mud with shell, (3) prodelta mud and silt, (4) oyster reefs and reef flanks, and (5) interreef mud with oyster shell.

Substrates of *mottled bay and lagoon mud with shell* characterize 128 square miles within the centers of Corpus Christi, Aransas, and Port Bays, and Laguna Madre (fig. 15). This environment occurs in water depths greater than 6 feet, except in Port Bay and Laguna Madre (fig. 23) where shallow bay and lagoon waters (< 6 feet deep) are significantly restricted from intense wave or current energy. Wave trains generated by winds move across the central parts of the bays and lagoons, but little of this physical energy affects the sediment-water interface. A varied bay-center fauna is characterized by burrowing molluscs that feed on the highly organic detritus that settles to the bay bottom.

Hurricane-aftermath stream flooding discharges sufficient fresh water into the bays of the Corpus Christi area to flush the bay-center environments; bay salinity slowly returns to normal by tidal exchange through Aransas Pass and Fish Pass. The bay-center sediment is composed principally of mottled (burrowed) organic-rich mud and in situ shells of the benthic fauna. The muddy blanket of sediments is interrupted only by oyster reefs or subaqueous spoil; the muddy sediments grade abruptly into high-energy, shallow-water sands deposited along the flank of bay-margin sand shoals. Along the trend of the buried valley of the Pleistocene Nueces and Aransas-Mission Rivers, the bay-center muds overlie estuarine sediments buried within relict channels. Elsewhere, the bay- and lagoon-center mud and shell form a thin blanket resting upon eroded Pleistocene deltaic and barrier-strandplain sediments. Two small areas within Corpus Christi Bay are underlain by *bay mud with shell*. This minor environment may represent areas of firmer substrate within the bay center where molluscan productivity is unusually high.

Deposits of *prodelta mud and silt* occur near the mouths of the Nueces (fig. 19) and Mission Rivers. These sediments are introduced into the bays while suspended in river floodwaters; the clay and silt flocculate and settle to the bay bottom. A thin, fanlike deposit of prodelta clay lies bayward of the river mouth. Between major floods, benthic organisms burrow the prodelta sediment in search of nutrients. The relationship of this environment to the building of the Nueces and Mission deltas is discussed elsewhere in this report under Modern-Holocene Delta Environments.

In the Corpus Christi map area, *oyster reefs and reef-flank environments* occupy about 7.5 square miles of the bay-estuary-lagoon system. The environments are concentrated in Copano Bay (fig. 25), but a few, generally relict, reefs occur within Corpus Christi (fig. 15) and Nueces Bays. The reefs are built chiefly by the edible oyster, *Crassostrea virginica*.

Small reefs are either elongate or L-shaped. Large reefs exhibit complex, highly sinuous and bifurcating forms. Elongate reefs are generally aligned transverse to the dominant current direction. Oysters are sessile organisms attached to the bay bottom and dependent on circulating waters both for food and for removing waste materials (Scott, 1968). Favored bottoms for oyster reef development are either fine, stable sands or stiff, compact muds; soft substrates or shifting sand bottoms are not conducive to reef growth and support. Salinity is also important to oyster reef growth and development. Oysters exist in a wide range of water salinities, but prefer 5 ‰ to 30 ‰. They can survive sudden changes of salinities for short periods by closing their valves and isolating themselves from unfavorable waters. Only the outer surface of a reef may contain living oysters; the core or framework of the reef is composed of relict shell.

Reefs mapped in the Corpus Christi area (*Environmental Geology Map*) include both exposed living and relict reefs. Reefs buried beneath bay sediment were not mapped; buried reefs can be mapped using shallow reflection seismic methods. Although a few living oysters still exist locally and periodically in the eastern part of Nueces Bay, and in Corpus Christi Bay at Indian Reef, Alta Vista Reef, Long Reef, and Donnel Reef (fig. 15), the principal living reefs of the Corpus Christi map area occur in Copano Bay (fig. 25). Oyster reefs are absent in those parts of the bays modified by tidal interchange and extensive river discharge. Reefs along the margin of Corpus Christi Bay, such as Long Reef and Donnel Reef, have been partially buried by sediment transported along the bay shoreline from nearby spoil deposits.

In Copano Bay (fig. 25), elongate reefs are flanked by reef debris. The reefs extend upward from bay bottoms generally deeper than 6 feet; the reef crests are in water depths less than 3 feet. The shoal reefs are strongly affected by waves and are, thus, high-energy environments. Numerous reef-associated invertebrates, as well as fish, inhabit the reef and reef flank. Protection supplied by the strong reef structure enables many organisms to utilize this favorable environment. Reefs produce a baffling effect within bays such as Copano Bay, thus reducing the fetch and size of waves traveling across the bays. The Copano Bay reefs are aligned approximately normal to the tidal currents operative within the bay system.

Over 43 square miles of *interreef mud with oyster shell* occupy the centers of Copano (fig. 25), Nueces, and Mission Bays. In Copano Bay, the interreef environment occurs in water depths greater than 6 feet. Oyster shell broken from the adjacent reefs during storms is carried down the reef flanks and onto the bay bottom. In addition, abundant small patch reefs and isolated areas of oyster growth occur within the subaqueous interreef flats, providing local sources of shell debris. A varied benthic community exists within the broad interreef flats. The environment grades marginally into bay-margin sand and sandy mud shoals.

In Nueces and Mission Bays, water depths are generally less than 3 feet and active oyster growth has become severely restricted. Local clumps and patch reefs occur periodically. Conditions conducive to reef growth and development in this natural environment are disappearing in Nueces Bay as increasingly large volumes of suspended mud are added to the bay system by dredging. Both Mission and Nueces Bays are too shallow for generation of strong waves except during tropical storms when the water level is greatly elevated.

Lake Environments

Small, enclosed, fresh- and salt-water bodies termed lakes or ponds occur within the Corpus Christi map area. These lakes, which are mapped in blue, are not specifically delineated within the map legends. There are two general lake types: (1) floodbasin lakes, such as those associated with Nueces, Chiltipin-Aransas, and Mission Rivers; and (2) coastal lakes and ponds, principally located on or landward of Pleistocene barrier-strandplain sands. The low rainfall and high evapotranspiration rates in the area preclude the development of extensive lakes and ponds. Following heavy rainfall, the abundant depressions on the coastal plain and barrier islands may be flooded for weeks or months.

Floodbasin lakes.—Several fresh- to brackish-water lakes are present on the floodplains and delta plains of the Nueces, Chiltipin-Aransas, and Mission Rivers (figs. 12, 18, and 19). Most of the lakes are subelongate and generally parallel to the valley trend. Water and sediment are supplied to these lakes when the rivers and creeks are in overbank flood stage. Lakes are shallow, about 1 to 3 feet deep, and are floored with muddy sand and sandy mud. Some of the lakes, such as Mission Lake, are tidally connected to the bay system; salinity of the water in these lakes ranges from fresh immediately after a flood to saline during droughts. Molluscs are common to abundant. Lake margins are characterized by fresh-water marsh; water hyacinth is seasonally abundant.

Coastal lakes and ponds.—Coastal lakes and ponds are an integral part of the limited coastal marsh complex in the Corpus Christi area (figs. 14 and 16). These water bodies are widely distributed, occurring in the Port Bay area, on Live Oak and Encinal Peninsulas, and in the Laguna Larga area (*Environmental Geology Map*). Water bodies are very shallow. Depth ranges from a few inches to a few feet; some lakes may become dry during periods of low rainfall. Water in these coastal lakes and ponds varies from fresh to saline depending upon climatological conditions, such as rainfall, runoff, and tidal inundation. Filamentous blue-green algae are the dominant plant that inhabits these water bodies. The margins of several of the coastal lakes and ponds, such as Laguna Larga, consist of unvegetated mudflats representing former bottoms of larger water bodies. Locally, these coastal lakes have been filled by muddy lake-bottom sediments.

Eolian System

A wide variety of eolian environments occur within the Corpus Christi area: active clay-sand dunes, inactive clay-sand dunes, loess sheet, sheet sand components of Pleistocene barrier-strandplains, fore-island dune ridges, sandflats or coppice dunes, stabilized and active blowout dunes, and back-island dune fields. In addition, wind-tidal flat environments are under the control of the wind regimes responsible for the South Texas eolian system. Most of these eolian environments are, however, components of other systems such as the Modern barrier island system. Only three eolian environments of the South Texas eolian system occur within the Corpus Christi map area: loess sheet, active clay-sand dunes, and inactive clay-sand dunes. Each of these environments has been discussed in the "Environmental Geologic Atlas of the Texas Coastal Zone—Kingsville Area" (Brown and others, in preparation), and the reader is referred to that report for a more complete description of the South Texas eolian system.

Loess sheet.—A portion of this environment (25 square miles) occurs in the southwestern part of the Corpus Christi map area. It is part of the extensive Riviera loess sheet that is so widespread in the Kingsville area. In the Corpus Christi area, the Riviera loess sheet is composed of a thin veneer of windblown silt particles that overlie Pleistocene meanderbelt (fluvial) sand and mud deposits. The loess is derived from the Sarita eolian lobe where southeasterly winds are eroding the lower coastal plain. The fine airborne particles are transported downwind where they settle from the atmosphere to form the Riviera loess sheet. The loess sheet thins and becomes unmappable north of San Fernando Creek. The thickness of the loess sheet varies from a few inches to a few feet and is locally absent. Thin areas are indicated on the *Environmental Geology Map* by a stippled pattern. Pleistocene deposits beneath the loess sheet are similar to those exposed in the region between Sinton and Woodsboro. The loess sheet drapes over sandy or muddy terrain to form a rolling, hummocky topography.

Clay-sand dunes.—Active and inactive clay-sand dunes occupy a total of about 4 square miles in the Port Bay area, in the Oso Bay area, near Laguna Larga, and on the Riviera loess sheet. Inactive dunes are stabilized by heavy grasses or brush. Active dunes are grass covered but are supplied with silt-sized clay aggregates and, locally, some silt and fine sand from adjacent deflation areas. In the Port Bay area, inactive dunes were supplied with sand and clay deflated from the Pleistocene delta system and Modern-Holocene lacustrine system. Principal eolian activity probably takes place during extended drought periods; subsequently, vegetation stabilizes both the sources and the dunes. A rise in the local ground-water table may also account for the stabilization.

Currently inactive dunes along the northwestern shore of Oso Bay may be activated occasionally during drought periods. Dune sediment has been derived from the margin of the shallow bay and from the Pleistocene deposits exposed in the low bluffs surrounding the bay. Along the lower reaches of Oso Creek in the Rodd Air Field area, the wind-tidal flats and adjacent bluffs composed of Pleistocene deposits are deflated by the southeasterly winds, producing active dunes along the northwest side of the creek.

Two large stabilized dunes, part of a series along the northwestern shore of Alazan Bay (Kingsville map area), extend into the Laguna Larga area. Although much larger, the origin of these dunes is similar to the Port Bay dunes; Pleistocene delta-front and Modern-Holocene lacustrine deposits provided a local source of sediment as described in the "Environmental Geologic Atlas of the Texas Coastal Zone—Kingsville Area" (Brown and others, in preparation).

Several large, conical to ovoid, inactive dunes occur in the area of the Riviera loess sheet. These dunes are part of a group (Kingsville map area) that were derived from locally deflated Pleistocene fluvial sand bodies. This in situ source of sand and clay is available during drought periods. The dunes are vegetated.

Artificial Units

A significant type of landform and environment within the Corpus Christi area results directly from the activity of man. As shown on the *Environmental Geology Map*, artificial units include made or reclaimed land and a variety of spoil dredged from intrabay and land-cut channels and canals.

Made land.—A common practice in low-lying coastal areas is to reclaim or build up lowlands. Physical use of wetlands in their natural state is limited. Locally, low-lying wetlands and even shallow parts of coastal water bodies are filled and reclaimed for various uses. Made land in the Corpus Christi area covers an area of almost 15 square miles. Five principal areas of made land are (1) the Corpus Christi port facilities along the southern shore of Nueces Bay; (2) the Corpus Christi Naval Air Base complex; (3) the resort developments near Packery Channel (fig. 21); (4) the docking-storage facilities at Harbor Island and adjacent Aransas Pass (fig. 24); and (5) the resort community of Frandolig Island (fig. 16). Wastes produced at the Reynolds Aluminum Company are placed in large holding ponds near Portland (fig. 15) and on the west side of Port Bay. Though filling is requisite for certain physical uses, it permanently alters the original natural landforms and environments.

Spoil.—The Corpus Christi area is covered by a total of about 42 square miles of spoil material dredged from transportation channels and canals (figs. 15, 21, 23, and 24). The natural environment is altered not only by the channel but also by the discharge of dredged sediment. Dredged spoil is further reworked and redistributed by natural processes; this is accomplished on land mainly by sheetwash associated with rainfall and within water bodies by currents and waves. The area of land and bay bottom covered by spoil is, therefore, markedly increased by the subsequent action of natural processes. Piling of spoil into mounds and ridges on land creates local artificial relief and commonly alters natural drainage.

Three kinds of spoil mapped on the *Environmental Geology Map* and certain other maps of this Atlas are *subaerial spoil heaps* or *mounds* (3 square miles), *subaerial reworked spoil* (12 square miles), and *subaqueous spoil* (27 square miles). Major spoil areas flank the land cuts and intrabay channels of the Intracoastal Waterway and associated subsidiary navigation systems. Besides the Intracoastal Waterway, the Corpus Christi area has been extensively dredged for deep-sea access to the Port of Corpus Christi and to Aransas Pass. In addition, extensive dredging for small boat access has occurred in the Nueces delta, in Redfish Bay, in Laguna Madre, and in resort developments on the bayside of barrier islands.

SPECIAL-USE ENVIRONMENTAL MAPS

The eight *Special-Use Environmental Maps* included in this Atlas are designed for direct and specific use in the evaluation and proper utilization of the natural resources and environments of the area. They were constructed through: (1) interpretation and derivation of units mapped for the *Environmental Geology Map*, (2) compilation of data from diverse sources and projection of this data onto the environmental base map, and (3) a combination of both derived and compiled data (fig. 2). Selection of the kinds of special-use environmental maps included in this Atlas was based on a survey of the greatest need and potential use by both professional and lay people concerned with proper resource use and environmental management.

The series is composed of the following maps: (1) *Physical Properties*; (2) *Environments and Biologic Assemblages*; (3) *Current Land Use*; (4) *Mineral and Energy Resources*; (5) *Active Processes*; (6) *Man-Made Features and Water Systems*; (7) *Rainfall, Stream Discharge, and Surface Salinity*; and (8) *Topography and Bathymetry*. They comprise only a basic series of maps; a variety of other specific-use maps may be prepared by overlaying or combining any of the more than 175 map units of the environmental series (table 1). For example, the pipeline network of the Corpus Christi area can be compared directly with the distribution of active or potentially active surface faults to identify those areas where faulting might result in damage to a pipeline. Likewise, current land use can be compared to areas of hurricane flooding to determine kinds and amounts of land use affected. To facilitate direct use, certain map units are common to several of the maps. Statistical analyses of all units and features included on the *Environmental Geology Map* and the various *Special-Use Environmental Maps* are summarized in tables 3, 5, and 7-12.

PHYSICAL PROPERTIES MAP

The special-use map delineating physical properties is designed to provide regional data for a variety of physical uses. Physical properties groups are three-dimensional units; hence, the application of the data to evaluate various physical uses encompasses not only the areal extent of the physical properties groups but also their vertical extent to significant depths below the land surface. Some groups, such as Group XI lands, have distinctive physical properties only to the depth of the shallow water table, whereas other land groups, such as Group I lands, have properties that are reasonably distinctive to depths of several tens of feet. Groups VIII, XI, and XII are based mainly on physical characteristics of the surface materials, and physical properties at depth are dependent on the substrate on which these lands have developed. The many geologic, biologic, active-process, and man-made units of the basic *Environmental Geology Map* are organized into 11 major groups in the Corpus Christi map area. Each group is composed of units having common physical features and properties.

Specific types of uses and activities within the various land groups can be evaluated from available data. Table 4 includes an evaluation of the degree of suitability of each physical properties group for potential engineering uses. A total of 16 activities and land uses of 7 principal types is indicated; these are by no means the only uses or activities that could be considered but are the major ones: road construction, fill material, foundation construction, subsurface construction, excavation, waste disposal, and water storage.

Road construction includes use of the land groups for miscellaneous earthen structures and general fill along a highway right-of-way, for a base or foundation for paved or improved roads, and for fill to establish the grade upon which the base and overlying pavement are laid. Fill for nonconstruction purposes includes topsoil for general landscaping needs, such as highway embankments, and subsoil for miscellaneous fill not designed to withstand extreme loads. Foundation suitability of different land groups is subdivided into heavy construction or large structures, such as major industrial complexes or large office buildings, and light construction, principally one- or two-family dwellings and other single-story construction. Subsurface construction encompasses large underground installations such as basements and tunnels, as well as the burial of cables and pipelines. Excavatability of the various land groups is controlled by degree of consolidation, presence of caliche, moisture content, and similar factors affecting ease of digging with conventional machinery. Use of lands for waste disposal includes septic-system waste disposal, solid-waste disposal, and unlined liquid-waste retention ponds on the land surface; different modes of waste disposal require different physical properties. Use of the land groups for surface-water storage includes dams or dikes to impound water, unlined surface reservoirs (for example, stock tanks) fed by surface waters, and unlined surface reservoirs that intersect the ground-water table.

Principal physical groups and land areas outlined on the *Physical Properties Map* include clay and mud

Table 4. Evaluation of the natural suitability of physical properties groups for various coastal activities and land uses, Corpus Christi map area, Texas.

Suitability is evaluated on the basis of natural properties and may be improved by special engineering and construction methods. Significant properties considered as positive criteria for evaluating land use suitability (+ = satisfactory; – = unsatisfactory; 0 = possible problems)

(1) Road construction: Earthen structures and fill material—low shrink-swell potential, low compressibility, and low plasticity.
(2) Road construction: Base material—low compressibility, low shrink-swell potential, and high shear strength.
(3) Road construction: Grade material—low compressibility, low shrink-swell potential and high shear strength.
(4) Fill material: Topsoil—loam or sandy/silty clay composition.
(5) Fill material: General, below topsoil—silty/sandy clay composition with low to moderate shrink-swell potential.
(6) Foundation: Heavy—high load-bearing strength, low shrink-swell potential, and good drainage.
(7) Foundation: Light—low shrink-swell potential.
(8) Underground installations: Low shrink-swell potential, high load-bearing strength, and good drainage.
(9) Buried cables and pipes: Low shrink-swell potential and low corrosivity.
(10) Excavatability: Ease of digging with conventional machinery.
(11) Waste disposal: Septic systems—moderate permeability, low to moderate shrink-swell potential, and good subsurface drainage.
(12) Waste disposal: Solid waste—low permeability and good surface drainage.
(13) Waste disposal: Unlined liquid-waste retention ponds—low permeability.
(14) Water storage: Earthen dams and dikes—low permeability, moderate shear strength, and moderate compressibility.
(15) Water storage: Unlined reservoirs or ponds above ground-water level—low permeability.
(16) Water storage: Reservoirs or ponds supplied by ground water—high permeability.

GENERAL PHYSICAL PROPERTIES	PRINCIPAL ENVIRONMENTAL GEOLOGIC MAP UNIT	Coastal Activities and Land Uses: Road Construction (1) Earthen structures and fill material	Road Construction (2) Base material	Road Construction (3) Grade material	Fill Material (4) Topsoil	Fill Material (5) General, below topsoil	Foundation (6) Heavy	Foundation (7) Light	(8) Underground installations	(9) Buried cables and pipes	(10) Excavatability	Waste Disposal (11) Septic systems	Waste Disposal (12) Solid waste	Waste Disposal (13) Unlined liquid-waste retention ponds	Water Storage (14) Earthen dams and dikes	Water Storage (15) Unlined reservoirs or ponds above ground-water level	Water Storage (16) Reservoirs or ponds supplied by ground water
Group I Dominantly clay and mud, low permeability, high water-holding capacity, high compressibility, high to very high shrink-swell potential, poor drainage, level to depressed relief, low shear strength, high plasticity, high to very high acidity, high corrosivity	Interdistributary muds, barrier-strandplain swales, abandoned channel-fill muds, overbank fluvial muds, mud-filled coastal lakes and tidal creeks	–	–	–	0	–	–	0	–	–	+	–	+	+	0	+	–
Group II Dominantly sand, high to very high permeability, low water-holding capacity, low compressibility, low shrink-swell potential, good drainage, low ridge and depressed relief, high shear strength, low plasticity	Beach, foredunes, stabilized eolian blowouts, vegetated barrier flats, washover channels, Pleistocene barrier-strandplain sands	+	+	+	0	+	+	+	+	+	+	0	–	–	–	–	+
Group III Dominantly clayey sand and silt, moderate permeability, drainage, and water-holding capacity, low to moderate compressibility and shrink-swell potential, level relief with local mounds and ridges, high shear strength	Meanderbelt sands, alluvium, levee, crevasse splay, and distributary sands, and Pleistocene fluvial, distributary, delta-front, and strandplain sheet sands	+	+	+	+	+	0	+	0	+	+	+	0	0	+	0	0
Group IV Coastal marsh, fresh to brackish, very low permeability, high water-holding capacity, very poor drainage, depressed relief, low shear strength, high plasticity, high organic content, subject to salt-water flooding, high to very high corrosivity, high biologic productivity	Fresh to brackish marsh, marsh-filled tidal creeks, and marsh-covered levees	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Group V Inland swamp and marsh, permanently high water table, very low permeability, high water-holding capacity, very poor drainage, very poor load-bearing strength, high organic content, subject to frequent flooding, very high acidity, high biologic productivity	Swamp, fresh-water marsh, marsh-filled abandoned channel and course	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Group VI Wind-tidal flat and salt marsh, subject to frequent tidal inundations, properties of wind-tidal flats and related units similar to Group II, properties of salt marsh similar to Group IV	Wind-tidal flat and salt marsh, washover distributary channel and distal-fan facies	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Group VII Made land and spoil, properties highly variable, mixed mud, silt, sand, and shell, reworked spoil commonly sandy and shelly with moderate sorting similar to Group III	Subaerial spoil heaps or mounds, subaerial reworked spoil, subaqueous spoil, made land	HIGHLY VARIABLE: USE WITH CAUTION															
Group VIII Transitional wind-tidal flat and stream floodplain, predominantly sand, subject to alternative periods of emergence and submergence, properties similar to Group II	Wind-tidal flat and small, headward-eroding stream	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–
Group IX Clay-sand dune and dune complexes, active and inactive, sparsely and heavily vegetated respectively, see *Environmental Geology Map* to differentiate dunes, mixed sand, silt, and clay with variable properties similar to Group III, older vegetated dune complexes have higher sand and caliche content, currently active dunes high in clay content	Inactive, brush-covered clay-sand dune complex, active, grass-covered clay-sand dune	+	+	+	+	+	0	0	0	+	0	+	0	0	+	0	0
Group XI Active dunes, sand, friable, very high permeability, low water-holding capacity, compressibility, and shrink-swell potential, good drainage, high shear strength, low plasticity, unstable due to migration	Back-island dune, fore-island blowout dune, coppice dune, sandflat	+	+	+	–	–	–	–	0	0	+	–	–	–	–	–	0
Group XII Loess sheet, silt and fine sand, moderate to very high permeability, low to moderate water-holding capacity, low compressibility and shrink-swell potential, good to fair drainage, high shear strength, low plasticity, overlies Pleistocene sand and mud with properties similar to Groups I and III	Loess sheet overlying Pleistocene fluvial deposits	THIN VENEER OVER VARIABLE SUBSTRATE: USE WITH CAUTION															

GROUP X is not present in this area.

soils and substrates, sand soils and substrates, soils and substrates of clayey sands and silts, fresh- to brackish-water coastal marshes, inland fresh-water marshes and wooded swamps, wind-tidal flats and salt marshes with frequent tidal inundation, made land and spoil, land transitional between wind-tidal flat and stream flood-plain, active and inactive clay-sand dune complexes, areas subject to eolian processes actively transporting and depositing sand grains, and areas covered with a thin sheet of windblown silt and fine sand (loess). Statistics for the *Physical Properties Map* are shown on table 5.

All physical properties groups have been derived from basic map units on the *Environmental Geology Map* by applying reasonable assumptions concerning physical properties of the substrates and relative importance of biologic activity (marshes, swamps), active processes (active sand dunes and clay-sand dune complexes), and man-made lands (spoil and made land).

Land units are characterized on map legends and in tables 4 and 5 in a qualitative manner only. Available test data within the Corpus Christi area are too limited in areal distribution to ascribe precise quantitative parameters to all units throughout the area. An initial study of the utilization of available engineering test data for quantitative characterization of resource capability units (now referred to as *land resource units*) in the Corpus Christi area indicates that such units have measurable, distinctive physical parameters (Kier and Bell, 1974; Kier and others, 1974). Though resource capability units (land resource units) are not identical to the physical properties groups on the *Physical Properties Map* (see discussion of resource capability on page 114), these studies suggest that the qualitative description of certain land groups reflects physical differences distinguishable by a suite of engineering tests. However, neither general quantitative data nor qualitative descriptions of these physical properties groups should be substituted for site-specific testing and evaluation. These descriptions can be used to rate large tracts of land for a particular suitability (table 4).

In addition to the major physical land types shown, principal zones of active or potentially active faults are defined. Current waste disposal sites, pits and quarries, and sludge pits are also plotted.

Group I Lands

Materials and lands classed as Group I on the *Physical Properties Map* consist chiefly of fine-grained clay and mud soils and substrates generally forming broad areas of the coastal uplands. Materials represent deposits from overbanking fluvial and deltaic streams and abandoned channels, including mud veneer units developed on Pleistocene meanderbelt sands and marine deltaic, delta-front, and reworked mud-filled coastal lakes and tidal creeks, and mud-filled barrier-strandplain swales. Principal soils developed on these fine-grained substrates include clay soil types of the Victoria and Banquete series, with less extensive development of the silty and sandy Orelia and Clareville series.

Materials classed in this physical group have low permeability. Accordingly, they form secure hosts for several kinds of disposed wastes (table 4) except where relief is depressed and ponding of surface water might occur. However, the very low permeabilities generally preclude satisfactory sites for septic tanks and septic fields. Relief of the lands in this group is low, with slopes chiefly less than 0.4 percent. Materials are poorly drained, with runoff and internal drainage very slow. Due to a fine-grained texture and the high content of plastic, montmorillonitic clay, Group I materials have a high water-holding capacity, high plasticity, very high shrink-swell potential, and high compressibility. These properties limit to varying extents the suitability of these lands for heavy construction, road building, and foundation construction unless artificial stabilization and special engineering are undertaken. Group I lands are the major land type, which includes more than 945 square miles or 40 percent of the Corpus Christi map area. Group I lands are evenly distributed over the area with the exception of the coastal barrier islands, where they are nearly absent.

Group II Lands

Materials of this group are dominantly fine- to medium-grained clean sands. In the Corpus Christi area, these sands form a major part of the Modern barrier islands, including the beach, foredunes, stabilized eolian blowouts, vegetated barrier flats, and washover channels. They compose parts of an ancient (Pleistocene) barrier island and strandplain system that extends from Live Oak Peninsula southward across Live Oak Ridge and Encinal Peninsula. Other occurrences of Group II materials are restricted to subaerial alluvial fans and fan deltas along bay margins and entrenched river-valley walls; bay-margin sands are exposed in several areas, including North Beach, Indian Point, and Demit, Pita, Dagger, Ransom, Hog, and Egery Islands. Sand and shell berms and beach ridges within entrenched Modern-Holocene river valleys are included in this group. Principal soils developed on these sand deposits in the Corpus Christi area are soils of the Mustang series (particularly in areas where sandy soils

Table 5. Areal extent, length, and number of individual environmental units shown on Physical Properties Map, Corpus Christi map area, Texas.† (Table pertains only to that part of each county occurring within the Corpus Christi map area. All values are in square miles unless otherwise indicated by symbol.)

SPECIAL-USE ENVIRONMENTAL MAP UNITS	Aransas County°	Bee County°	Jim Wells County°	Kleberg County°	Nueces County°	Refugio County°	San Patricio County°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Corpus Christi map area (excluding offshore area)	Percentage of Corpus Christi map area covered by map unit (excluding offshore area)
GROUP I Dominantly clay and mud, low permeability, high water-holding capacity, high compressibility, high to very high shrink-swell potential, poor drainage, level to depressed relief, low shear strength, high plasticity. Geologic units include interdistributary muds, barrier-strandplain swales, abandoned channel-fill muds, overbank fluvial muds, mud-filled coastal lakes and tidal creeks	11.5	37.5	0.1	61.7	453.0	103.5	279.2	–	946.5	40.2
GROUP II Dominantly sand, high to very high permeability, low water-holding capacity, low compressibility, low shrink-swell potential, good drainage, low ridge and depressed relief, high shear strength, low plasticity. Geologic units include Modern barrier island sands (beach, foredunes, stabilized eolian blowouts, vegetated barrier flats, washover channels), and Pleistocene barrier-strandplain sands	48.3	0	0	24.9	52.3	0.4	19.5	–	145.4	6.2
GROUP III Dominantly clayey sand and silt, moderate permeability, drainage, and water-holding capacity, low to moderate compressibility and shrink-swell potential, level relief with local mounds and ridges, high shear strength. Geologic units include meanderbelt sands, alluvium, levee, crevasse splay, and distributary sands, and Pleistocene fluvial, distributary, strandplain sheet, and delta-front sands, delta-front facies may be covered by loess	15.2	68.4	0.2	45.6	207.6	126.9	235.3	–	699.2	29.7
GROUP IV Coastal marsh, fresh to brackish, very low permeability, high water-holding capacity, very poor drainage, depressed relief, low shear strength, high plasticity, high organic content, subject to salt-water flooding. Geologic units include fresh to brackish marsh, marsh-filled tidal creeks, and marsh-covered levees	2.3	0	0	0	0.2	1.7	10.0	–	14.2	0.6
GROUP V Inland swamp and marsh, permanently high water table, very low permeability, high water-holding capacity, very poor drainage, very poor load-bearing strength, high organic content, subject to frequent flooding. Geologic units include swamp, fresh-water marsh, marsh-filled abandoned channel and course, ephemeral in Port Bay and Laguna Larga areas, locally thin mud may veneer sand substrate	4.7	0	0	3.4	3.0	5.2	8.2	–	24.5	1.0
GROUP VI Wind-tidal flat and salt marsh, sand with minor amounts of mud and algal mat laminations, subject to frequent tidal and wind-tidal inundation, eolian transport of sand on back side of Modern barrier island, properties on the Modern barrier similar to Group II, and properties on the bay margin similar to Group IV. Geologic units include wind-tidal flat, salt marsh, and washover distributary channel and distal-fan facies	10.6	–	–	1.1	16.8	4.2	8.8	–	41.5	1.8
GROUP VII Made land and spoil, properties highly variable, mixed mud, silt, sand, and shell, reworked spoil commonly sandy and shelly with moderate sorting similar to Group III. Geologic units include subaerial spoil heaps or mounds, subaerial reworked spoil, subaqueous spoil, made land	5.9	0	0	4.8	43.9	0	1.9	0.8	56.5	2.4
GROUP VIII Transitional wind-tidal flat and stream floodplain, brief periods of tidal inundation alternating with longer sustained periods of wind deflation and occasional flooding by stream runoff, properties similar to Group II, essentially an area of wind destruction of eolian sand sheet. Geologic units include wind-tidal flat and small, headward-eroding stream	0	0	0	0.4	0.2	0	0	–	0.6	0.03
GROUP IX Clay-sand dune and dune complexes, active and inactive, sparsely and heavily vegetated respectively, see *Environmental Geology Map* to differentiate dunes, mixed sand, silt, and clay with variable properties similar to Group III, older vegetated dune complexes have higher sand and caliche content, currently active dunes high in clay content. Geologic units include inactive, brush-covered clay-sand dune complex, active, grass-covered clay-sand dune	1.5	0	0	1.9	1.0	0	0.5	–	4.9	0.2
GROUP XI Active dunes, sand, friable, very high permeability, low water-holding capacity, compressibility, and shrink-swell potential, good drainage, high shear strength, low plasticity, unstable due to migration, local relief up to 30 feet. Geologic units include Modern barrier back-island dune field, fore-island blowout dune, coppice dune, and sandflat	1.8	0	0	9.3	3.7	0	0	–	14.8	0.6
GROUP XII Loess sheet, silt and fine sand, thin and locally discontinuous, overlying fluvial sand and mud, locally sandy near underlying Pleistocene channel bodies, loess variable thickness, moderate to very high permeability, low to moderate water-holding capacity, low compressibility and shrink-swell potential, good to fair drainage, high shear strength, low plasticity, shallow water table, flat to hummocky or ridgelike topography, underlying non-eolian sediments resemble Groups I and III, engineering plans should involve consideration of depth of silt and sand and nature of subjacent Pleistocene sediment. Geologic unit is loess sheet overlying Pleistocene fluvial deposits	0	0	1.0	24.3	0.2	0	0	–	25.5	1.1
Pit or quarry, commonly in fluvial deposits■	0	0	0	0	6	0	6	–	12	–
Sludge pit or miscellaneous waste disposal site, may be abandoned■	1	0	0	0	14	0	3	–	18	–
Sewage disposal site, liquid effluent, normally treated■	1	0	0	0	9	1	5	–	16	–
Solid-waste disposal site, sanitary landfills, and open dumps■	2	0	0	0	8	1	10	–	21	–
Active or potentially active fault, based on lineament or grain displayed on aerial photographs, some faults from published sources▲	25.6	62.0	0	48.0	469.2	180.0	276.0	–	1060.8	–

GROUP X is not present in this area.

†Data accuracy approximately 90 to 95 percent; area determined by point-count method and linear values determined by map-measuring wheel.

°Only part of each county lies within map area.

–Data not measured or unit not applicable.

■Number of specific occurrences of map feature.

▲Value is linear distance in miles.

To convert square miles to other units, use the following factors:
- square miles x 2.59 = square kilometers
- square miles x 640 = acres
- square miles x 2.49 = square leagues
- square miles x 3,613,041 = square varas

To convert miles to other units, use the following factors:
- miles x 1.6 = kilometers
- miles x 5,280 = feet
- miles x 1,760 = yards
- miles x 0.33 = leagues (statute)
- miles x 1900.8 = varas (Texas)
- miles x 0.87 = nautical miles

are occasionally flooded), Galveston series, and thin soils on coastal dunes and beach (Franki and others, 1965).

Materials and lands classed in this physical group have high to very high permeabilities. The sands are surrounded, underlain, and contained by tight, impermeable muds, making them discrete, shallow aquifers. Occurrence of ground water and the high permeability of the sands make this group highly unsatisfactory for solid- or liquid-waste disposal (table 4). In addition to direct contamination of the aquifer, wastes are readily transmitted through these permeable materials and may be discharged at the surface at lower elevations. Group II sands have a low water-holding capacity and rapid internal drainage. Due to lack of significant fine-grained and clay-sized sediments, Group II materials have low compressibility, low shrink-swell potential, high shear strength, and low plasticity. Accordingly, from a physical standpoint, areas underlain by these sands provide suitable sites for nearly all kinds of construction; however, surface recharge is local, and extensive construction would seriously limit the amount of ground-water recharge. Approximately 145 square miles, or 6 percent of the total land within the Corpus Christi map area, are included in Group II lands. This is the principal land type of the coastal barrier islands and the Pleistocene barrier-strandplain system.

Group III Lands

Materials of Group III are dominantly clayey sands and silts. In the Corpus Christi area, these occur mainly as narrow, elongate belts situated in the coastal uplands, broad, elongate belts flanking the Nueces, Aransas, and Mission Rivers, and narrow to broad belts parallel to and just inland of older barrier-strandplain deposits. The narrow belts, aligned normal to the coast, represent ancient (Pleistocene) deltaic distributary channel silts and sands; the broad belts flanking the rivers are both older and younger Modern-Holocene meanderbelt sand and silt deposits; and the belts parallel to the north-south mainland coast are mud, silt, and fine sand with local mud veneer developed on reworked delta-front and sheet sand deposits inland from the Pleistocene Ingleside barrier strandplain. Principal soils developed on these lands include the Miguel, Willacy, Clareville, Trinity, Frio, Orelia, and Banquete series.

Earth materials classed in this physical group show permeability that is moderately low but generally sufficient to host septic tanks (table 4). Suitability of sites for solid-waste disposal is generally marginal to poor. Due to the admixture of clays in these sands and silts, water-holding capacity, plasticity, shrink-swell potential, and compressibility are higher than those for the sand materials of Group II but are significantly lower than those of the clay materials of Group I. Accordingly, areas underlain by Group III materials are generally suitable for most kinds of construction. The clayey sands and silts of Group III comprise about 30 percent of the total land area of the Corpus Christi region, covering approximately 700 square miles. With the exception of the coastal barrier islands and Pleistocene barrier strandplain, Group III lands are rather evenly distributed throughout the mapped area.

Group IV Lands

Lands in this physical group include the extensive fresh- to brackish-water coastal marshlands that are most common along the downstream parts of the Nueces River valley, on marsh-covered levees along the Nueces, Aransas, and Mission Rivers, and in marsh-filled tidal creeks; they are contiguous to the more seaward salt marshes. Suitability of Group IV lands for physical use is seriously limited by very low relief, very poor drainage, susceptibility to flooding, and a permanently high water table. These lands are subject to inundation during very high tides or storms; accordingly, the marshes range from fresh to intermittently brackish. The soils and substrates underlying these wetlands are highly organic; generally they are not sufficiently stable for construction (table 4). Although permeabilities are very low, the permanently high water table precludes suitability for solid- or liquid-waste disposal. Fresh to brackish marshlands are a significant part of the coastal ecosystem, serving as environments of high organic productivity. As a natural unit, they have little suitability for most direct physical uses. Reclamation or filling is necessary for most direct physical uses, but this activity destroys the marshland permanently. Fresh to brackish wetlands cover approximately 9 square miles in the Corpus Christi map area, representing less than 1 percent of the total mapped land area.

Group V Lands

Lands included in this group are fresh-water marshes and swamps that are not subjected to salt-water flooding except during high hurricane-surge floods. The fresh-water marshes and swamps are most extensively developed just inland from the wetlands of Group IV, along the valleys of the major rivers—Nueces, Aransas, and Mission. In addition, Group V lands occur in abandoned channels and courses and in areas near Port Bay and Laguna Larga during times of extensive fresh-water flooding and ponding. Their existence in these latter areas is ephemeral as they are reduced or eliminated during extended dry periods. From the standpoint of physical use, fresh-water marshes and swamps are comparable to the fresh- to brackish-water marshlands (table 4), the principal distinction being that the former are rarely subjected to salt-water inundation. In addition, swamps differ from marshes in that they support tree rather than grass vegetation.

Lands classed in Group V are subject to fresh-water flooding, have a permanently high water table that essentially intersects the ground surface, and have depressed relief. Permeability is very low, and internal drainage very slow; water-holding capacity is high, and load-bearing strength is very poor. Like Group IV lands, they are poor sites for waste disposal and can be utilized for most development only after filling and reclamation. Group V lands occupy about 25 square miles of land area on the Corpus Christi map, making up about 1 percent of the total mapped land area. Swamps are not common in the Corpus Christi area and cover only 1.5 miles within entrenched channels of the Modern-Holocene Nueces River valley.

Group VI Lands

Lands classed in this group include wind-tidal flats and salt marshes, both developed along the coastlines of the bays and estuaries and both subject to periodic inundation by salt water. Principal development of salt-water marshlands is along the lowlands on downstream portions of Mission and Aransas Rivers, along low areas marginal to Port Bay, along the Harbor Island area, and along the slowly compacting distal portions of the abandoned Nueces River delta. General increase in aridity to the south across the map area is reflected in the restriction of salt-water marshland development. Generally less vegetated wind-tidal flats become increasingly more common to the south, and, in the Corpus Christi area, are extensively developed on the back sides of the Modern barrier islands.

Physical properties of the salt marshlands are similar to those of the wetlands of Groups IV and V, except that salt marshlands are regularly inundated by salt water and are, consequently, subject to a greater impact by wave activity. Permanently high water tables preclude suitability for waste disposal (table 4), and construction requires land reclamation and filling, a practice that permanently destroys the marshlands. Wind-tidal flats are extensively developed along the back side of Mustang Island and locally on the bayside of St. Joseph and Padre Islands. In addition, wind-tidal flats occur along Oso Creek at the head of Oso Bay and on low, inland portions of the Nueces, Aransas, and Mission deltas and Mullens Bayou, along the mainland shoreline, and in the Harbor Island area.

Most of the local tidal flats are barren sandflats that support little or no vegetation, with the exception of blue-green algae. Lack of stabilization precludes most types of physical use. Salt marshes and wind-tidal flats cover about 42 square miles of the lowest coastal lands, representing about 2 percent of the Corpus Christi map area.

Group VII Lands

Lands composing this physical group include subaerial spoil heaps or mounds, subaerial reworked spoil, subaqueous spoil, and made land. Principal occurrence of subaerial dredged spoil banks is along the artificially constructed Intracoastal Waterway, Corpus Christi Ship Channel, and La Quinta Channel. Extensive areas of subaqueous spoil occur along these same channels and in the middle of Corpus Christi Bay, as well as north of the Corpus Christi industrial area in Nueces Bay. Areas of made land include part of Harbor Island, the Port Aransas Causeway, Frandolig Island, Corpus Christi Naval Air Station, Indian Point, the area west of Packery Channel, and principally, the industrial corridor on the south shore of Nueces Bay along Tule Lake-Viola-Corpus Christi Ship Channel.

Physical properties of spoil and made land are highly variable, dictated in part by the natural material dredged or utilized (table 4). Excavation generally leaves materials less compact than in their original state and increases permeability. Most spoil areas are unvegetated and subject to erosion and reworking. Their utilization should be approached with caution and with adequate site testing. These lands occupy 57 square miles or 2 percent of the map area.

Group VIII Lands

Lands included in this group occur as narrow strips along three small streams in the mapped area, including Oso and Petronila Creeks. Occurring just upstream from areas subject to wind-tidal flooding, these lands are transitional between the stream floodplain (occasional fresh-water flooding) and wind-tidal flats (periodic flooding by saline waters). Following the relatively brief periods of tidal flooding and infrequent occasions of fresh-water flooding, these lands are subject to eolian processes which actively deflate the dry land surface.

Physical properties of these sandy lands are similar to Group II: high permeability, low water-holding capacity, low shrink-swell potential, low plasticity, and high shear strength. Constraints on land use arise from the occasional flooding of the surface by stream waters or saline bay waters which alternates with longer periods of wind deflation. Such episodic flooding precludes most land use by man, such as construction; sparse vegetation limits utility as rangeland. Soils along the tidal flats are principally Lomalta clay and saline, gullied land soil types. Only 0.6 square mile, or less than 0.1 percent of the land area is included in Group VIII.

Group IX Lands

Materials of Group IX are dominantly a mixture of fine sand, silt, and clay with physical properties similar to Group III lands. Group IX lands represent both active and inactive clay-sand dunes formed leeward of wind-deflated flats where eolian processes actively transport and deposit sand-sized fragments of clayey materials formed from the desiccated surfaces of these occasionally flooded lowlands. Inactive clay-sand dune complexes are stabilized by extensive grass and shrub vegetation and are partially calichified. Active clay-sand dune complexes are predominantly clay with very limited vegetative development.

Group IX lands are limited to the land surface; substrate physical properties may vary greatly. Use of these lands is limited because of exposure to active eolian processes and hummocky topography. Inactive clay-sand dune complexes are generally used as rangeland; active complexes are unsuitable for most uses. Point Isabel clay and saline, gullied land soil types are most common on these lands. Group IX lands comprise about 0.2 percent or 5 square miles of the mapped area of the Corpus Christi Atlas.

Group XI Lands

Lands classed in this group include areas of sand dunes having unstable, migrating surfaces influenced principally by onshore winds. These active dune complexes occur as fore-island blowout dunes, coppice dunes, and sandflats on Padre Island, Mustang Island, and the southern end of St. Joseph Island. Extensive dune sheets on the back side of the coastal barriers occur mainly on Padre Island, as well as on southern Mustang Island. High permeability and low water-holding capacity make these lands unsuitable for waste disposal of any kind. Instability due to active migration renders such lands unsuitable for road and foundation construction without special engineering precautions and poses potential problems for any pipes, cables, or other installations buried beneath their surface. Ease of excavation and high shear strength are physical properties favoring use of these lands as a source of fill material. Group XI lands comprise 0.6 percent of the Corpus Christi map area, totaling about 15 square miles.

Group XII Lands

Fine sand and silt form a thin (few inches to several feet) loess sheet over about 25 square miles or about 1 percent of the map area. Group XII lands on the Corpus Christi map represent a northerly extension of the vast Riviera loess sheet developed in the Kingsville area. Physical properties of these eolian deposits include moderate to very high permeability, low to moderate water-holding capacity, low compressibility, high shear strength, and low plasticity and shrink-swell potential. These flat to hummocky or ridgelike lands have good to fair drainage and may have a shallow water table. Generally these lands are not suitable for waste disposal but are satisfactory for most kinds of construction; however, the thinness of these deposits dictates that the variable physical properties of underlying Pleistocene fluvial units (meanderbelt sands and floodplain silts and muds) must be considered and evaluated before utilization. Presently, these lands support grazing. Sandy loam soils of the Delfina and Nueces series are developed on the loess deposits.

Land-Surface Subsidence

Land-surface subsidence is a natural hazard that plagues certain portions of the Texas Coastal Zone (Brown and others, 1974). The most serious and permanent effects of subsidence are the loss of land elevation and an actual loss of land to Gulf or bay encroachment in the low-relief coastal areas. Loss of elevation increases substantially the amount of coastal area subject to flooding from hurricane surge. In addition to land and elevation loss, subsidence also may cause changes in the land slope, thus affecting surface-water drainage patterns and stream gradients.

Land-surface subsidence is caused by withdrawal of subsurface fluids from pore spaces of the unconsolidated sediments that underlie the Texas Coastal Zone. Fluid withdrawal, resulting from ground water, oil, or gas production, increases the relative weight of the overlying rocks and causes dewatering and compaction of muddy sediments, which may result in land-surface subsidence.

Releveling of survey lines in the Corpus Christi area by the National Geodetic Survey indicates that land-surface subsidence in excess of 0.2 foot occurred over an area of approximately 150 square miles between 1942 and 1951. This region extends from the City of Corpus Christi across the Nueces River delta into San Patricio County (fig. 26) and includes the low-lying lands along the Nueces River and the industrial corridor of the Port of Corpus Christi. A subcircular area near Clarkwood and McNorten (fig. 26) subsided over 1 foot between the years 1942 and 1951. Within the Clarkwood-McNorten area, re-leveling of some survey lines in 1959 indicates subsidence of 3 feet since 1942 over the area of the Saxet oil and gas field (C. W. Kreitler, personal communication, 1976). Total subsidence over the Saxet field is approximately 6 feet.

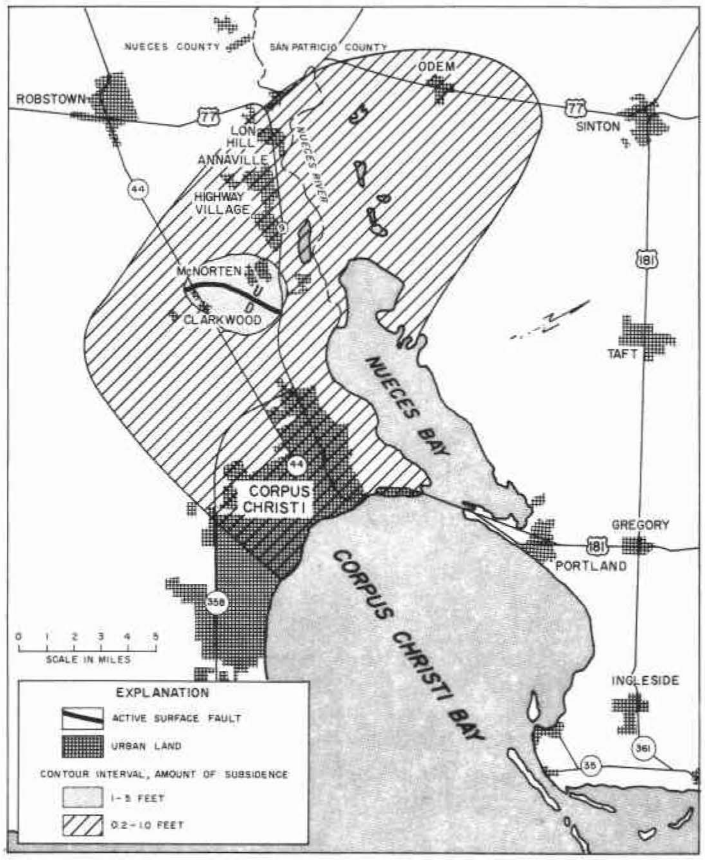


Figure 26. Land-surface subsidence in the Corpus Christi area (1942-1951). Level data from National Oceanic and Atmospheric Administration. After Brown and others (1974). Subsidence probably caused by oil and gas production.

Subsidence in the Corpus Christi area is largely the result of oil and gas withdrawal in the Saxet field. Data presented by Gustavson and Kreitler (1976), indicate that most of this subsidence is the result of shallow gas production from less than 5,000 feet deep.

The upper Coastal Zone of Texas is subject to significant land-surface subsidence because of extensive ground-water withdrawal. Ground-water withdrawal will probably not contribute to land subsidence in the Corpus Christi area for at least three reasons: (1) surface water currently supplies most of the water needs of the Corpus Christi area; (2) withdrawal of ground water significantly above the current volume probably will be limited to aquifers present in Refugio County; (3) aquifers in the Corpus Christi area are not analogous to aquifers in the upper Coastal Zone because those in the Corpus Christi area are deeper and contain a larger proportion of sand to mud. Future production of geothermal waters in the Corpus Christi map area could initiate some land-surface subsidence or faulting. Geothermal water is another interstitial fluid that may be withdrawn from deeply buried reservoirs underlying the Texas Coastal Zone (Gustavson and Kreitler, 1976).

Surface Faulting and Lineations

Another natural hazard in the Texas Coastal Zone is surface faulting. Surface faulting is most common in the Houston area where severe land-surface subsidence occurs as a result of ground-water withdrawal (Kreitler, 1976). In the Corpus Christi area, an active fault with a surface displacement of 6 feet occurs over the Saxet oil and gas field in the Clarkwood-McNorten area. This surface fault coincides with the surface extrapolation of a major subsurface fault that serves as a trap for the Saxet oil and gas reservoirs (Gustavson and Kreitler, 1976). Fault movement at the surface has occurred since the beginning of oil and gas production. Prominent topographic escarpments in Bee County (Burkes Ridge) have also been interpreted as evidence of recent surface faulting (Price, 1933).

Approximately 1,060 miles of aerial photographic lineations were mapped within a land area of 1,960 square miles in the Corpus Christi map area (*Physical Properties Map*). These lineations were identified on the basis of linear tonal variations on black-and-white photomosaics (scale 1:24,000). Such variations generally reflect linear anomalies involving straight segments and right-angle bends in such natural patterns as drainage, vegetation, and geologic facies, as well as topographic escarpments. Similar photographic lineations mapped in the upper Coastal Zone have been shown by Kreitler (1976) to coincide with portions of active surface faults and the traces of subsurface faults that are extrapolated to the land surface. The surface fault in the Clarkwood-McNorten area near Corpus Christi is an active segment of the subsurface fault controlling oil and gas production from the Saxet field (Poole, 1940; Gustavson and Kreitler, 1976).

The strong parallelism in the trend of surface and subsurface faults indicates that most surface faults are the surface expression of segments of numerous long-trending coastwise faults extending upward from several thousands of feet below the surface. This association of surface and subsurface faults suggests that the surface features are natural geologic structural elements having a long geologic history. Though such faults are natural geologic elements that existed long before man, some evidence indicates certain of man's activities have increased the frequency of surface fault movement. These activities include extensive subsurface fluid withdrawal that results in land-surface subsidence; differential subsidence on either side of a fault may activate fault movement.

Lineations shown on the *Physical Properties Map* of the Corpus Christi Atlas represent active and potentially active faults; most of these faults are currently inactive. However, if land-surface subsidence should become severe enough to activate fault movement as it has in the upper Coastal Zone (Kreitler, 1976), the lineations represent zones along which surface faulting may be expected to occur. Surface faults, either active or inactive, need cause no real hazard provided they are recognized. Future construction of buildings, power plants, highways, and pipelines should either be planned to avoid active or potentially active faults or be engineered to accommodate potential movement and displacement.

Waste Disposal

A significant activity in the heavily populated and industrial area of the Texas Coastal Zone is waste disposal. Certain wastes are treated and discharged directly into water bodies, other wastes are incinerated, and a large volume of both solid and liquid wastes is disposed of on or beneath its surface. Ultimately, recycling of waste materials will reduce the waste load, but because of the present level of technology and the costs of the recycling processes, full-scale recycling is generally precluded. Where wastes are disposed of on or beneath the land, physical properties of soils and underlying geologic substrate units should be considered thoroughly. The principal types of waste disposal in the Corpus Christi map area include placement of solid wastes in dumps or landfills (fig. 27), retention of liquid industrial wastes in surface pits or lagoons, and disposal of human wastes through septic fields.

Requirements for safe disposal of solid and liquid wastes differ. Solid wastes generally require confinement to avoid leakage of leachate into nearby surface- or ground-water supplies until normal chemical and bacterial processes can mollify harmful materials. Solid-waste disposal should occur in sites composed of impermeable materials such as clay soils and substrates. Surface topography and the depth to the water table must be adequate to allow proper drainage of the disposal site in order to avoid direct contamination of ground water and surface ponding of contaminated water. Solid-waste disposal in the Coastal Zone has been considered in more detail by Brown and others (1972).

Liquid-waste disposal requires placement in materials capable of rendering the liquid effluent harmless. Such modification includes dilution of harmful constituents, chemical transformation into harmless forms, and physical deposition or containment. In the Coastal Zone, disposal of liquid wastes generally occurs by direct subsurface disposal, by dumping wastes offshore, and in septic tank systems. Septic tank systems require placement in moderately permeable materials which allow some movement of effluent through the soil and substrate so that chemical reaction with surrounding sediment can render the waste harmless. Sediment composed of mixtures of fine sand, silt, and clay allows for the necessary moderate transmission of liquid waste and, in addition, contains substances capable of reacting with and transforming the waste products.

Properties that must be considered in land disposal of solid and liquid wastes include: (1) the nature of the substrate and overlying soil—permeability and solution-holding capacity, reactivity of host and cover materials, excavation characteristics, and thickness of specific host units; (2) the hydrologic character of the locale—depth to water table, seasonal variations in water table, transmissibility, and direction of subsurface flow; and (3) the nature of the land surface or terrain—slope, topography, and surface drainage. These characteristics have been considered in the preparation of the *Physical Properties Map* of this Atlas. The eleven basic land types discussed previously may be grouped into four main solid-waste suitability groups (fig. 27).

From a physical standpoint (table 4), lands mapped as Group I on the *Physical Properties Map* provide good and generally secure hosts for solid-waste disposal; lands graded as Group III constitute hosts of only marginal suitability that should be carefully tested and monitored if utilized. Lands classed as Groups II, VIII, and XI have high permeabilities and very little capacity to hold disposed solid wastes securely. Wetlands of Groups IV, V, and VI have permanently high water tables and are thus undesirable sites for solid-waste disposal. Made land and spoil of Group VII

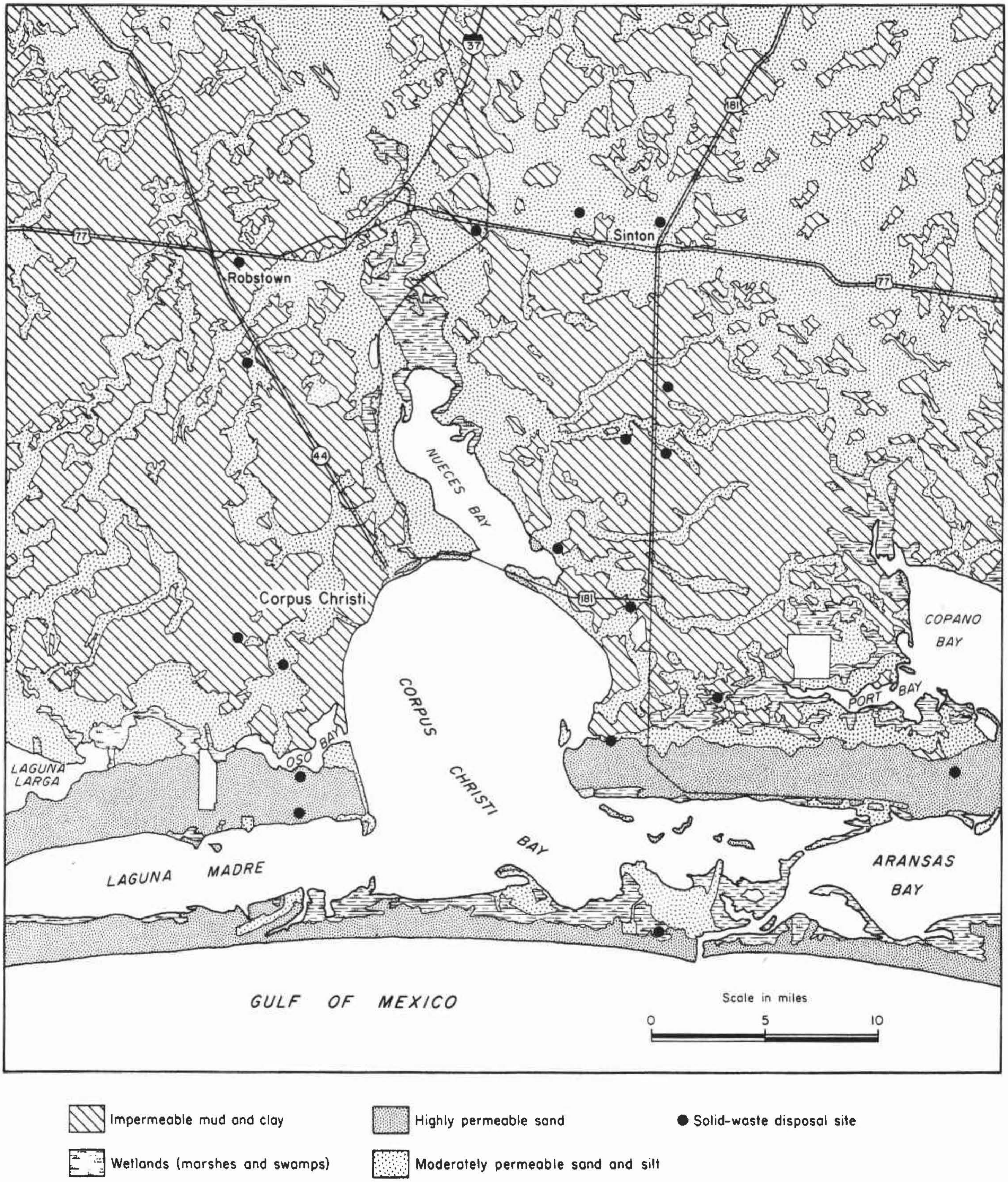


Figure 27. Distribution of solid-waste disposal sites in various substrate units in the Corpus Christi map area. Eighteen of the 21 sites in the Corpus Christi map area occur within the area of this illustration. Location of disposal sites, courtesy Texas Health Department.

have highly variable physical properties and must be utilized only after thorough testing and evaluating. Groups IX and XII represent only a thin veneer of clay, silt, and sand (Group IX) or loess (Group XII) over substrate of varying physical properties; thorough site evaluation should precede use for waste disposal. Site-specific studies should be undertaken to verify the suitability of each current and proposed disposal site.

Group I materials, chiefly mud and clay soils and substrates, provide secure sites for solid-waste disposal and will eliminate most problems of leachate contamination of surface and ground waters. Excavated clays provide excellent backfill or impermeable cover for disposed wastes. A principal limitation of lands in this group is their normally flat to depressed relief. Proper siting and grading can reduce ponding over filled areas. The high plasticity of these materials may produce some difficulty in excavation and dozing operations. For most of the lands of Group I, permeability is probably too low to allow for adequate percolation of liquid wastes such as those released by septic tank systems.

Lands classed under Groups II, VIII, and XI are among the least suitable for solid- and liquid-waste disposal in the area because of high to very high substrate and soil permeability. These sand bodies constitute shallow aquifers that are commonly perched on impermeable muds. Liquid wastes and leachate from solid wastes may be transmitted to the ground-water system or may drain downslope into surface drainage systems. Sites in these groups should be carefully monitored. A number of abandoned sand pits exist on lands of this type and are commonly used for waste disposal in many areas of the Texas Coastal Zone. Such abandoned pits preclude the expense of excavation; sandy backfill is available and easily bulldozed, and real-estate and aesthetic values of such areas are normally low compared to many other potential sites. The economic advantages of these sites, however, should be weighed carefully against a very poor natural suitability for waste disposal. Maintenance of acceptable environmental quality will depend upon site selections based on scientific rather than economic factors. If inadequate sites are utilized, they will require expensive engineering to insure against pollution.

Lands classed as Group III on the *Physical Properties Map* consist of clayey sand and silty soils and substrates. They are normally less permeable than sands of Groups II, VIII, and XI but more permeable than clays of Group I. Group III lands are generally suitable for liquid-waste disposal such as septic tank systems; moderate permeability and reactive materials allow for modification of effluent over short lateral distances. However, Group III lands are only marginally suitable for solid-waste disposal. Careful testing, monitoring, and maintenance are necessary to properly locate solid- and liquid-waste disposal sites in these lands.

Wetlands of the Corpus Christi area (Groups IV, V, VI), including fresh- to brackish-water coastal marshes, salt marshes and wind-tidal flats, and inland fresh-water marshes and swamps, make poor sites for waste disposal because of permanently high water tables and frequent flooding.

Groups IX and XII include lands with physical properties distinctive to only very shallow depths below the land surface. Group XII lands consist of a thin (few inches to a few feet) veneer of silt; disposal sites in these lands may intersect highly variable substrates. Group IX lands have physical properties generally favorable for disposal sites, but are rarely more than a few to several feet thick; liquid wastes or effluent from solid wastes are likely to enter substrates with highly variable physical properties. Use of these lands for solid- or liquid-waste disposal requires consideration of the physical characteristics of underlying sediments; careful testing and evaluation should precede any plans to locate disposal sites in Groups IX and XII lands.

Within the mapped portion of the Corpus Christi area, approximately 21 solid-waste disposal sites, including sanitary landfills and open dumps, are currently in operation. These sites are plotted on the *Physical Properties Map* of this Atlas; location of most of the sites is from a 1968 survey by the Texas State Health Department. Of the currently operated solid-waste disposal sites, approximately one-third are within host materials that are physically secure. About 30 percent of the sites are located in lands constituting very poor hosts, principally permeable sands of Live Oak Peninsula, Live Oak Ridge, Encinal Peninsula, and Mustang Island. The remaining sites, composing more than one-third of the total, are located in lands classed as marginal for waste disposal; several of these sites may be secure while others may constitute a source of ground- and surface-water pollution. No adequate studies have been conducted in the area to determine, in quantitative terms, the extent of water pollution from waste disposal sites in insecure or marginal hosts, but techniques for such monitoring are well known and should be applied in the Texas Coastal Zone. Other sites exist for sewage disposal and for miscellaneous waste disposal facilities such as sludge pits.

Within the mapped portion of the Corpus Christi area, approximately 40 percent of the total land area provides adequate and secure hosts for solid-waste disposal. About 30 percent of the area is classed as marginal from a physical standpoint, and the remaining 10 percent constitutes poor disposal potential because of a high water table and excessively high soil and substrate permeability. One-fifth of the total land area is characterized by lands which are thin and cover substrates with highly variable physical characteristics. Geographic distribution of secure hosts is extensive for the Corpus Christi area and most of the other population centers. For Port Aransas, most nearby and readily available lands are poor natural hosts for disposed waste. Lands beneath the Corpus Christi Naval Air Station and surrounding areas are poor natural hosts for waste disposal.

It should be emphasized that a considerable part of the secure and favorable lands for waste disposal are also agricultural lands of higher economic value. On the other hand, the poor host lands for waste disposal are economically attractive. Thus, economic factors and potential pollution are involved in selection of waste disposal sites in the area. In the long term, proper siting may far outweigh short-term economic gain.

The *Physical Properties Map* provides the basis for a rapid, regional evaluation of waste disposal suitability. Specific studies should now be undertaken in the Coastal Zone.

Comparative Uses of Physical Properties Map

The *Physical Properties Map* of this Atlas is designed for evaluating properties of land units for a variety of physical uses. When additional specific information is needed, various features shown on the map can be overlain or compared with features displayed on other maps of the Atlas. For example, the pipeline network of the area can be compared with the distribution of active or potentially active faults to identify areas where surveillance may be necessary. A comparison of bay-line erosion or deposition displayed on the *Active Processes Map* with physical substrate types indicates that shorelines cut into mud and clay substrates are more stable than those cut into sandy substrates. The *Topography and Bathymetry Map* can be used in conjunction with the *Physical Properties Map* for the terrain analysis important in landfill siting or construction. The variety of comparisons and complementary uses of the various maps in the Atlas is determined by the types of specific information desired by different users.

ENVIRONMENTS AND BIOLOGIC ASSEMBLAGES MAP

The *Environments and Biologic Assemblages Map* depicts the distribution of major biologic communities and the environments they inhabit in the Corpus Christi map area. These include: (1) subaqueous environments and assemblages of the bays, estuaries, tidal passes, shoreface, and open shelf, defined primarily by assemblages of fixed or mobile benthonic (bottom-dwelling) organisms, which are chiefly faunal (though locally important subaqueous floral assemblages such as marginal grassflats are included); and (2) subaerial environments and assemblages, defined primarily by land vegetation. A number of the biologic assemblages are of first-order environmental significance and, accordingly, appear as specific map units on the basic *Environmental Geology Map*. These include such units as reefs, the various wetland environments, and much of the Modern grass-covered barrier island and associated units. Other natural environments have been derived from the basic *Environmental Geology Map* by utilizing previously known and compiled information on animal and plant distribution in the Texas Coastal Zone (fig. 2). Several environmental geologic units are embraced by single biologic assemblages; for example, Pleistocene meanderbelt sands support extensive stands of oak and brush, as well as prairie grasses; oak and brush are characteristic of this particular environmental geologic unit. Also, Pleistocene distributary channel sands and interdistributary muds originally supported extensive coastal prairie grasslands, but much of this assemblage and natural environment has been modified and converted into agricultural lands (compare with *Current Land Use Map*).

The *Environments and Biologic Assemblages Map* is not intended to be a biologic assay of the area but rather to show areal distribution of the type and number of major environments defined by dominant biologic assemblages (table 6). In short, it outlines the natural condition of the Coastal Zone. Comparison with current land use readily shows the extent of man's modification of the natural biologic environment. The area covered by each of 36 environments and assemblages is noted on table 7.

Subaqueous and subaerial biologic assemblages in this portion of the Texas Coastal Zone (table 6) are compiled from several sources, including Andrews (1970), Hoover (1968), Gould (1962), Parker (1959, 1960), Simmons (1957), Ladd (1951), Siler and Scott (1964), Fruh and others (1973), Andrews (1971), Huffman and Price (1949), and Oppenheimer and Isensee (1973).

Table 6. Common macro-biologic assemblages within Texas coastal environments, Corpus Christi map area, Texas.*

SUBAQUEOUS, PRINCIPALLY BENTHONIC ASSEMBLAGES

SHELF (INNER) AND LOWER SHOREFACE:
Atrina, Arca, Dosinia, Dinocardium, Spisula, Tellina (clams); *Anachis, Nassarius, Oliva, Busycon, Terebra* (snails); *Callianassa* (mud shrimp); *Mellita* (sand dollar); *Luidia* (starfish); various crabs

UPPER SHOREFACE:
Donax, Spisula, Tellina, Labiosa (clams); *Architectonica, Oliva, Phalium, Sinum, Neosimnia, Busycon, Olivella, Terebra* (snails); *Mellita* (sand dollar); *Astropecten, Luidia* (starfish); various crabs

INLET AND TIDAL DELTA:
Inlet includes *Atrina, Anadara, Lucina, Aequipecten, Dosinia, Tagelus, Trachycardium, Abra, Pandora, Tellidora, Crassinella* (clams); *Ostrea* (oyster); *Cantharus, Thais, Anachis, Epitonium, Busycon, Polinices* (snails); *Dentalium* (scaphopod); *Astrangia* (coral); *Mellita* (sand dollar); *Astropecten, Luidia* (starfish); *Ophiothrix* (brittle star); bryozoans, crustaceans, and clionid sponges; tidal delta region includes marine grasses and fauna similar to grassflats

BAY AND LAGOON MARGIN:
Ensis, Macoma, Mercenaria, Chione, Tagelus, Aequipecten, Anomalocardia (clams); *Cerithium, Bittium* (snails); sparse marine grasses, such as *Diplanthera (Halodule) wrightii* and *Thalassia testudinum*

GRASSFLATS:
Marine grasses common, including *Diplanthera (Halodule) wrightii, Ruppia maritima, Thalassia testudinum, Syringodium filiforme, Halophila engelmanni; Phacoides, Laevicardium, Tellina, Mercenaria, Anomalocardia, Amygdalum* (clams); *Coecum, Cerithium, Cerithidea, Vermicularia, Bittium, Melampus* (snails); hypersaline grassflats characterized by lower density of marine grasses and lower diversity of invertebrate fauna (*Anomalocardia* and *Cerithium* are dominant molluscs)

OPEN BAY:
Abra, Anadara, Diplodonta, Corbula, Nuculana, Mulinia, Periploma, Pandora (clams); *Nassarius, Retusa, Neritina, Polinices, Cantharus* (snails)

ENCLOSED HYPERSALINE BAY OR LAGOON CENTER:
Anomalocardia, Mulinia, Tellina (clams); *Cerithium* (snail)

ENCLOSED BAY WITH REEF:
Nuculana, Mulinia, Tagelus, Ensis (clams); *Retusa* (snail); *Amphiodia* (brittle star); reef-associated organisms (see reef)

REEF:
Crasssostrea virginica, Ostrea equestris (oysters); *Brachidontes recurvus* (clam) and *Crepidula* (snail) common with *Crassostrea* (distributed in lower salinity areas); *Brachidontes exustus, Anomia* (clams) and *Anachis, Mitrella, Thais* (snails) common with *Ostrea* (distributed in higher salinity areas); *Balanus* (barnacle); bryozoans, clionid sponges; *Crangon, Menippe* (crustaceans)

REEF FLANK AND MARGIN:
Clumps of *Crassostrea, Ostrea* (oysters) with broken shell and reef debris

ENCLOSED BAY:
Nuculana, Mulinia, Trachycardium (clams); *Retusa* (snail)

RIVER-INFLUENCED BAY:
Rangia, Macoma, Mulinia (clams); *Littoridina* (snail); *Callinectes* (blue crab); *Macrobrachium* (river shrimp)

SUBAQUEOUS AND SUBAERIAL SPOIL:
Variable assemblages

FRESH- TO BRACKISH-WATER BODIES:
Fresh- to brackish-water marsh plants; *Littorina, Neritina* (snails); *Uca* (fiddler crab); *Cambarus* (crustacean)

SUBAERIAL, PRINCIPALLY FLORAL ASSEMBLAGES

BEACH:
Donax (clam); *Olivella, Terebra* (snails); *Ocypode* (ghost crab); *Uniola paniculata* (sea-oats); halophytes

VEGETATED BARRIER FLAT, FOREDUNE RIDGE, AND STABILIZED BLOWOUTS:
Paspalum monastachyum (Gulf-dune paspalum), *Andropogon scoparius littoralis* (seacoast bluestem), *Uniola paniculata* (sea-oats), *Spartina spartinae* (coastal sacahuista), *Prosopis glandulosa* (mesquite), *Celtis* spp. (hackberry), *Zanthoxylum* spp. (pricklyash), *Monanthochloe littoralis* (shoregrass), *Salicornia perennis* (glasswort), *Chenopodium* sp. (goosefoot), *Ipomoea* spp. (morningglory), *Croton punctatus* (beach tea), *Helianthus annus* (sunflower), *Panicum amarum* (bitter panicum); local fresh-water marsh (see description below); *Ocypode* (ghost crab), kangaroo rats, other small rodents, snakes, fowl

WASHOVER CHANNEL AND FAN:
Mostly barren; scattered mats of blue-green algae; scattered stand of *Spartina alterniflora* (cordgrass), *Salicornia perennis* and *S. bigelovii* (glasswort), and *Batis maritima* (saltwort)

ACTIVE DUNES:
Largely barren; occasional scattered salt-tolerant grasses

SANDFLATS:
Mats of blue-green algae; *Spartina alterniflora* (cordgrass)

ACTIVE CLAY-SAND DUNES:
Spartina spartinae (coastal sacahuista), *Leersia virginica* (whitegrass), *Buchloe dactyloides* (buffalograss), *Prosopis glandulosa* (mesquite), *Opuntia* spp. (pricklypear), *Yucca torreyi* (Spanish dagger); chaparral; snakes

BERMS ASSOCIATED WITH BAY-LAGOON MARGINS:
Batis maritima (saltwort), *Salicornia perennis* (glasswort), *Monanthochloe littoralis* (shoregrass), *Spartina spartinae* (coastal sacahuista), *S. alterniflora* (cordgrass), *Avicennia nitida* (black mangrove), *Prosopis glandulosa* (mesquite), *Tamarix gallica* (saltcedar); snakes, fowl

SALT-WATER MARSH:
Spartina alterniflora (cordgrass), *Salicornia perennis* (glasswort), *S. bigelovii* (glasswort), *Distichlis spicata* (saltgrass), *Sesuvium portulacastrum* (sea purslane), *Batis maritima* (saltwort), *Avicennia nitida* (black mangrove), *Suaeda* spp. (seepweed), *Borrichia* spp. (sea-oxeye); *Uca* spp. (fiddler crab), *Littorina irrorata, Melampus bidentatus* (snails); waterfowl, raccoon, other small mammals

BRACKISH- TO FRESH-WATER MARSH:
Spartina spartinae (coastal sacahuista), *S. patens* (marshhay cordgrass), *S. cynosuroides* (big cordgrass), *Scirpus* spp. (bulrush), *Juncus* spp. (rush), *Typha* spp. (cattail); mammals, snakes, waterfowl

INLAND FRESH-WATER MARSH:
Spartina spartinae (coastal sacahuista), *Andropogon scoparius littoralis* (seacoast bluestem), *Elyonurus tripsacoides* (balsamgrass), *Paspalum plicatulum* (plaited *Paspalum*), *P. monostachyum* (singlespike *Paspalum*), *Buchloe dactyloides* (buffalograss), *Sorghastrum nutans* (Indiangrass), *Acacia farnesiana* (huisache); some areas with thicker stands of chaparral, *Prosopis glandulosa* (mesquite), *Celtis* spp. (hackberry), *Quercus* spp. (oak)

PRAIRIE GRASSLANDS:
Angropogon spp. (bluestem), *Sorghastrum nutans* (Indiangrass), chaparral, *Prosopis glandulosa* (mesquite), *Celtis* spp. (hackberry), *Acacia farnesiana* (huisache), *Opuntia* spp. (pricklypear); small mammals, fowl; some areas have dense brush and oaks (*Quercus virginiana*)

SWAMP:
Sabal minor (dwarf palmetto), *Ulmus* spp. (elm), *Morus* spp. (mulberry), *Quercus nigra* (water oak), *Ilex vomitoria* (yaupon), *Vitis* spp. (grape); raccoon, opossum, some mink, squirrel, snakes, fowl

FREQUENTLY FLOODED FLUVIAL AREAS:
Juncus spp. (rush), *Typha* spp. (cattail), *Salix* spp. (willow), *Phragmites communis* (common reed); various mammals and fowl similar to swamp; in many areas to south, assemblage is transitional with that of poorly drained depressions (occasionally flooded)

FLUVIAL WOODLAND:
Carya illinoensis (pecan), *Carya* spp. (hickory), *Quercus virginiana* (live oak), *Q. nigra* (water oak), *Q. marilandica* (blackjack oak), *Ulmus* spp. (elm), *Celtis* spp. (hackberry), *Crataegus viburnifolia* (red haw), *Fraxinus* spp. (ash), *Axonopus* spp. (carpetgrass), *Cynodon dactylon* (Bermudagrass), *Smilax* spp. (greenbriar), *Ilex vomitoria* (yaupon), *Vitis* spp. (grape); squirrel, fox, raccoon, opossum, other small mammals and rodents, snakes, fowl

FLUVIAL GRASSLAND:
Andropogon spp. (bluestem), *Spartina spartinae* (coastal sacahuista), *Prosopis glandulosa* (mesquite), *Acacia greggii* (catclaw); rabbits, opossum, skunk, fox, quail, other fowl and small mammals, snakes

OAK MOTTES AND GROVES:
Quercus virginiana (live oak); small rodents, snakes

POORLY DRAINED DEPRESSIONS:
Prairie grasses, such as *Andropogon* spp. (bluestem), *Buchloe dactyloides* (buffalograss), *Paspalum* spp. and water-tolerant plants, such as *Spartina pectinata* (sloughgrass) and *Juncus* spp. (rush); distribution and growth tied to seasonal, wet periods; transitional to north with frequently flooded fluvial areas

LOOSE SAND AND LOESS PRAIRIES:
Quercus virginiana (live oak); occasional areas of fresh-water marsh (see description above); bunch grasses, such as *Sporobolus* spp. and *Andropogon* spp.; small rodents, mammals, snakes, fowl

BRUSHLAND:
Prosopis glandulosa (mesquite), chaparral, *Opuntia* spp. (pricklypear), *Yucca torreyi* (Spanish dagger), *Buchloe dactyloides* (buffalograss), *Leersia virginica* (whitegrass), *Spartina spartinae* (coastal sacahuista), *Muhlenbergia porteri* (mesquitegrass), *Spergularia* spp. (sandspurry), *Cynodon dactylon* (Bermudagrass); wild game (deer, turkey, quail), fowl

BARREN LAND:
No significant vegetation or wildlife

MADE LAND:
Variable assemblages

*This table supplements legend description on the *Environments and Biologic Assemblages Map*. Generic rather than specific names are used for most subaqueous invertebrate organisms. Common names have been placed in parentheses. The list does not include an inventory of land and marine vertebrates or plant and animal micro-organisms. Plants and animals listed are common, environmentally diagnostic organisms that are predominantly bottom-dwelling invertebrates in subaqueous environments and also higher order plants in subaerial environments.

Table 7. Areal extent of individual units shown on Environments and Biologic Assemblages Map, Corpus Christi map area, Texas.† (Table pertains only to that part of each county occurring within the Corpus Christi map area. All values are in square miles unless otherwise indicated by symbol.) See tables 3 and 5 for conversion tables.

SPECIAL-USE ENVIRONMENTAL MAP UNITS	Aransas County°	Bee County°	Jim Wells County°	Kleberg County°	Nueces County°	Refugio County°	San Patricio County°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Corpus Christi map area (excluding offshore area)	Percentage of Corpus Christi map area covered by map unit (excluding offshore area)
SUBAQUEOUS ENVIRONMENTS AND ASSEMBLAGES (Principally benthonic organisms with limited mobility)										
Shelf, open marine, normal salinity (35 °/₀₀), mottled mud, diverse organisms, principally molluscs, crustaceans, and echinoderms, depth > 30 feet	–	–	–	–	–	–	–	–	–	–
Lower shoreface, open marine, normal salinity (35 °/₀₀), moderate wave action, sand, silt, and mud, infauna dominant, mud shrimp molluscs, depth 15 to 30 feet	–	–	–	–	–	–	–	23.0	–	–
Upper shoreface, surf zone, shifting sand, normal salinity (35 °/₀₀), molluscs, sand dollars, starfish, and crustaceans, depth low tide to 15 feet	–	–	–	–	–	–	–	16.8	–	–
Inlet and tidal delta, connects open Gulf and bays, sand, mud, and shell, diverse epifauna, molluscs, echinoderms, coral and bryozoans, clionid sponges, depth < 40 feet; small tidal deltas in bays < 10 feet; sand, mud, and shell, fauna variable	3.8	–	–	0	0.7	0.9	0	9.0	5.4	0.2
Bay and lagoon margin, shoal water bordering bay, sand to mud, shifting sandbars, sparse marine grass, variable salinity and temperature, molluscs, depth < 3 feet; in Laguna Madre, seasonally hypersaline shoal water bordering mainland, sand, some shell, shifting sandbars, sparse grass, algae, salinity 30 - 60 °/₀₀, temperature 12 - 43°C, molluscs, low diversity, depth < 3 feet; unmapped salt-water marsh along shore	8.6	–	–	1.7	19.7	1.7	0	–	31.7	1.3
Grassflats, shallow bay margin with dense grasses, salinity 25 to 35 °/₀₀, moderately diverse mollusc assemblage, depth < 5 feet; (lighter shade) hypersaline, sparse to moderate grass, sand, shell, and muddy sand, salinity 30 - 60 °/₀₀, temperature 12 - 43°C, abundant molluscs, low diversity, algae, depth < 4 feet	4.7	–	–	17.6	30.9	0.2	0	–	53.4	2.3
Open bay, lower end of bay with tidal influence, salinity 20 to 35 °/₀₀, mottled mud, high species diversity, infauna, molluscs, depth 6 to 15 feet	37.8	–	–	0	128.1	0	0	–	165.9	7.0
Enclosed hypersaline bay or lagoon center, away from tidal or river influence, mottled mud, salinity 30 - 60 °/₀₀, abundant molluscs, low diversity, depth 4 to 6 feet	0	–	–	4.4	0	0	0	–	4.4	0.2
Enclosed bay with reef, away from tidal or river influence, mottled mud, similar to open bay but reduced species diversity, clams, oyster reefs, depth 3 to 8 feet	22.3	–	–	0	0	15.7	0	–	38.0	1.6
Reef, dense oysters, distinct mounds or ridges commonly aligned normal to circulation, firm substrate, salinity 10 to 30 °/₀₀, depth < 8 feet, associated molluscs, coral, bryozoans	1.0	–	–	0	1.7	0.2	0	–	2.9	0.1
Reef flank and margin, level bottom between reefs, few clumps of oysters, sand, mud, and broken shell, salinity 10 to 30 °/₀₀, depth < 12 feet	1.6	–	–	0	1.5	1.5	0	–	4.6	0.2
Enclosed bay, little tidal or river influence except during extreme high tides or rainfall, mottled mud, similar to open bay but reduced species diversity, clams, depth 3 to 6 feet	5.0	–	–	0	4.5	0	0.2	–	9.7	0.4
River-influenced bay, very low salinity during high rainfall periods, near fresh-water discharge, laminated mud and silt, mottled mud, low species diversity with molluscs and crustaceans, depth 3 to 6 feet	0.5	–	–	0	22.0	5.3	0	–	27.8	1.2
Subaqueous and subaerial spoil, artificial, sand and silt, poorly sorted, assemblage depends on age of spoil, depth and elevation variable	4.1	0	0	4.8	32.1	0	0.9	0.8	41.9	1.8
Fresh- to brackish-water bodies, landlocked ponds and lakes, variable substrate, inland bodies fresh, coastal bodies temporarily brackish or saline	7.0	0.1	0	13.5	9.7	3.1	5.4	–	38.8	1.6
SUBAERIAL ENVIRONMENTS AND ASSEMBLAGES (Principally floral assemblages)										
Beach, swash zone, high wave energy, sand, shell, molluscs and crustacean infauna, backbeach sea-oats and halophytes, dunes, ghost crab, low tide to + 5 feet	1.0	–	–	1.0	1.2	0	0	–	3.2	0.1
Vegetated barrier flat, foredune ridge, stabilized blowouts, sand, shell, relief 5 to 30 feet, salt-tolerant grasses, vines, local fresh-water marsh, ghost crab, rodents, snakes, fowl	7.7	–	–	7.6	17.5	0	0.2	–	33.0	1.4
Washover channel and fan, sand, local mud, barren, algal mats, local ponds and fresh-water marsh	2.9	–	–	0	1.2	0	0	–	4.1	0.2
Active dunes, coppice dune, blowouts, back-island dunes, barren, relief 3 to 30 feet, rodents, snakes	1.8	0	0	9.3	3.7	0	0	–	14.8	0.6
Sandflats, wind-tidal, local mud, algal mats, emergent-submergent, -1 foot to +2 feet MSL; and barren lower stream courses, ephemeral, sand	8.0	0	0	1.2	15.5	2.7	3.7	–	31.1	1.3
Active clay-sand dunes, accretionary, intense wind, salt-tolerant grasses, snakes	0	0	0	0.2	0.5	0	0	–	0.7	0.03
Berms along and near bay-lagoon margin, storm deposits, sand, shell, local salt- and brackish-water marsh in swales and ponds, salt-tolerant grasses, snakes, fowl	1.3	0	0	0.2	1.5	0.2	1.5	–	4.7	0.2
Salt-water marsh, frequently inundated by tides, sand, muddy sand to mud, cordgrass, glasswort, seepweed, sea-oxeye, mammals, fowl	2.6	–	–	0	1.5	1.5	5.1	–	10.7	0.5
Brackish- to fresh-water marsh, sand, muddy sand, and mud, grades into salt-water marsh, coastal sacahuista, marshhay cordgrass, big cordgrass, bulrush, cattail, rush, mammals, snakes, fowl	2.3	0	0	0	0	0	6.3	–	8.6	0.4
Inland fresh-water marsh, sand or mud, rush, cattail, sloughgrass, mammals, snakes, fowl; some areas occupied by high-moisture, non-marsh plants, ephemeral marsh (lighter shade)	4.7	0	0	3.4	3.2	6.9	11.7	–	29.9	1.3
Prairie grasslands, flat to gently rolling upland, prairie grasses, mud and sand substrate, much of area cultivated, bluestem, Indiangrass, chaparral, mesquite, hackberry, huisache, cactus, fowl, and small mammals, stippled in areas of dense brush and oaks	51.4	87.7	0.2	62.9	608.3	188.7	456.1	–	1455.3	61.8
Swamp, drainage poor, sediment and water supplied by overbanking fluvial systems, dwarf palmetto, elm, bay, mulberry, water oak, grapevine, and yaupon, raccoon, opossum, some mink and squirrel, fowl, snakes	0	0	0	0	0	0	0.2	–	0.2	0.01
Frequently flooded fluvial areas, water-tolerant plants, mud to sand, fresh-water reeds, rushes, and trees, mammals and fowl	0	6.6	0	0	4.4	17.4	23.9	–	52.3	2.2
Fluvial woodland, water-tolerant hardwoods, pecan, hickory, live oak, water oak, blackjack oak, elm, hackberry, red haw, ash, carpetgrass, Bermudagrass, greenbriar, yaupon, grape, mammals, fowl, snakes	0	9.1	0	2.2	14.3	15.0	20.5	–	61.1	2.6
Fluvial grassland, grass and brush, bluestem, sacahuista, mesquite, catclaw, *Acacia*, mammals, fowl, snakes	0	1.1	0	0	8.1	9.8	21.0	–	40.0	1.7
Oak mottes and groves, live oak and dwarfed live oak, permeable and well-drained, near the coast, salt spray may kill leaves on windward side, grow rapidly leeward producing sculptured oak mottes, rodents, snakes	9.9	1.1	0	0	1.2	0	10.0	–	22.2	0.9
Poorly drained depressions, mud substrate, occasionally flooded, locally seasonal hydrophytes, other high-moisture plants and prairie grasses	0.5	0.3	0.1	17.8	17.6	0.2	0.7	–	37.2	1.6
Loose sand and loess prairies, bunch grasses, commonly overgrazed, scattered oak mottes, fresh-water marsh in blowouts and depressions in wet cycles, rodents, mammals, snakes, fowl	0	0	0	55.4	38.3	0	0	–	93.7	4.0
Brushland, moderately stabilized dunes, inactive clay-sand dunes, some loess deposits, mesquite, chaparral, other scrub, distinctive grasses, cactus, game, fowl, climax vegetation	0.5	0	1	11.5	0.7	0	0.5	–	14.2	0.6
Barren land, abandoned tidal creeks, small bayside beaches, sandflats, active point bars	0.3	0	0	0	0.2	0.2	0.2	–	0.9	0.04
Made land, filled, graded, sand, mud, and shell, locally some vegetation	1.8	0	0	0	11.8	0	1.0	–	14.6	0.6

†Data accuracy approximately 90 to 95 percent; area determined by point-count method and linear values determined by map-measuring wheel.
°Only part of each county lies within map area.
–Data not measured or unit not applicable.

Subaqueous Environments and Biologic Assemblages

A total of 15 natural environments and biologic assemblages is delineated for the Corpus Christi area (table 6). These may be grouped broadly into: (1) the innermost part of the open Gulf shelf and the high-energy upper and lower shoreface environments; (2) the high-energy environments of the tidal channels and associated flood and ebb deltas that serve as permanent zones of interchange between the bay and Gulf; (3) a variety of environments within the interior bays and estuaries; and (4) landlocked, fresh- to brackish-water coastal ponds.

By far the greatest diversity of environments and biologic assemblages occurs in the bays and estuaries. These may be considered broadly as: (1) open-bay areas, where tidal interchange is most prominent and water salinities approach those of the Gulf; (2) enclosed-bay areas, away from tidal interchange and with relatively restricted circulation; (3) river-influenced bay environment at the mouths of the Nueces, Aransas, and Mission Rivers, where turbidity is relatively high and salinity markedly reduced; (4) open- and enclosed-bay environments, where reef growth is prominent; (5) restricted, shallow lagoons and grassflats subject to hypersaline conditions; and (6) marginal areas made up chiefly of bay-margin shoals and grassflats. Subaqueous and subaerial spoil is included as the only man-made unit on the map; biologic assemblages developed on spoil depend to a great extent on the age of the spoil and its position relative to a natural environment.

Subaerial Environments and Biologic Assemblages

A total of 21 subaerial environments and associated biologic assemblages is delineated on the Corpus Christi map (table 6). These are defined chiefly on the basis of vegetation, though most are coextensive with distinct faunal assemblages, including mammals, reptiles, and birds.

Subaerial biologic assemblages can be grouped broadly into: (1) lowland vegetation, (2) upland vegetation, and (3) vegetation associated with the coastal barriers. A major type of lowland vegetation in the Coastal Zone is the extensive wetlands. These include salt-, brackish-, and fresh-water marshes that border the bays or occupy coastal lowlands and the marshes and swamps within the lower parts of major river valleys. All are characterized by permanently high water tables. Swamps comprise the wooded wetlands, and marshes make up the grassed wetlands. The marshes are further zoned by the extent and frequency of salt- and fresh-water flooding. A distinct assemblage of water-tolerant, wooded vegetation is developed along the drainage of most of the smaller streams of the coastal uplands and the inland parts of the valleys of the Nueces, Aransas, and Mission Rivers. Associated with fluvial woodland along the main river courses is an assemblage of water-tolerant grasses. Sinuous, abandoned channels on the coastal upland support a local water-tolerant flora, but the character of this assemblage and environment undergoes a major change from north to south across the mapped area. Due to increasing aridity and less frequent flooding to the south, abandoned channel courses are defined more commonly by seasonal hydrophytes and less definitive water-tolerant assemblages; prairie grasses are more common in these poorly drained depressions. This transitional change in vegetation has been arbitrarily drawn at the Nueces River; precise definition of boundaries is not feasible.

The coastal uplands, underlain chiefly by Pleistocene sediments, originally supported an extensive prairie grassland, but most of the grassland has been converted into agricultural land. Dense stands of oak and brush occur along uplands lateral to Chiltipin Creek, Aransas River, and Mission River; south of Nueces County, prairie grasslands are used extensively as ranching and grazing lands. Oak mottes are developed on older (Pleistocene) barrier-strandplain sand deposits on Live Oak Ridge and Live Oak Peninsula and locally on Encinal Peninsula.

The vegetation of the coastal barrier islands comprises a distinct complex. Inland from the beach and backbeach, which are largely barren, is the fore-island dune area. Dunes are vegetated along their lower parts by sea purslane, morningglory, and rush saltgrass. Vegetation on the middle and upper parts of dunes is characterized by sea oats, bitter panicum, and *Croton*. In places where fore-island dunes are not present, largely barren sandflats and coppice sand-dune fields are present. Behind fore-island dunes and the barren sandflats or coppice dune fields are the beach ridge and barrier flat environment (extensively covered with a variety of grasses, shrubs, and cacti) and grass-covered stabilized blowout dune areas. On Padre Island, extensive back-island dune fields extend to the bay shoreline. Active and inactive washover channels and fans stretch across the barrier island in several places. The bayside of the barrier island complex is occupied by mostly barren wind-tidal flats that are occasionally flooded and covered by blue-green algal mats and scattered marsh plants. Salt-water marsh, with the typical assemblage of salt-tolerant flora, occurs bayward of the wind-tidal flats and vegetated back-island areas.

Historical Changes of Environments and Biologic Assemblages

The *Environments and Biologic Assemblages Map* represents the distribution of major biologic assemblages and other environments at a given time and does not convey information concerning sequential changes in map units. Historical monitoring of environments, using several vintages of aerial photography and topographic maps, can illustrate changes of these environments over a span of time. Few areas of the Texas Coastal Zone have been analyzed using historical monitoring techniques. Notable exceptions are the Gulf shoreline (see discussion in section, Active Processes Map), bay shorelines, marshy areas in Matagorda Bay (McGowen and Brewton, 1975), and Mustang and north Padre Islands (White and others, in preparation).

Figure 28 shows the distribution of major environments on Mustang and north Padre Islands as mapped using aerial photography taken in 1938, 1956, and 1974. Figure 29 graphically illustrates changes in areal extent of these environments over this time period. Maps in figure 28 were constructed for resource capability analysis (see discussion in this text on page 114) and, therefore, map units are similar but not identical to map units on the *Environmental Geology Map* and the *Environments and Biologic Assemblages Map*.

Three general trends of environment changes on Mustang and north Padre Islands from 1938 to 1974 are evident from the historical monitoring study of White and others (in preparation). These trends are summarized on figures 28 and 29. [Refer to White and others, in preparation, for a complete review of this area and a discussion of the applications and limitations of historical monitoring analysis.] First, the areal extent of active dunes has decreased sharply since 1938 due to the stabilizing effect of vegetation. Note the increase in areal extent of the vegetated dunes and barrier flats map unit. Second, marine grassflats have expanded into areas that were formerly wind-tidal flats and subaqueous sand shoals. Third, spoil and made land were four times more extensive in 1974 than in 1938.

Besides delineating trends of environmental changes through time, historical monitoring analysis provides a basis for understanding the observed changes. Increased areal extent of subaerial, vegetated environments and the concurrent decrease of active sand dune areas point to a climate favoring vegetation growth and expansion. The spread of grassflats over sand shoals may indicate a decrease in sand movement into shallow bay areas and the spread of marine vegetation into these same areas. Decreased sand movement across the barrier islands may reflect decreased storm surge and eolian activity due to considerable expansion of stabilizing vegetation. Decrease of wind-tidal flat areas and expansion of marine grassflats in the north Mustang Island area, particularly, may indicate a relative rise in sea level or compactional subsidence of the land area. The increased areal extent of spoil and made land is directly related to man's activities, including petroleum exploration and development, dredging of deep-water access channels, and land filling for recreational/community development.

Historical monitoring analysis provides a more complete understanding of environments, biologic assemblages, land use patterns, and active processes by defining environmental changes through time. This four-dimensional approach more clearly indicates trends in land use, climatic characteristics, impact of active processes, variations in relative land-sea positions, displacement of major biologic assemblages, and many other changing patterns. As this approach is applied to other areas of the Texas Coastal Zone, we can expand our information base upon which to plan and manage our use of the coastal environment.

CURRENT LAND USE MAP

A number of factors in the Texas Coastal Zone contribute to diversified and extensive land and water use. First, it is an area of high population concentration, particularly in the Corpus Christi area and to an even greater extent in the upper Coastal Zone. Second, it is an area endowed with extensive mineral resources—notably oil, gas, and chemical raw materials (sulfur, salt, and lime)—supporting major petroleum-refining and petrochemical centers. The Corpus Christi region, with its abundance of oil and natural gas production and concentration of petrochemical operations is a prime example. Third, it is an area with fertile and productive lands that support extensive agriculture. Finally, it embraces major port facilities with extensive intracoastal waterways and ship channels that have led to a high-volume flow of imports and exports; Corpus Christi is the third leading port in Texas with respect to tonnage handled annually.

Many of the factors that have led to extensive and diverse land and water use in the Texas Coastal Zone have also led to limitations and conflicts. Many of the resources of the area have varied uses, both present and potential. For example, water bodies are used simultaneously for transportation, commercial and sport fishing, recreation, oil and gas well locations, pipeline

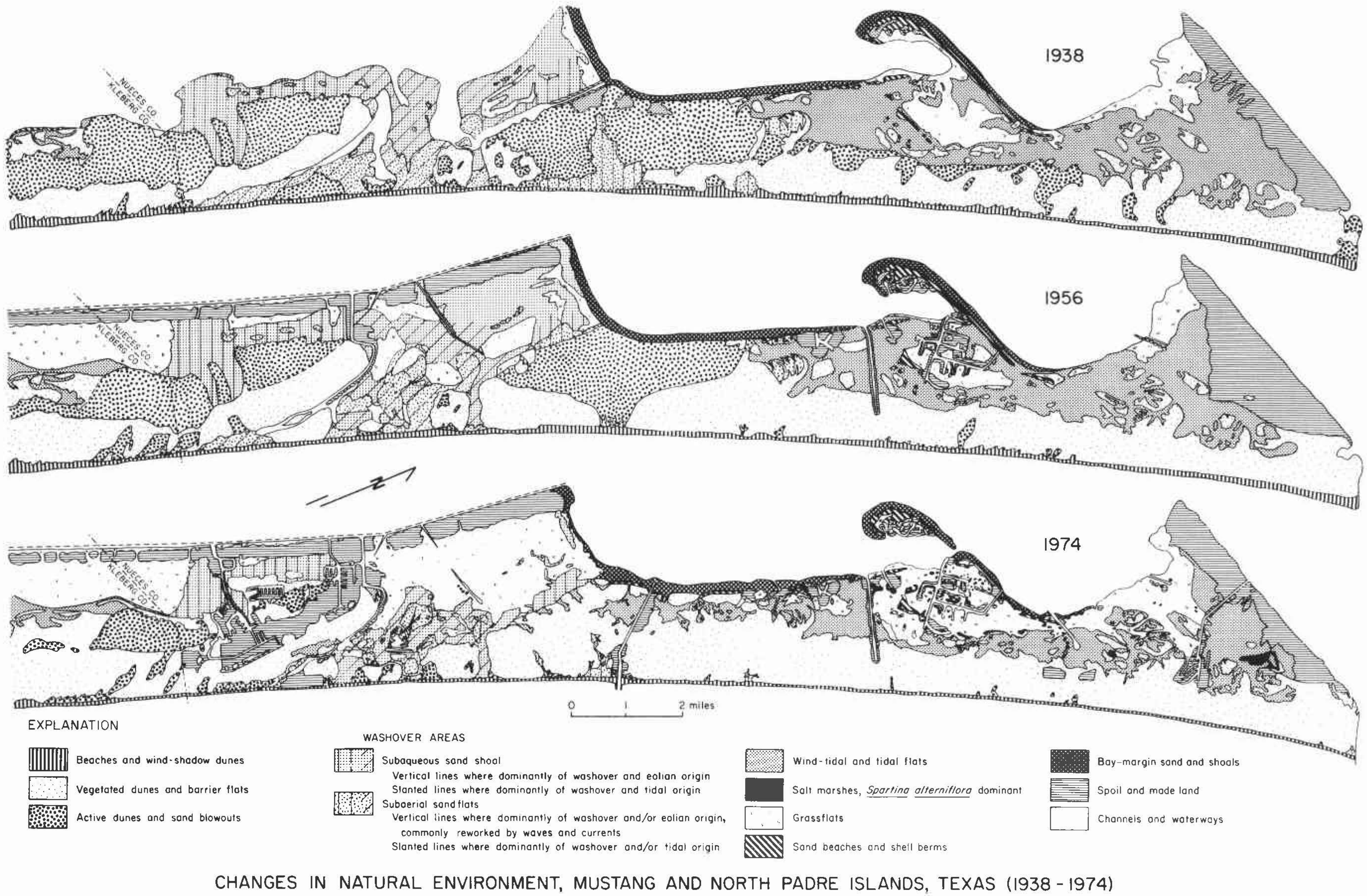


Figure 28. Historical monitoring analysis, 1938-1974, for Mustang and north Padre Islands, Texas. Modified from White and others (in preparation). Natural environments mapped represent land and water resource units.

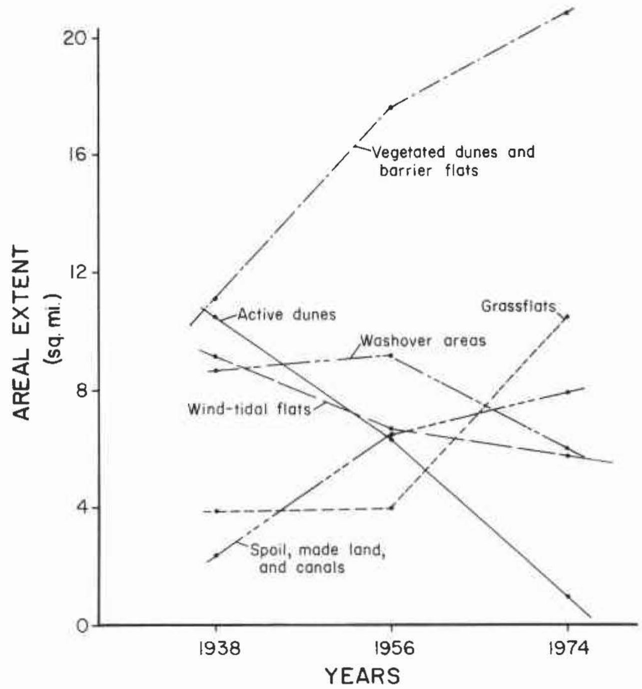


Figure 29. Changes in areal extent of land and water resource units based on historical monitoring analysis of Mustang and northern Padre Islands, Nueces County, Texas, 1938-1974. Modified from White and others (in preparation).

routes, a landfill area for real-estate developments, as part of a waste disposal system, and, until recently, for production of shell. Certain of these uses are obviously in conflict. The natural area is one of rapid and dramatic physical change involving active shoreline processes, hurricane flooding and damage, subsidence, and surface faulting; these dynamic changes interface with a variety of land and water uses. Furthermore, the area embraces a fundamental legal boundary between largely privately owned lands on the coastal barriers and publicly owned gulfside beaches and offshore waters. Because the legal boundary is also a high-energy geological boundary, actions taken by one proprietor have an immediate and significant effect on others.

Current land use in the Corpus Christi area is classed in 16 major use categories on the *Current Land Use Map* of this Atlas. Most of the information utilized in compiling this map was derived from 7.5-minute U. S. Geological Survey topographic maps and similar Tobin controlled photomosaics (fig. 2); supplementary data were obtained by field observation and by derivation from the *Environmental Geology Map*. Aerial photographs available for the entire area are generally a decade old (fig. 3A). Where more recent, detailed photographs existed, they were used to update the land use patterns. Land use information should be updated at least every decade, or whenever new coastwide aerial photography becomes available.

Major classes of current or potential land use in the Corpus Christi area include agricultural lands, timber and wooded lands, marshes and grassed wetlands, urban and industrial lands, government lands (State and Federal), general recreational lands, made and reclaimed lands, dredged spoil and barren lands, areas overlying oil and gas fields, and artificial surface reservoirs. The major classes—agricultural, timber, marsh, and urban lands—are divided into smaller land use units. Statistical tabulation of different land uses, by area and percent of total lands, is given in table 8. In addition, the *Current Land Use Map* shows location and distribution within the Corpus Christi map area of 204 oil and gas fields, 119 educational sites, 12 pits and quarries, 18 sludge pits, 16 sewage treatment and disposal sites, 21 solid-waste disposal sites, 14 offshore petroleum production platforms, and 8 airfields. Major pipeline, transportation-navigation, and irrigation-drainage networks are also indicated.

An evaluation of current and potential use of land and water resource units is included elsewhere in the text of this Atlas and is further treated by Brown and others (1971).

Agricultural Lands

Although the Corpus Christi area is one of the major population and industrial centers of the State, approximately 69 percent of the total land area is used for agriculture. Of total agricultural lands, approximately 55 percent is under cultivation, and the balance is used for rangeland and pasture. Principal use of cultivated lands, situated almost entirely on the Pleistocene coastal uplands, is for production of grain sorghums and cotton. A relatively small amount of hay and grain is produced to support beef production, the main use of rangeland and pastures. An extensive network of irrigation canals, drainage canals, and artificially constructed surface reservoirs is utilized in agricultural production.

Timber and Wooded Lands

Approximately 56 square miles, or 2 percent of the Corpus Christi map area, are wooded and are largely associated with the various river and stream systems,

Table 8. Areal extent and number of individual units shown on Current Land Use Map, Corpus Christi map area, Texas.† (Table pertains only to that part of each county occurring within the Corpus Christi map area. All values are in square miles unless otherwise indicated by symbol.) Map units total more than 100% due to overlap of Corpus Christi oil and gas fields. See tables 3 and 5 for conversion tables.

SPECIAL-USE ENVIRONMENTAL MAP UNITS	Aransas County°	Bee County°	Jim Wells County°	Kleberg County°	Nueces County°	Refugio County°	San Patricio County°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Corpus Christi map area (excluding offshore area)	Percentage of Corpus Christi map area covered by map unit (excluding offshore area)
Agriculture, cultivated land and orchards, significant acreage presently out of cultivation, locally silage crops for grazing, developed predominantly on Pleistocene fluvial-deltaic sand and mud facies	4.4	9.0	0	4.3	489.8	55.5	332.5	–	895.5	38.0
Range-pasture, uncultivated or permanently removed from crop use, some local silage fields, land use varies adjacent to residential-urban areas, predominantly on Modern barrier-strandplain vegetated flats, Pleistocene delta-front sand and mud, grass- and scrub-covered, Pleistocene fluvial-deltaic sand and mud, Pleistocene barrier-strandplain sand	45.5	88.9	1.3	150.3	113.0	171.8	165.8	–	736.6	31.3
Woodland-timber, water-tolerant hardwoods on floodplains of Modern streams, live-oak mottes chiefly on Pleistocene fluvial-deltaic sands and barrier-strandplain sands, scattered cattle throughout, wildlife locally abundant	9.9	7.9	0	0	6.5	10.8	21.0	–	56.1	2.4
Saline- and brackish-water marsh, locally inundated by tides, water table may be locally above surface, developed on back side of barrier islands, Modern delta plains and bayfill areas, common cordgrass, saltgrass, sacahuista, cattail, bulrush, and other marsh plants, some cattle on drier fringes, abundant wildlife, and tidal creeks	11.2	0	0	0.3	1.5	2.6	11.0	–	26.6	1.1
Fresh-water marsh, continually wet floodplains, abandoned channels, and inland parts of Modern deltas, ephemeral in depressions on Pleistocene delta front and delta areas, vegetated with rush, cattail, and sloughgrass, wildlife locally abundant	4.7	0	0	3.3	3.0	5.2	8.0	–	24.2	1.0
Residential-urban, commercial and residential development, includes metropolitan areas and small rural villages and settlements, may include some minor industrial areas	8.3	0.1	0	0.8	24.3	2.0	13.5	–	49.0	2.1
Industrial, heavy industrial areas, railyards, docks, municipal works, refineries, and chemical plants	0.3	0	0	0.1	6.0	0.3	2.5	–	9.2	0.4
Undifferentiated urban land, undeveloped tracts, greenbelts, cemeteries	0	0	0	0	4.0	0	0	–	4.0	0.2
Park and recreational facility, formally defined Federal, State, and most county and municipal facilities such as ball parks, athletic fields, golf courses, includes some private facilities	0.5	0	0	11.3	9.8	0	0.5	–	22.1	0.9
Government land, Federal and State, excluding recreational and educational, includes Department of Defense property, major tracts only, may be inactive or abandoned	1.3	0	0	1.5	18.3	0	0.5	–	21.6	0.9
General recreational land, public beach between mean low tide and mean high tide along Texas coastline available for recreation, up to 200-foot easement provides most Gulf beaches with access, informal recreational area	2.3	0	0	0.5	1.8	0	0	–	4.6	0.2
Made land, graded and filled area utilizing spoil or other fill, used for urban-residential and industrial expansion, commonly developed over shallow bay areas or marsh-vegetated barrier flats, reclaimed land	0.5	0	0	0	7.3	0	2.0	–	9.8	0.4
Spoil, subaerial land resulting from dredging, some waterfowl, locally used for fishing sites, relatively barren areas within coastal marshes	1.6	0	0	1.3	10.9	0	1.5	–	15.3	0.6
Barren land, commonly sand, mostly on back side of barrier island and Modern delta plain, transitional area between wind-tidal flat and stream floodplain (lighter shade), commonly associated with marsh, some waterfowl	17.4	0	0	5.3	18.8	3.3	5.8	–	50.6	2.1
Oil or gas field	80.5(19)■	19.8(11)■	0.3(1)■	27.8(13)■	259.3(81)■	30.7(26)■	104.0(72)■	40.3(8)■	522.4(204)■•	22.2
Education site, public school, college, university■	3	1	0	1	88	2	24	–	119	–
Pit or quarry, commonly in fluvial terraces and alluvium■	0	0	0	0	6	0	6	–	12	–
Sludge pit or miscellaneous waste disposal site, commonly related to oil production, may be abandoned■	1	0	0	0	14	0	3	–	18	–
Sewage-disposal site, liquid effluent, commonly treatment plant site■	1	0	0	0	9	1	5	–	16	–
Solid-waste disposal site, sanitary landfill, and open dumps■	2	0	0	0	8	1	10	–	21	–
Pipeline, major lines only, incomplete	–	–	–	–	–	–	–	–	–	–
Offshore petroleum production platform, Gulf of Mexico■	–	–	–	–	–	–	–	14	–	–
Private airfield, paved, graded, or sod■	0	0	0	0	1	2	5	–	8	–
Artificial reservoir, flood control, municipal water supply, industrial purposes, or recreation	8.8	0	0	0.5	3.5	0	2.8	–	15.6	0.7

†Data accuracy approximately 90 to 95 percent; area determined by point-count method and linear values determined by map-measuring wheel.
°Only part of each county lies within map area.
–Data not measured or unit not applicable.
■Number of specific occurrences of map feature.
•18 oil fields common to two or more counties.

especially where drainage is developed on sandy soils and substrates. A major wooded land unit occurs along the smaller streams of the coastal uplands and in the valleys of the Nueces, Aransas, and Mission Rivers. Principal vegetation includes water-tolerant hardwood, pecan, hickory, live oak, water oak, blackjack oak, elm, hackberry, red haw, and ash. Swamp vegetation develops in areas with permanently high water tables, primarily along lowlands of the Nueces and Mission Rivers. Swamps include dwarf palmetto, elm, bay, mulberry, and water oak. Oak mottes occur locally on Encinal Peninsula and are extensively developed along Live Oak Ridge and Live Oak Peninsula.

Current use of wooded lands in the Corpus Christi area is as a wildlife habitat. Locally, some cattle grazing occurs in these areas.

Marshes and Grassed Wetlands

Marshlands are concentrated along coastal and river lowlands in the Corpus Christi area, representing about 50 square miles or 1 percent of the mapped area. About 51 percent of the wetlands is salt- or brackish-water marsh, with principal distribution at the lowermost part of the Nueces, Aransas, and Mission Rivers, along Mud and Egery Flats, around Swan Lake and Port Bay, along the back sides of the coastal barrier islands, and on the emergent areas in the Harbor Island area. Fresh-water marshes comprise the remaining marshlands in the area and develop locally along inland parts of most waterways and in elongate depressions and swales just inland of the Pleistocene barrier-strandplain sand bodies.

Little direct use is made of the marshlands in the Corpus Christi area. A few areas have been filled and reclaimed, and oil and gas fields and well locations occur in some of the marshlands. Principal current use is for a wildlife habitat. The coastal marshes are areas of high organic productivity and form a fundamental nutrient link throughout the bay and estuary system. Fruh and others (1972) evaluate use of Texas wetlands and review literature pertinent to wetland environments.

Urban and Industrial Lands

The mapped portion of the Corpus Christi area includes about 85 square miles of urban-industrial land. By far the greatest concentration is in the populous and highly industrialized Greater Corpus Christi area. Other major population centers include the urban-industrial lands of Portland, Ingleside, Aransas Pass, Port Aransas, Rockport, Fulton, Flour Bluff, Bayside, Gregory, Taft, Woodsboro, Sinton, Peary Place, Odem, Robstown, and Bishop. Several smaller towns and settlements define the remaining urban and industrial lands within the mapped area.

Urban and industrial lands on the accompanying *Current Land Use Map* are classed as: (1) residential-urban, areas of commercial and residential development, including metropolitan areas, small rural villages and settlements, and some minor industrial developments; (2) heavy-industry areas, including railyards, docks, municipal works, and refineries and chemical plants, as well as other processing and manufacturing plants; (3) undifferentiated urban lands, including undeveloped tracts, greenbelts, and cemeteries; and (4) park and recreational facilities as parts of urban areas, including ball parks, athletic fields, and golf courses. Most of these are public facilities, though some private facilities are included as well. Of lands so classed, approximately 58 percent is residential-urban land, about 26 percent is devoted to parks and recreational facilities (mainly Padre Island National Seashore and Mustang Island State Park), and the balance includes 11 percent heavy-industry lands and about 6 percent undeveloped urban lands. The principal heavy-industry lands are concentrated along the Corpus Christi Ship Channel at Harbor Island and the Greater Corpus Christi area from the Turning Basin westward along Tule Lake and Viola Channels. Other heavy-industry lands include the area serviced by La Quinta Channel between Portland and Ingleside. Large tank farms exist at several places within the mapped area.

Other Land Use Categories

Other types of current land use comprise less than 5 percent of the total mapped area. Approximately 22 square miles exist as Federal, State, county, or municipal lands, including the Corpus Christi Naval Air Station and numerous Naval Auxiliary Fields, and Waldron, Rodd, and Cabiniss Fields, Aransas County Airport, Corpus Christi International Airport, several small municipally owned airfields, and the military reservation at the mouth of Aransas Pass. Only the major tracts of government land, both active and inactive, are indicated.

Approximately 5 square miles of lands classed as general recreational lands include the public beaches along the gulfside of the coastal barrier islands. About 10 square miles of lands exist as made or reclaimed lands, including extensive areas in the Corpus Christi industrial corridor, Harbor Island, along Aransas Channel and the Intracoastal Waterway in the Aransas

Pass area, and the Indian Point area west of Portland. An extensive area of barren sandflats (50 square miles), including areas of wind-tidal flats, is developed in lowlands along major streams and on the back side of the coastal barrier islands. Also included are dune areas subject to active movement of sand by onshore winds. Subaerial spoil from dredging, situated mainly along the land cuts of the Intracoastal Waterway, Corpus Christi Ship Channel, and La Quinta Channel, also has limited use. The numerous oil and gas fields of the area cover a total of about 520 square miles, though much of this land is used simultaneously for other purposes. Surface reservoirs constructed for flood control, irrigation, municipal and industrial water supplies, and recreation occupy approximately 16 square miles.

Historical monitoring of environments in the Mustang and north Padre Islands area (White and others, in preparation) indicates that the areal extent of spoil and made land has increased from about 2 to 8 square miles from 1938 to 1974 (figs. 28 and 29). This trend represents the increasing impact of man's activities on a portion of the Texas coast and indicates that land use patterns in this area have changed and are subject to future change. The increase in man's activities on Mustang and north Padre Islands is due to petroleum production and exploration, dredging of deep-water access channels, and land filling for recreational/community development.

Utility of Current Land Use Map

The *Current Land Use Map* shows distribution, kind, and amount of present land use and provides a method for projecting both the type and the distribution of future land use. It should be used in conjunction with most of the other special-use maps of this Atlas. Comparison with the *Active Processes Map* will show land use currently in conflict with natural physical processes and will define areas of future land use that will not conflict with or unbalance active natural processes. Comparison of the *Current Land Use Map* with the *Physical Properties Map* will define the compatibility of present use with the physical capabilities of the land and will identify urban and industrial areas situated along active or potentially active faults. Comparison with the *Environments and Biologic Assemblages Map* will show the type and amount of natural land that has been utilized and the purpose for which it has been used; such comparison will also define areas of future development and growth that will least upset natural environments.

MINERAL AND ENERGY RESOURCES MAP

The Corpus Christi area, as well as the rest of the Texas Coastal Zone, is richly endowed with mineral and energy resources. Chief among these resources are oil and natural gas, which serve not only for fuel but also provide raw material for many petrochemical processes. In addition, the Coastal Zone contains important resources of chemical raw materials—sulfur, salt, and shell. In the Corpus Christi area, shell production has ceased; sulfur and salt are not locally produced. The abundance of these chemical and petroleum raw materials and their occurrence in a zone with ocean access make the Coastal Zone one of the major petrochemical and petroleum-refining centers of the world. Many major refining and chemical companies have plants in the Corpus Christi area, located along two industrial corridors comprising the Viola-Tule Lake-Corpus Christi Ship Channel at the Port of Corpus Christi and the La Quinta Channel from Ingleside to Portland.

The *Mineral and Energy Resources Map* of this Atlas shows the occurrence and distribution of all known mineral deposits, including oil and gas fields, shell deposits, clay deposits, and general fill and aggregate materials. Also shown are existing pits and quarries, cement plants, lime plants, and the aluminum metal refining complex north of Ingleside. The energy-distribution network is outlined by all major pipeline transmission facilities, major power or utility transmission lines, and existing power-generation stations. In addition, petroleum production platforms located offshore in the Gulf of Mexico are indicated. Statistical data for each map unit are shown in table 9.

Oil and Natural Gas

A total of 209 oil and gas fields are currently producing within the mapped area. Major active and inactive fields are indicated on the *Mineral and Energy Resources Map*. Of the 209 active fields, 82 produce both oil and gas, 64 are oil fields, and 63 produce only gas. Most of the producing reservoirs are traps associated with down-to-the-coast gravity faults and related closures (rollovers) on their downthrown sides; the chief producing unit is the Frio Formation (fig. 30). Of these 209 fields, 30 are developed below the waters of Laguna Madre, the Gulf of Mexico, and Corpus Christi, Nueces, Redfish, Aransas, and Copano Bays. At least four fields within the mapped offshore area are active; no significant production comes from Federal Blocks farther offshore.

Table 9. Areal extent and number of individual units shown on Mineral and Energy Resources Map, Corpus Christi map area, Texas.† (Table pertains only to that part of each county occurring within the Corpus Christi map area. All values are in square miles unless otherwise indicated by symbol.) See tables 3 and 5 for conversion tables.

SPECIAL-USE ENVIRONMENTAL MAP UNITS	Aransas County°	Bee County°	Jim Wells County°	Kleberg County°	Nueces County°	Refugio County°	San Patricio County°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Corpus Christi map area (excluding offshore area)	Percentage of Corpus Christi map area covered by map unit (excluding offshore area)
Sand, includes all subaerial sandy deposits, fluvial sand, distributary sand and silt with local mud, barrier-strandplain sand, eolian sand, wind-tidal flat sand and silt and subaerial and subaqueous spoil; see *Physical Properties Map* for specific description	81.0	68.4	1.2	112.3	320.8	132.0	257.5	0.8	973.2	41.3
Mud, includes all subaerial muddy deposits, floodbasin mud, interdistributary mud, marsh and swamp facies, filled lakes, clay dunes; see *Physical Properties Map* for specific description	20.5	37.5	0.1	65.1	462.0	109.9	305.9	–	1001.0	42.5
Oyster reef, areas of prominent oyster colonies, includes both live and dead oysters, buried reef not included	1.0	–	–	0	1.7	0.2	0	–	2.9	0.1
Oyster shell, Nueces Bay, relict shell dredged from bay bottom, source of lime for cement, locally used in construction■	0	0	0	0	1	0	0	–	1	–
Pit or quarry, commonly in fluvial terraces and alluvium■	0	0	0	0	6	0	6	–	12	–
Oil or gas field	80.5(19)■	19.8(11)■	0.3(1)■	27.8(13)■	259.3(81)■	30.7(26)■	104.0(72)■	40.3(8)■	522.4(204)■*	22.2
Cement plant■	0	0	0	0	1	0	0	–	1	–
Lime plant■	0	0	0	0	1	0	0	–	1	–
Aluminum plant■	0	0	0	0	0	0	1	–	1	–
Power-generation plant■	0	0	0	0	3	0	0	–	3	–
Utility line or cable, major power transmission line, incomplete	–	–	–	–	–	–	–	–	–	–
Pipeline, major lines only, incomplete	–	–	–	–	–	–	–	–	–	–
Offshore petroleum production platform, Gulf■	–	–	–	–	–	–	–	14	–	–

†Data accuracy approximately 90 to 95 percent; area determined by point-count method and linear values determined by map-measuring wheel.
°Only part of each county lies within map area.

–Data not measured or unit not applicable.
■Number of specific occurrences of map feature.
*18 oil fields common to two or more counties.

Cumulative production of crude oil in the Corpus Christi map area was slightly less than 1 billion barrels through 1973. This production came from a total of more than 1,000 pay zones distributed in 241 fields (including inactive fields). One field in western San Patricio County—Plymouth—has produced more than 100 million barrels of oil, and a field in eastern San Patricio County—East White Point—has produced in excess of 98 million barrels.

Gas is produced from a total of 145 fields in the mapped area, and annual production exceeds 380 billion cubic feet. Fourteen fields produced more than 5 billion cubic feet of natural gas in 1973, including Agua Dulce, Laguna Larga, Chevron, Encinal Channel, Flour Bluff, East Flour Bluff, East Flour Bluff Deep, GOM-ST-904, Luby, Mobil-David, North Redfish Bay, Redfish Bay-Mustang Island, Stratton, and East White Point.

The production of oil, natural gas, and natural gas liquids figures prominently in the total economy of the Corpus Christi area. In addition to the direct value of these minerals, oil and gas production supports extensive industries within the area by providing readily available fuels and raw materials. Approximately 520 square miles of land and water within the map area are included in the 204 fields shown on the *Mineral and Energy Resources Map*; the major nonagricultural land use in the Corpus Christi area is directly or indirectly related to oil and gas production.

Shell

The scarcity of constructional aggregates and limestone for cement and lime manufacture, both necessary for a physical and chemical industrial complex, has led to extensive dredging of shell from the shallow bays and estuaries of the Texas Coastal Zone. Dredged shell has been a locally available substitute for these resources with physical properties suitable for use as aggregate and road base and chemical properties suitable for lime, cement, and other chemical uses. If shell were not used, import of these resources would be necessary; the nearest conventional source of industrial carbonate raw materials is Central Texas, approximately 150 miles inland.

Shell occurs either as discrete reefs and banks or mixed with bottom sand and mud in the shallow bays of

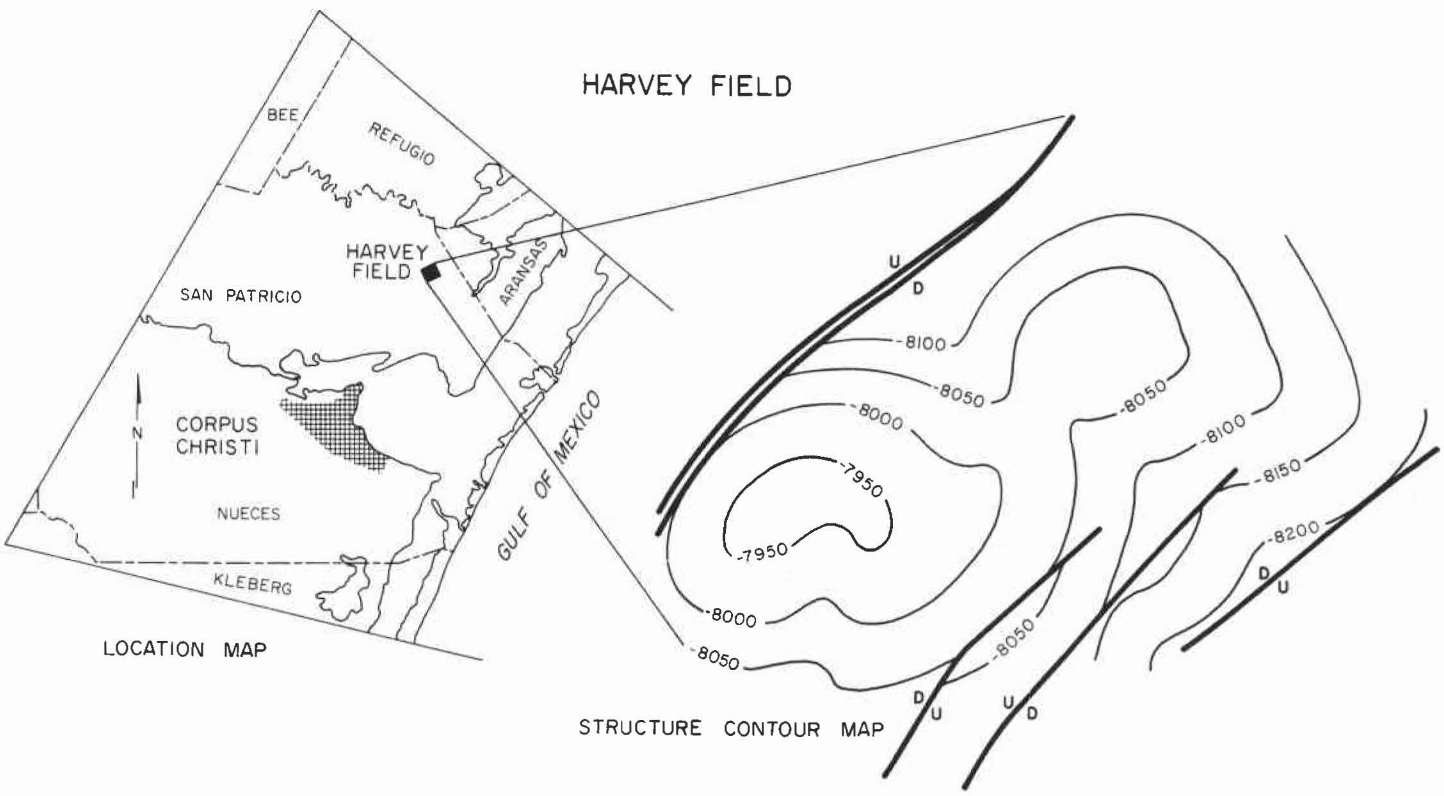


Figure 30. An example of rollover structures associated with growth faults that provide traps within the Frio trend in the Corpus Christi map area. The structure contours of the Harvey Field are subsea elevations. After Dyer (1967).

the Coastal Zone from Corpus Christi north to Sabine Lake. The principal shell source is the oyster, *Crassostrea*; smaller amounts are provided by the clam, *Rangia*. Parts of certain reefs support living oysters; other reefs consist entirely of dead shell. The dead reefs either occur at the bay-bottom surface or buried in bay mud at varying depths. Reefs range in thickness from 5 to 25 feet and are generally within 10 feet of the water surface.

Shell is a basic part of the existing coastal industry. Initial use began in the late 1800's for road base material, with shell first used in the manufacture of cement in 1916 and of lime in 1929. Shell was used in the middle 1930's in the manufacture of caustic soda, which is used in petroleum refining. This was followed shortly by use in the manufacture of glass, soap, plastics, acetate rayon, and glycols. In the early 1940's, shell was calcified to make lime for the production of magnesium compounds from sea water.

Shell production from Texas bays more than doubled after World War II, leveling off at an average annual production of 11.8 million cubic yards during the 1956-57 to 1966-67 production years. Since the all-time high of over 12.6 million cubic yards in 1966-67, Texas shell production has steadily declined to about 7 million cubic yards per year. Cumulative production during the past 52 years exceeds 325 million cubic yards, with most of the production coming from Trinity and Galveston Bays.

About one-half of the present production of shell in the Texas Coastal Zone is used for aggregate and constructional base materials. The other half is used in the manufacture of cement, lime, and chemicals. Most of the shell formerly produced from Nueces Bay in the Corpus Christi area was used in the manufacture of cement, lime, and chemicals.

In February 1974, dredging for shell ceased in Nueces Bay. Between the years 1959 and 1974, more than 13 million cubic yards of oyster shell were produced from Nueces Bay. Records for individual bays were not kept prior to that time, but shell production in this area began many years before 1959. Though figures are not available, it is believed that much of the shell legally and economically extractable has been dredged from this bay.

All shell dredged from waters of Texas bays is the property of the State. Current royalty paid by operators is $0.25 per cubic yard. At present, shell is being dredged only in Matagorda Bay from buried, relict shell deposits.

The *Mineral and Energy Resources Map*, along with certain other maps of this Atlas, shows the distribution of oyster reefs within Nueces, Corpus Christi, Aransas, Copano, and Mission Bays. The reefs delineated are those that are exposed on the bay bottom or that form bathymetric highs; they cover nearly 3 square miles. The largest reefs are located in Corpus Christi, Copano, and lower Nueces Bays. Smaller reefs occur in the upper Nueces, Aransas, and Mission Bays. A few reefs have developed in Nueces and Mission Bays near the mouths of small rivers and creeks.

No adequate studies of shell reserves in the Coastal Zone have been published. Estimates of reserves in Galveston and Trinity Bays range from 40 to 90 million cubic yards. Several factors preclude a reasonable estimate of reserves: (1) inadequate field investigation (bottom profiling, coring, and probing), (2) changes in State regulations controlling dredging procedures and sites available for dredging permits, and (3) changes in recovery techniques that may make presently uneconomic deposits recoverable in the future.

Regardless of what the total reserves of shell may be, they are finite and, at present rates of consumption, will be depleted in the not too distant future. Substitute materials will then have to be imported, either from inland sources or by ocean barge. Constructional aggregate substitutes can be manufactured from clay and other raw materials or imported from inland sources.

Constructional Raw Materials

Notably absent in the Texas Coastal Zone, as in many other low-lying coastal areas, are natural aggregates and bulk constructional materials (for example, gravel and crushed stone). This scarcity exists along with the high consumption of these materials in the heavily populated and industrialized areas; therefore, a large volume of these materials must be imported from inland sources. A partial substitute for aggregate exists in local shell and caliche deposits; local supplies of fine-grained fill sand are plentiful, but some gravel and crushed stone must be imported.

Most of the gravel supply of the Coastal Zone and the Corpus Christi area comes from sources as far as 50 miles inland along some major streams; crushed stone must be imported from Central Texas. The existing sources of coarse aggregate (local shell, caliche, and the nearest inland gravel deposits) are being depleted; future supplies must come from sources farther inland. Although the unit value for bulk constructional materials is generally only about $1.00 per ton, the large volume necessary for construction projects means significant transportation costs, about $0.05 per ton-mile. Such materials are absolutely essential to the heavy construction in the industrial and urban parts of the area, and their availability at the lowest possible cost is desirable.

The chief constructional raw material, other than shell, produced in the Corpus Christi area is fill sand, obtained largely from old stream deposits in the vicinity of the larger metropolitan areas and in some cases from dredged spoil. A possible substitute for natural aggregate is obtained by artificial manufacture of aggregate from clays. Such clay deposits are numerous within the area, as indicated on the *Mineral and Energy Resources Map* of this Atlas. The process involves calcining or partial calcining of the clay to give an indurated material, forming either lightweight or a standard-weight aggregate. The artificial product is obtained at a higher cost than the natural material, but prices will become increasingly more competitive as imports from longer distances become necessary. Caliche (calcium-carbonate-impregnated sand or gravel) is produced locally for use as concrete aggregate and road metal, and for other constructional purposes.

Industrial sands.—Some of the sand deposits of the Coastal Zone have potential industrial or specialty uses. In contrast to ordinary fill sand, sands of high purity and specific physical properties can be utilized for special industrial products such as foundry sands, glass sands, and chemical silica. Recent inventory and analysis of Coastal Zone sands, including those of the barrier islands, as well as the older sands on the Pleistocene uplands, indicate that these sands require upgrading and beneficiation to qualify for special industrial use (Garner, 1967). At present in the Corpus Christi area, industrial sands are being supplied by outside sources. Industrial sands command a much higher unit price than ordinary constructional fill sand, so that the necessary beneficiation might be economically feasible. Modern beach and dune sands of the area have been analyzed locally for heavy-mineral content as possible local sources of ilmenite, magnetite, and rutile, but known concentrations are low (Garner, 1967).

Common clay.—Common clays of the Texas Coastal Zone are used in the manufacture of certain clay products, including brick and tile. Reserves of common clays in the area are essentially limitless. Most of the clays are unsuitable for the manufacture of high-grade structural clay products or fine-grade ceramic products owing to high plasticity and to the relatively high content of carbonates, iron, and other impurities. They are of only marginal value for special nonceramic uses, such as bleaching clays and drilling muds.

Local clays of the Coastal Zone and the Corpus Christi area have been utilized for the manufacture of lightweight aggregate, although no plants are currently operating. The process involves expansion or bloating of the partly vitrified clay by rapid firing to give a lightweight aggregate for such uses as concrete blocks and precast concrete. At present, such manufacture is limited to areas outside the Coastal Zone.

Cement and lime.—Cement is manufactured at one plant and lime at another plant along the Corpus Christi Ship Channel industrial corridor. One of the chief raw materials used in preparing cement is natural calcium carbonate. Lime is produced by burning natural calcium carbonate to calcium oxide. The chief source of this raw material was dredged shell, and now a significant amount of Central Texas limestone is imported. Cement is used chiefly in construction; lime is used both for construction and as a raw material for the chemical industry.

Imported Raw Materials

A variety of mineral raw materials and ores is imported to the Corpus Christi area for processing due to easy ocean access, available fuel sources, and favorable location for distribution of processed ores to local and inland markets. Reynolds Metals Company treats imported bauxite ores to obtain alumina from which aluminum metal is produced to be sold for further finishing. Zinc ores and concentrates are imported for processing at an electrolytic plant to produce zinc metal and cadmium (recovered from flue gas). The location of the port at Corpus Christi makes this area one of Texas' major centers for import and export of mineral and agricultural products.

Summary

The Corpus Christi area contains a variety of mineral resources that contribute to the economy of the area either directly through the value of produced raw material or indirectly through the industries they support, supply, and attract. Mineral resources range from those naturally scarce or nearing depletion, such as aggregate and shell, to those present in almost limitless supply, such as common clay and fill sand. Oil and natural gas constitute the bulk of the area's mineral wealth. Reserves of oil and natural gas remain large, though in recent years additions to reserves have not kept pace with production. The decline and ultimate depletion of some of these basic raw materials will call for a fundamental readjustment of the entire Coastal Zone industrial complex.

ACTIVE PROCESSES MAP

The *Active Processes Map* of this Atlas outlines the major physical and biologic processes of the Coastal Zone that are critical for a variety of land and water uses. The main features of the map are a delineation of areas inundated by hurricane-surge floods and a characterization of bay and Gulf shorelines in their present state—erosional, depositional, or in equilibrium. The *Active Processes Map* also delineates areas of oyster reef deposition, wind-tidal flooding, eolian sand transport and deposition, active clay-dune accretion, and reworking and redistribution of subaqueous spoil. Also shown are bay areas characterized by slow to moderate rates of deposition, rapid deposition, and moderate erosion or scour. Statistical data for each map unit are given in table 10.

Hurricane Flooding

Flooding by hurricane surges is a dramatic and highly significant physical process throughout the Coastal Zone and is of prime consideration in the use of coastal lowlands (fig. 10). In the mapped portion of the Corpus Christi area, a total of 209 square miles of lowlands was flooded by storm surges of Hurricane *Carla* in 1961; this is approximately 9 percent of the entire mapped area. Hurricane *Beulah* (1967), a hurricane of similar intensity in this part of the Texas coast, resulted in the flooding of approximately 183 square miles of coastal land. Areas of salt-water inundation by these two recent major hurricanes, indicated on the *Active Processes Map* of this Atlas, were determined by fitting flood elevations from records of tide or river gages and from high-water marks (U. S. Army Corps of Engineers) to detailed topographic maps. Extensive rainfall and river flooding associated with Hurricane *Beulah* affected an additional 212 square miles (9 percent) of the mapped area. Flood elevations were obtained from the U. S. Army Corps of Engineers (1962, 1968) and are indicated by station on the accompanying map. A 50- or 100-year hurricane centered on Corpus Christi Bay could conceivably flood several hundred square miles of the map area if the

Table 10. Areal extent, length, and number of individual units shown on Active Processes Map, Corpus Christi map area, Texas.† (Table pertains only to that part of each county occurring within the Corpus Christi map area. All values are in square miles unless otherwise indicated by symbol.) See tables 3 and 5 for conversion tables.

SPECIAL-USE ENVIRONMENTAL MAP UNITS	Aransas County°	Bee County°	Jim Wells County°	Kleberg County°	Nueces County°	Refugio County°	San Patricio County°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Corpus Christi map area (excluding offshore area)	Percentage of Corpus Christi map area covered by map unit (excluding offshore area)
Lower shoreface and shelf, under normal conditions a decrease in wave and current energy occurs below 8 feet, burrowing by marine organisms common, some longshore and onshore sand transport in shallow areas especially during storms, deposition of some fine suspended sediment	–	–	–	–	–	–	–	–	–	–
Normal surf or breaker zone, high wave energy area, shifting subaqueous bars, zone extends to depth of about 8 feet, longshore and onshore transport of sand common	–	–	–	–	–	–	–	10.0	–	–
Area of moderate erosion or scour to slight deposition, tidal channels shift laterally by cut and fill unless artificially stabilized	1.8	–	–	0	0	0	0	0.8	1.8	0.08
Area of rapid deposition, predominantly tidal delta accretion and aggradation or prodelta progradation	1.3	–	–	0	1.5	1.3	0	9.5	4.1	0.2
Site of active or potential hurricane-washover channel■	8	–	–	0	9	0	0	–	17	–
Shoreline, erosional, eolian processes active along gulfside of barriers▲	7.2	–	–	7.0	16.0[22.0]+	9.8	[22.0]+	–	62.0	–
Shoreline, depositional, accretionary, eolian processes active along gulfside of barriers▲	54.4	–	–	15.0	116.0[8.4]+	6.2	[8.4]+	–	200.0	–
Shoreline in depositional-erosional equilibrium, eolian processes active along gulfside of barriers▲	29.2	–	–	4.8	28.8[6.4]+	2.4	[6.4]+	–	71.6	–
Shoreline stabilized by seawall, dredging, or other man-made structures▲	11.6	–	–	1.6	27.6[10.4]+	0	[10.4]+	–	51.2	–
Area of slow to moderate deposition within bays, predominantly suspension deposition in deeper bay, accretion in some marginal areas	86.1	–	–	23.7	185.3	19.3	0	–	314.4	13.3
Area of active reworking and redistribution of subaqueous spoil by waves and currents	2.6	–	–	3.4	21.2	0	0	–	27.2	1.2
Oyster reef deposition, predominantly vertical growth with some lateral growth, mapped reefs not necessarily all live communities	1.0	–	–	0	1.7	0.2	0	–	2.9	0.1
Area of wind-tidal flooding, commonly generated by persistent north (winter) or southeast (summer) winds, alternating submergence and emergence, extensive wind-driven sand transport during exposure, algal mat development during submergence, fluvial sand locally deposited on flats at mouth of ephemeral streams entering Baffin and Oso Bays	5.4	–	–	1.2	15.5	2.7	3.7	–	28.5	1.2
Active clay-dune accretion on the margin of wind-tidal flats adjacent to Petronila and Oso Creeks	–	–	–	0.2	0.5	–	–	–	0.7	0.03
Eolian sand dunes, active, back-island longitudinal dune fields, barrier island blowouts, areas of active eolian sand transport and deposition, deflation on windward side of migrating dunes	0.2	0	0	2.5	0.2	0	0	–	2.9	0.1
Area inundated by marine water, Hurricane *Carla* storm-surge tide	60.6	0	0	18.8	71.5	15.3	42.8	–	209.0	8.9
Hurricane *Carla* recording tide gage, high watermark elevation, datum mean sea level■	0	–	–	0	3	0	0	–	3	–
Hurricane *Carla* recording site, still, high watermark elevation, datum mean sea level■	5	–	–	0	2	1	2	–	10	–
Hurricane *Carla* storm-surge debris or driftline elevation, datum mean sea level■	1	–	–	0	3	0	1	–	5	–
Area inundated by marine water, Hurricane *Beulah* storm-surge tide	45.8	0	0	16.8	67.3	17.2	36.0	–	183.1	7.8
Area inundated by river flooding and rainfall runoff, Hurricane *Beulah* rainfall and aftermath storms, extensive ponding in depressions and poorly drained areas	2.6	25.0	0.3	14.5	60.0	46.0	64.3	–	212.7	9.0
Hurricane *Beulah* recording tide or river gage, high watermark elevation, datum mean sea level■	3	0	0	0	7	1	2	–	13	–
Hurricane *Beulah* recording site, still, high watermark elevation, datum mean sea level■	9	0	0	0	14	2	6	–	31	–
Hurricane *Beulah* storm-surge and river-flooding debris or driftline elevation, datum mean sea level■	0	2	0	0	13	5	9	–	29	–
Map color patterns overlap where active processes occur in the same area, resulting in a unique color code as follows:										
a Eolian sand dunes covered by Hurricane *Carla* storm-surge tide	0.6	–	–	1.0	0.3	–	–	–	1.9	0.08
b Eolian sand dunes covered by Hurricane *Beulah* storm-surge tide	0	–	–	5.8	2.5	–	–	–	8.3	0.4

†Data accuracy approximately 90 to 95 percent; area determined by point-count method and linear values determined by map-measuring wheel.
°Only part of each county lies within map area.
–Data not measured or unit not applicable.
■Number of specific occurrences of map feature.
▲Value is linear distance in miles.
+Miles along county line common with adjacent county.

hurricane-tidal surge reached 25 feet above mean sea level.

Besides extensive salt-water inundation and river flooding, hurricanes can inflict significant wind damage on natural environments and, particularly, man-made structures. McGowen and others (1970) refer to Hurricanes *Carla* and *Beulah* as typical of hurricanes characterized by high storm surge (extensive salt-water inundation of low-lying areas) and by large amounts of associated rainfall (extensive river flooding), respectively. Hurricane *Celia*, which struck the coast near Port Aransas in 1970, is considered more typical of hurricanes characterized by high winds with extensive wind damage being their major impact on the coast. McGowen and others (1970) completely discuss and compare hurricane types as well as describe the Corpus Christi area following the passage of Hurricane *Celia*. Figure 31 compares the different impacts on the Corpus Christi area by Hurricanes *Carla*, *Beulah*, and *Celia*. Hurricane *Celia* resulted in less extensive salt-water and river flooding in the Corpus Christi map area, even though the eye of the hurricane passed directly over the Port Aransas-Aransas Pass area, and the eyes of *Beulah* and *Carla* struck the coast 125 miles north and 70 miles south, respectively. Figure 31B illustrates the large area of intensive wind damage focused on the north side of Corpus Christi and Nueces Bays and the even larger area of significant wind damage to structures and disruption of utility service.

In addition, sites of active or potentially active hurricane-washover channels are indicated on the *Active Processes Map*. These were determined from the mapping of active and abandoned, partially healed washover channels shown on the *Environmental Geology Map*. A more detailed treatment of the physical processes of hurricanes and their effect and impact on the Coastal Zone is given elsewhere in the text of this Atlas. Coastal hazards, including the effects of hurricanes and shoreline erosion, have been described in a report of the Bureau of Economic Geology (Brown and others, 1974).

Shoreline Processes

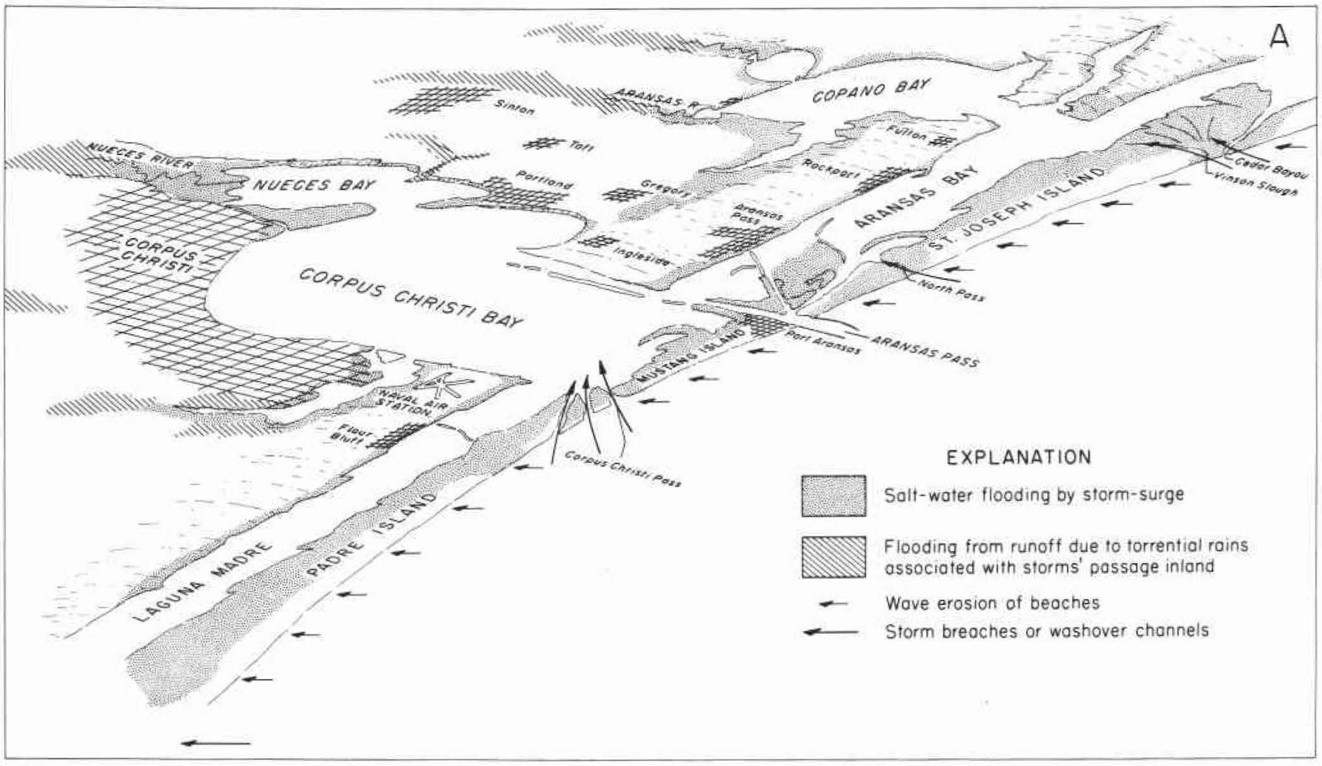
The state of a shoreline, whether erosional, depositional, artificially stabilized, or in natural equilibrium, is largely determined by natural processes (fig. 8), which are commonly altered by a variety of shoreline activities involving construction. On the *Active Processes Map*, approximately 385 linear miles of bay and Gulf shorelines of the Corpus Christi area are characterized by a specific, dominant active process.

Shoreline changes indicated on the *Active Processes Map* of the Corpus Christi Atlas represent *long-term* trends. Such trends and changes of shoreline positions occur over a period of at least several tens of years. However, historical monitoring of Gulf shorelines (Morton and Pieper, 1976; Morton and Pieper, in press) delineates *short-term* shoreline changes in addition to documenting the *long-term* trends. *Short-term* changes are more likely to reflect the impact of storms and storm-related processes or recent human activity on bay and Gulf shorelines and do not necessarily reflect *long-term* trends such as variation in eustatic sea level, climatic changes affecting sediment supply, or regional compactional subsidence.

The nature of shorelines shown on the *Active Processes Map* reflects the state of knowledge concerning long-term shoreline conditions as of the early 1970's. Such determinations, based mainly on observational data and limited aerial photography, are subject to some revision by the more detailed, comprehensive historical monitoring programs currently being completed. With such programs (Morton and Pieper, 1976; Morton and Pieper, in press; White and others, in preparation), refinement of knowledge of bay and Gulf shoreline conditions is now and will be possible.

Except for two areas, the Gulf shoreline in the Corpus Christi map area is shown to be in equilibrium on the *Active Processes Map*. Historical monitoring data tend to verify the stability of this shoreline as only low rates of net erosion (1 to 3 feet per year) have occurred between the 1860's and 1974. The vicinity of the Aransas Pass jetties and the Gulf shoreline on Padre Island about 5 miles south of Packery Channel have experienced low to moderate rates of accretion during this same time span. The low rates of change over more than 100 years of record suggest relatively stable Gulf shorelines. Rates of shoreline change within the last 10 to 15 years (short term), however, exhibit moderate to high rates of erosion all along the Gulf shoreline in the Corpus Christi area except for net accretion several miles south of Packery Channel. These higher rates of shoreline change reflect relative instability of the Gulf shorelines and the more dominantly erosional character of most of the Texas Gulf shoreline in recent times.

Refinement of knowledge of shoreline conditions in the Corpus Christi map area has been determined for the bay shoreline of Mustang Island. Historical monitoring analysis points to low rates of net erosion along the north shore of Shamrock Island, with the remainder of this bay shoreline segment accurately depicted on the *Active Processes Map*. Updated information on bay shoreline conditions in Corpus Christi, Nueces, Redfish,



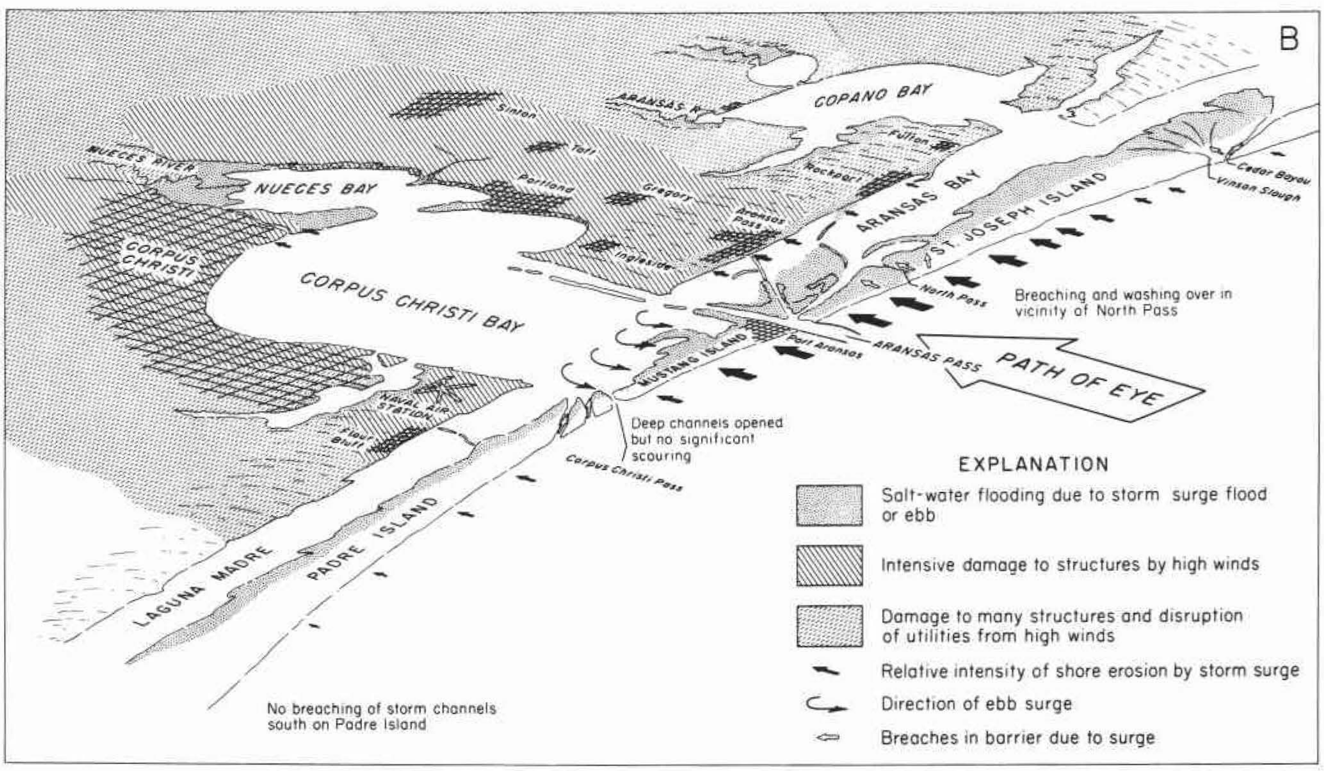


Figure 31. Comparison of the impact of Hurricanes *Carla* and *Beulah* with *Celia* on the Corpus Christi area. (A) *Carla's* and *Beulah's* effects on the Coastal Bend region. These hurricanes made landfall about 70 miles northeast and 125 miles south of Corpus Christi, respectively. (B) *Celia* struck the Coastal Bend at Port Aransas, resulting in severe wind damage. After McGowen and others (1970).

Aransas, Copano, and Mission Bays and Laguna Madre will necessarily await future historical shoreline monitoring programs. Initiation and completion of such programs throughout the Coastal Zone will eventually permit refinement of knowledge of shoreline conditions in other Texas bay and Gulf areas as well.

Within the Corpus Christi map area, about 50 linear miles of shoreline have been stabilized artificially by seawall construction, continued dredging activity and spoil disposal, or construction of other man-made structures. Artificial stabilization of bay shores results from maintenance of deep-water channels and canals, protection of shorelines from erosion, and establishment of made or reclaimed lands. Approximately 70 linear miles, or about 18 percent of the total shorelines of the area, are naturally stabilized or essentially in erosional-depositional equilibrium; that is, the shoreline is undergoing neither accretion nor erosion. A principal natural agent of shoreline stabilization in the Corpus Christi area is vegetation associated with salt marshes, especially where this vegetation is developed on compact clay substrates. Stabilized shores at Whites Point, along Lydia Ann Channel, and at the mouth of Mission Bay reflect the binding nature of salt marsh vegetation. A second principal natural agent of shoreline stabilization is a balance between depositional processes favoring shoreline accretion and erosional processes favoring net loss of land. The stabilized shores at Rattlesnake Point, along Egery Island, in the Copano Village area, and along the southeast side of bay-margin sand and mud islands in Redfish Bay are examples of shores that are near sources of sediment and are subject to high wave and current energy at the same time. This same balance of erosional-depositional processes is reflected over most of the Gulf shoreline within the Corpus Christi area; however, moderate to high rates of erosion over the last 15 years have been recently measured over much of this same shoreline (Morton and Pieper, in press). Generally, the combined sediment input from longshore drift and the inner shelf are in balance over the *long term* with the relatively high energy of the open coast.

Approximately 200 linear miles, or about 52 percent of the total shoreline of the mapped area, are undergoing some degree of long-term accretion or net gain in land. These are invariably shorelines receiving a surplus volume of sediment. Accretion of the offshore barrier shoreline is most pronounced near the mouth of Aransas Pass (the main tidal pass in the Corpus Christi area) and along Padre Island, several miles south of Packery Channel. An ebb-tidal delta located at Aransas Pass documents the movement of sediment out of the tidal pass and bays, and the accreting shore of Padre Island reflects the deposition of sediment entrained by longshore currents as well as the sands moved onshore from the inner continental shelf. Most areas of spoil dredging are characterized by accreting shorelines as waves and currents rework spoil along major transportation channels and at sites of oil well pads, such as those at Shamrock Cove and near Encinal Peninsula. High sediment input from rivers causes shorelines at river mouths (deltas) to accrete; examples are the active portion of the Nueces River delta in Nueces Bay and the deltas of Aransas and Mission Rivers. An abundant local supply of sandy sediment from Pleistocene sheet sand and barrier-strandplain deposits is causing Port Bay shorelines to accrete; this shallow bay is gradually filling with sediment. Similarly, Oso Bay shorelines are accreting due to sediment input from Oso Creek and from the nearby sandy, poorly vegetated Encinal Peninsula.

About 62 linear miles of shoreline in the mapped area (about 16 percent of the total bay and Gulf shoreline) are undergoing some degree of long-term erosion or net loss of land. Bay shorelines downwind from the predominant wind directions are subjected to relatively high wave energy, particularly when wind orientation, such as in the Corpus Christi map area, favors strong wave activity due to the long fetch across bay waters. Both northerly and southeasterly winds generate waves impinging on the bay shores; southeast-generated waves strike the north shores of Corpus Christi and Nueces Bays and north-generated waves strike the southwest shore of Corpus Christi Bay and the back side of Mustang Island. In these areas, wave energy is sufficiently high to produce net erosion or loss of land. The inactive portions of Nueces River delta are undergoing a net loss of land due to compaction of mud sediment and the impingement of waves on abandoned parts of the bayhead delta. Small areas of spoil are being reworked and eroded in the Redfish Bay area.

The state of a shoreline, whether erosional, depositional, or in equilibrium, is largely a function of natural processes. Chief among these processes are availability of sediment supply and intensity of wave activity (fig. 8). This natural balance can be altered only on a local basis. A common practice is to construct groins or other obstructions that check the lateral movements of longshore currents and sediments along the shoreline, but each alteration in the natural process is simply compensated for in another place. For example, construction of a jetty or groin along an erosional shoreline of the Texas coast will trap sediment immediately upcurrent from the structure but may generate even more serious erosion downcurrent from the structure. In some instances, specific local management or alteration of shoreline processes may be necessary, but modification to diminish erosion and accelerate shoreline accretion cannot be effective on a regional basis. Proper management requires the recognition of the nature of a specific shoreline, the processes that determine its nature, and the development of shoreline uses in accordance with this natural state.

Other Active Processes

Several other active processes, in many ways less dramatic than hurricane flooding and shoreline processes, are important to a variety of land and water uses. Certain of these are indicated on the *Active Processes Map*.

Rates of sediment deposition within the bays and estuaries of the Coastal Zone, as well as within the offshore areas, are variable. The areas of most rapid marine deposition in the Corpus Christi map area are the flood and ebb deltas of the main tidal pass—Aransas Pass—and the prodeltas of the Nueces and Mission Rivers. Tidal passes are, of course, the principal areas of water interchange between the Gulf and the bays. Although tidal action is relatively slight along the Texas coast (1.7 feet in daily range in the Port Aransas area), tidal currents are sufficiently strong to scour the tidal channels and carry a sediment load. The process involves transport of sediment into the bay with the flood tide and transport of sediment to the gulfside with the ebb tide. Through deposition at the bay and Gulf termini of the tidal channels, active sediment build-up occurs. Eventually, flood deltas of tidal passes may emerge; Harbor Island between Lydia Ann Channel and Aransas Channel is an example of an emergent flood delta. In addition, intrabay areas experience tidal interchange at natural passes near Demit Island, Shellbank Island, and the mouths of both Mission Bay and Mission Lake. Tidal delta accretion is associated with each of these areas.

The area of rapid deposition off Nueces River results in sediment debouchment at the river mouth (fig. 8). The relatively small traction load of sand-sized sediment is dropped immediately at the mouth of the river, forming a delta-front shoal. Suspended mud-sized sediment is carried farther bayward; dams on the Nueces River have effectively decreased sediment input, though prodelta progradation continues to some extent. Remaining areas in the bays in the Corpus Christi map area are characterized by slow to moderate rates of deposition. Unfortunately, no quantitative studies of depositional rates throughout the bay system have been made.

Zones of highest physical energy are restricted to two main areas. One zone includes the tidal channels, where confined tidal currents scour the deeper parts of the channel; the other zone of higher energy is the upper part of the shoreface, extending seaward from the beach to water depths of about 8 feet, where breaking waves expend large amounts of physical energy.

Biologic processes within the Coastal Zone are diverse and contribute significantly to a variety of active processes. One of the most prominent expressions of biologic activity is reef development. Reefs, both live and dead, are shown on several maps of this Atlas. Built mostly of oysters, they cover approximately 3 square miles of bottom in the bay-estuary-lagoon system. Principal reef development is in Copano Bay, Nueces Bay, and upper portions of Corpus Christi Bay.

Alternating submergence and emergence of land areas by wind-generated tides occur over 29 square miles of the low-lying areas in the Corpus Christi map area. Wind-tidal areas are essentially barren with algae growth in the form of algal mats common during periods of submergence. Blowing sand characterizes these areas during times of emergence when surface sediment becomes desiccated.

Eolian processes dominate less than 1 percent of the Corpus Christi map area, principally on north Padre, south Mustang, and St. Joseph Islands. Here wind activity is sufficient to move sand grains and create active blowout dunes and extensive back-island dune fields. These active dunes on the barrier islands cover about 13 square miles. On the mainland along Petronila and Oso Creeks, active clay-sand dune accretion takes place within localized areas comprising less than 1 square mile. Clay-sand dunes accrete as strong winds deflate surfaces of occasionally flooded lowlands and move sand- and silt-sized pellets of clay across the flats and onto the windward side of an active dune.

Another prominent physical process in the Texas Coastal Zone is the reworking and redistribution of spoil dredged from channels. In fact, the principal supply of sediment in the shallow bays of the Coastal Zone is spoil. Dredged spoil banks form loose, uncompacted masses of sediment subject to rapid reworking and redistribution by ordinary waves and currents. Perhaps the most serious effect of spoil redistribution is the blanketing of bay-margin grassflats. Veneering of these marine habitats by barren spoil destroys environments of high organic productivity, affecting the entire ecosystem of the bays and estuaries. In addition, piling of subaqueous spoil tends to compartmentalize shallow coastal bays, modifying natural circulation and altering temperature and salinity gradients.

The major active processes of the Corpus Christi area are treated here only in a qualitative manner. Unfortunately, much of the observation and monitoring necessary for quantitative assessment of the nature and effects of active processes has not been initiated within the Coastal Zone. Further, certain important processes, such as water-circulation patterns in the bays and estuaries, are inadequately known. For certain processes, statistical or numerical models have been developed, but few of these have been sufficiently tested against observed processes in the field. Similarly, the array of natural variables within the bay-estuary-lagoon system is poorly understood and, therefore, has not yet been included in theoretical modeling. Recently, historical monitoring analysis of natural environments on Mustang and north Padre Islands (White and others, in preparation) has demonstrated the dynamic nature of coastal environments (figs. 28 and 29). Detailed monitoring of the areal extent of environments suggests significant trends of environmental change and defines the active processes causing these changes. Unfortunately, few parts of the Texas Coastal Zone have been studied using historical monitoring programs; exceptions are Texas Gulf shorelines, bay shorelines, and marshy areas in Matagorda Bay, and the subaerial and shallow subaqueous environments on Mustang and north Padre Islands.

Since active processes not only are a vital expression of the Coastal Zone environment but also are of prime consideration in proper management and use of the Zone, they must be understood far better than they are at present.

MAN-MADE FEATURES AND WATER SYSTEMS MAP

The *Man-Made Features and Water Systems Map* of this Atlas combines on one sheet the products of man's construction activities and the various surface water systems, including natural and artificial water bodies. Presentation on a single map is for cartographic convenience. Statistical data for each map unit are included on table 11.

Man-Made Features

Features delineated as man made are compiled, in part, from the *Current Land Use Map* and illustrate man's impact on the Corpus Christi area. One aspect of man's activity here is urban and industrial construction; indicated are urban and residential areas, heavy-industry areas, and undifferentiated urban land, including chiefly undeveloped urban tracts, greenbelts, and cemeteries. Another major alteration by man in this area of the Coastal Zone is shown by the extent of dredged spoil and made land. Spoil is most extensive along land cuts and intrabay dredged channels of the Intracoastal Waterway, Viola, Tule Lake, La Quinta, Aransas, and Corpus Christi Ship Channels, and Aransas Pass. The principal areas of made land are along the Viola-Tule Lake-Turning Basin shipping corridor of the Corpus Christi Ship Channel, and in several other areas, including Harbor Island, Frandolig Island, the Aransas Pass Causeway, the area south of Rockport, the area west of Portland, and the Encinal Peninsula. Also adopted from the *Current Land Use Map* are sewage, solid-waste, and industrial-waste disposal sites.

The major pipeline networks of the area are indicated and are also a part of the *Mineral and Energy Resources* and *Current Land Use Maps*; they include only the major lines and are, of necessity, incomplete. Several sources, including the Railroad Commission of Texas (1971) and Transcontinental Gas Pipe Line Corporation (1970), were used in the compilation of the pipeline networks of the area. Petroleum production platforms in the offshore areas are also plotted. Small oil and gas production facilities are present in Nueces and Corpus Christi Bays; these are not shown on the map.

A significant type of coastal or shoreline construction is the building of piers, jetties, and groins. Principal concentrations of piers and jetties are along the bay shores west of Whites Point, at Corpus Christi, North Beach, Portland, Rockport, Fulton, Bayside, and the Salt Lake area, and within numerous other areas bordering the bays which are not indicated on the map. In addition, a 12-foot-high seawall was constructed along the Gulf shore in the Packery Channel area in an effort to protect privately owned recreational/community development on the barrier island.

Water Systems

The surface water systems of the Corpus Christi area include over 400 square miles of natural and artificial water bodies excluding the Gulf. The natural water systems include about 32 square miles of fresh-water bodies (streams, natural lakes and ponds, and sloughs of abandoned channels) and 340 square miles of marine bodies excluding the Gulf (tidal inlets, bays, lagoons, and estuaries). Wind-tidal flats, covering approximately 30 square miles, are intermittently flooded by bay and lagoonal waters and then subaerially exposed. The principal fresh-water streams in the area

Table 11. Areal extent, length, and number of individual environmental units shown on Man-Made Features and Water Systems Map, Corpus Christi map area, Texas.† (Table pertains only to that part of each county occurring within the Corpus Christi map area. All values are in square miles unless otherwise indicated by symbol.) See tables 3 and 5 for conversion tables.

SPECIAL-USE ENVIRONMENTAL MAP UNITS	Aransas County°	Bee County°	Jim Wells County°	Kleberg County°	Nueces County°	Refugio County°	San Patricio County°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Corpus Christi map area (excluding offshore area)	Percentage of Corpus Christi map area covered by map unit (excluding offshore area)
MAN-MADE FEATURES										
Urban and residential area, metropolitan and minor villages	8.3	0.1	0	0.8	24.3	2.0	13.5	–	49.0	2.1
Undifferentiated urban land, undeveloped tracts, greenbelts, cemeteries	0	0	0	0	4.0	0	0	–	4.0	0.2
Industrial area, concentrated in metropolitan areas but includes isolated industrial developments	0.3	0	0	0.1	6.0	0.3	2.5	–	9.2	0.4
Made land, filled, graded, composed of dredge-spoil or other fill material	1.8	0	0	0	11.8	0	1.0	–	14.6	0.6
Subaerial spoil, includes spoil heaps or mounds and reworked spoil, small wash areas common	1.5	0	0	1.4	10.9	0	0.9	–	14.7	0.6
Subaqueous spoil, in part reworked by waves and currents	2.6	–	–	3.4	21.2	0	0	0.8	27.2	1.2
Jetty or pier, individual structure or area of numerous structures	–	–	–	–	–	–	–	–	–	–
Seawall including associated berm or levee■	0	–	–	0	3	0	0	–	3	–
Pipeline, major lines only, incomplete	–	–	–	–	–	–	–	–	–	–
Offshore petroleum production platform, Gulf■	–	–	–	–	–	–	–	14	–	–
Private airfield, paved, graded, or sod■	0	0	0	0	1	2	5	–	8	–
Sewage disposal site, liquid effluent, normally treated■	1	0	0	0	9	1	5	–	16	–
Solid-waste disposal site, sanitary and open sites■	2	0	0	0	8	1	10	–	21	–
Sludge pit or miscellaneous waste disposal site, may be abandoned■	1	0	0	0	14	0	3	–	18	–
WATER SYSTEMS										
Open ocean	–	–	–	–	–	–	–	–	–	–
Tidal inlet and pass, natural pass, commonly dredged or otherwise modified for navigation purposes	2.7	–	–	0	0.8	0.9	0	–	4.4	0.2
Lagoon, bay, and estuary, variable salinity depending upon rainfall and runoff	84.5	–	–	23.7	208.2	19.3	0.3	–	336.0	14.3
Transportation canal and channel, including intracoastal system and other ship channels▲	25.6	0	0	17.2	128.0	0	2.8	–	173.6	–
Wind-tidal flats, intermittently flooded by bay and lagoonal waters	8.0	–	–	1.2	15.5	2.7	3.7	–	31.1	1.3
Tidally affected stream, influenced by low astronomical or wind tide▲	1.2[1.6]+	0	0	0	[10.0]+	10.0[7.6]+	36.4[16.0]+	–	65.2	–
River or stream, natural drainage	–	–	–	–	–	–	–	–	–	–
Slough or abandoned course and cutoff, water-filled	2.3	0	0	0	1.8	0	1.8	–	5.9	0.3
Lake or pond, natural with minimum modification	4.3	0.1	0	0	0.7	3.1	2.6	–	10.8	0.5
Lake or pond, natural with minimum modification, ephemeral	0	0	0	13.0	2.0	0	0	–	15.0	0.6
Drainage or irrigation ditch and canal, major system only, supplies or drains many small systems▲	0	0	0	2.0[6.4]+	140.0[6.4]+	0	89.6	–	238.0	–
Artificial reservoir, flood control, municipal water supply, industrial waste disposal, power plant cooling, or recreation, some quarries and pits	8.8	0	0	0.5	3.5	0	2.8	–	15.6	0.7
Principal rivers and streams▲	[1.6]+	0	0	5.2	11.2[10.0]+	5.6[18.0]+	1.6[26.4]+	–	51.6	–
Bay-estuary-lagoon shoreline▲	82.8	–	–	18.4	95.2[44.0]+	18.4	1.2[44.0]+	–	258.8	–
Open Gulf shoreline▲	14.0	–	–	10.0	21.2	0	0	–	45.2	–

†Data accuracy approximately 90 to 95 percent; area determined by point-count method and linear values determined by map-measuring wheel.
°Only part of each county lies within map area.
–Data not measured or unit not applicable.
■Number of specific occurrences of map feature.
▲Value is linear distance in miles.
+Miles of principal rivers, canals, and channels along county line; common with adjacent county.

are the Nueces River, Aransas River, and portions of the Mission River, along with several secondary streams such as San Fernando, Petronila, Oso, Chiltipin, Papalote, Melon, Sous, and Medio Creeks, and Mullens Bayou, and Chocolate Swale. Although tide levels are low, about 65 linear miles of streams have some tidal influence in their lower parts; examples are the lower portions of Nueces, Aransas, and Mission Rivers, as well as Mullens Bayou, McCampbell Slough, and the largely inactive distributaries of the Nueces River delta.

A number of natural lakes and ponds covering 26 square miles are concentrated: (1) along the lower parts of the Nueces, Aransas, and Mission river valleys, (2) in depressions and other low-lying areas on and just inland of Pleistocene barrier-strandplain deposits, (3) in marshlands on Pleistocene deltaic deposits, and (4) in low areas isolated by made land or subaerial spoil. The largest natural lake is the ephemeral Laguna Larga formed in an isolated depression behind the Pleistocene barrier-strandplain sand body south of Encinal Peninsula. Most of these water bodies are circular to elliptical; exceptions are certain of the lakes that formed in elongate swales on the coastal barrier islands and in depressions along Modern river valleys. All these landlocked coastal water bodies are fresh to locally brackish but may pond salt water following high tides and storms. All are very shallow, and several are in the process of filling with sediment.

A third type of natural fresh-water body in the Corpus Christi area consists of about 6 square miles of elongate sloughs formed from abandoned loops and channels of older streams or now-closed tidal passes on the coastal barrier. Packery Channel, Newport Pass, North Pass, and Corpus Christi Pass are the most extensive sloughs in the mapped area. These and other similar sloughs on the coastal barrier islands represent former tidal passes that are presently sealed on their gulfside. Slough development representing an abandoned stream course is developed just north of Nueces River.

The major water bodies in the mapped area are Laguna Madre, Corpus Christi, Nueces, Aransas, and Copano Bays, and several smaller bays such as Oso, Redfish, South Port, and Mission Bays. Bay waters range from less than 10 ‰ salinity in the upper river-influenced portions to near normal marine salinity in the open-bay and tidal-channel areas to commonly hypersaline conditions in northern Laguna Madre. Open Gulf waters, of course, have a normal marine salinity of approximately 35 ‰. The various subdivisions of the bay and offshore water bodies are delineated on the *Environments and Biologic Assemblages Map*.

Artificial water bodies include numerous surface reservoirs and an extensive system of land and water canals. Canal systems are of two types: (1) approximately 175 linear miles of transportation canals, including the Intracoastal Waterway and the Corpus Christi Ship Channel, as well as shorter branches and extensions of these systems, such as the La Quinta and Aransas Channels, and (2) about 240 miles of major drainage and irrigation canals, which form extensive networks in the agricultural coastal uplands. The transportation canals are constructed as land cuts and as dredged channels within the bays, estuaries, and tidal passes, whereas the irrigation and drainage canals on the coastal uplands have been developed largely in support of the extensive crop cultivation. Most of the irrigation canals have been privately constructed, and others are maintained by local government units; transportation canals were dredged and are maintained by U. S. Army Corps of Engineers.

A large number of surface reservoirs have been constructed throughout the area and are used for municipal, industrial, and irrigation water supplies, as well as for power plant cooling, flood control, and recreation needs. Artificial reservoirs cover 16 square miles of the mapped area.

RAINFALL, STREAM DISCHARGE, AND SURFACE SALINITY MAP

The *Rainfall, Stream Discharge, and Surface Salinity Map* of this Atlas summarizes salient climatic features of the Corpus Christi area. Data were selected for the three-year period from 1965 to 1967, for which detailed and continuous coverage exists.

Rainfall recorded as precipitation in inches per month is shown for 10 stations within or adjacent to the mapped area: Robstown, Corpus Christi Airport, Corpus Christi, Chapman Ranch, Rockport, Aransas Pass, Sinton, Welder Wildlife Foundation, Alice, and Mathis (the last two stations are beyond the boundary of the mapped area). Data for the 1965-67 period were taken from reports of the U. S. Weather Service and are shown graphically on the map.

Discharge data, recorded as average daily discharge in cubic feet per second, are shown graphically for this same three-year period. Discharge data, compiled from reports of the Water Resources Division of the U. S. Geological Survey, are shown for the following four stations, all of which are located upstream, just outside the mapped area: Station 8-2119 on San Fernando Creek, Station 8-2110 on the Nueces River, Station

8-1897 on the Aransas River, and Station 8-1895 on the Mission River.

Measurements of surface salinity were compiled from 35 stations within Laguna Madre, Lydia Ann Channel, and Corpus Christi, Nueces, Redfish, Aransas, and Copano Bays. These data were obtained from yearly reports of the Texas Parks and Wildlife Department and include the same period of time covered by discharge and rainfall data; measurements from 16 stations are shown graphically. Surface salinity of the bays is contoured for three general periods: (1) extremely low salinity, corresponding to periods of relatively high precipitation and discharge; (2) extremely high surface salinity, corresponding to periods of relatively low rainfall and runoff; and (3) calculated average salinity.

Correlation between precipitation and discharge for the three-year period covered is obvious, with the greatest discharge following high rainfall. During periods of high rainfall and discharge, surface salinity in the bays is reduced and ranges from less than $2\,^{\circ}/_{\circ\circ}$ to $26\,^{\circ}/_{\circ\circ}$. Lowest salinities are recorded during these periods in the upper part of Nueces Bay, where stream discharge is greatest; highest salinities occur in the area of Aransas Pass, where interchange of bay and Gulf waters takes place (fig. 8).

High surface salinity in the bays is recorded during periods of low rainfall and stream discharge. When these conditions occurred during the three-year period (1965-67), salinities ranged from nearly $32\,^{\circ}/_{\circ\circ}$ in the upper parts of Copano Bay to more than $58\,^{\circ}/_{\circ\circ}$ in the area of Laguna Madre, where the highest maximum reading for salinity during this period was recorded in the restricted portion of northern Laguna Madre—over $59\,^{\circ}/_{\circ\circ}$.

Calculated average surface salinities for the 1965-67 period ranged from less than $24\,^{\circ}/_{\circ\circ}$ in the upper part of Copano Bay to about $30\,^{\circ}/_{\circ\circ}$ in the vicinity of Lydia Ann Channel in Aransas Bay and over $41\,^{\circ}/_{\circ\circ}$ in partly restricted Laguna Madre. Salinity contours show variation in average surface salinity and illustrate the reduction of salinity near areas influenced by river discharge and the increase in surface salinity in the vicinity of tidal passes. In addition, areas where restricted circulation inhibits exchange of bay waters and evaporation rates are high, surface salinity of the bays reaches hypersaline levels; such conditions exist in Laguna Madre. Daily variations in wind, tide, and runoff result in a continually changing pattern of surface as well as three-dimensional salinities; the map is intended to show, nevertheless, the basic patterns to be expected within the system.

TOPOGRAPHY AND BATHYMETRY MAP

The *Topography and Bathymetry Map* included in this Atlas is a basic tool in the evaluation of land and water use and capability. Topography is indicated on the map with a distinct but graduated color pattern for each 5-foot interval of ground elevation. Elevations range from sea level to nearly 145 feet in the inland portions of the Corpus Christi map area, specifically Burkes Ridge in Bee County. Topographic control for this map, scale 1:250,000, and on the *Environmental Geology Map*, scale 1:125,000, was compiled from U. S. Geological Survey detailed 7.5-minute topographic maps, scale 1:24,000.

Bathymetric contours are shown at intervals of 6 feet, or 1 fathom, and are also represented by distinct gradational color patterns for ready determination of bottom relief and configuration. These contours are shown on the *Environmental Geology Map* and were compiled from 7.5-minute topographic sheets and U. S. Coast and Geodetic Survey nautical charts (fig. 3B). Depths range from mean sea level to more than 30 feet. Deepest areas are within the active tidal channels, dredged channels, and the inner shelf area. Depth of the navigation channels varies according to project depths and certain specifications.

A slope map can be constructed from the *Topography and Bathymetry Map*, though more detail and better presentation of land and bottom configuration are obtained for the flat-lying Coastal Zone by shaded contour intervals.

The *Topography and Bathymetry Map* is an important adjunct to other special-use environmental maps of this Atlas. For example, it can be used in conjunction with the *Physical Properties Map* in evaluating lands for waste disposal and construction suitability. It serves as a convenient base for determining the land areas subject to flooding with a given flood crest. The map allows a user to calculate the effect that potential subsidence will have on the elevation of a specific area. In turn, location and amount of flooding by bay water (if subsidence lowers the area below sea level) can be calculated; the effects of hurricane-tidal surge of various heights can also be postulated for the subsiding area.

Table 12 gives the areal extent of each contour interval (topography and bathymetry). Such information readily inventories the amount of land that occurs between selected elevations (topography) or depths (bathymetry). For example, if a flood crest is predicted at 25 feet, the amount of land subject to flooding can be determined immediately.

Table 12. Areal extent of each 5-foot topographic contour interval and each 6-foot bathymetric contour interval shown on Topography and Bathymetry Map, Corpus Christi map area, Texas.† (Table pertains only to that part of each county occurring within the Corpus Christi map area. All values are in square miles unless otherwise indicated by symbol.) See tables 3 and 5 for conversion tables.

SPECIAL-USE ENVIRONMENTAL MAP UNITS		Aransas County°	Bee County°	Jim Wells County°	Kleberg County°	Nueces County°	Refugio County°	San Patricio County°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Corpus Christi map area (excluding offshore area)	Percentage of Corpus Christi map area covered by map unit (excluding offshore area)
ABOVE SEA LEVEL (feet)	140-145	0	0.5	0	0	0	0	0	–	0.5	0.02
	135-140	0	0.7	0	0	0	0	0	–	0.7	0.03
	130-135	0	1.7	0	0.5	0	0	0	–	2.2	0.09
	125-130	0	2.4	0	0.5	0	0	0	–	2.9	0.1
	120-125	0	1.5	0	1.3	0.3	0	0	–	3.1	0.1
	115-120	0	2.0	0.5	2.5	2.3	0	2.9	–	10.2	0.4
	110-115	0	2.0	0.3	2.8	7.0	0	7.0	–	19.1	0.8
	105-110	0	3.5	0.3	3.3	8.0	0	15.7	–	30.8	1.3
	100-105	0	6.9	0	4.3	8.5	0	14.0	–	33.7	1.4
	95-100	0	9.2	0	3.3	10.0	0	16.9	–	39.4	1.6
	90-95	0	20.2	0	4.5	29.0	1.0	14.0	–	68.7	2.9
	85-90	0	19.8	0	2.8	29.5	1.5	12.6	–	66.2	2.8
	80-85	0	18.2	0	2.3	36.5	5.8	15.0	–	77.8	3.3
	75-80	0	9.4	0	3.3	33.3	8.6	15.2	–	69.8	2.9
	70-75	0	4.5	0	2.5	38.5	13.0	19.3	–	77.8	3.3
	65-70	0	3.0	0	1.0	46.3	14.7	19.3	–	84.3	3.5
	60-65	0	0.2	0	0.5	39.5	14.2	23.2	–	77.6	3.3
	55-60	0	0.2	0	0.5	39.3	10.3	41.8	–	92.1	3.9
	50-55	0	0	0	2.8	44.8	18.1	50.7	–	116.4	4.9
	45-50	0	0	0	6.0	44.8	20.3	35.3	–	106.4	4.5
	40-45	0	0	0	4.3	48.0	21.7	36.2	–	110.2	4.6
	35-40	0	0	0	11.0	52.5	14.0	30.9	–	108.4	4.6
	30-35	0	0	0	16.7	42.3	24.7	28.0	–	111.7	4.7
	25-30	0.5	0	0	12.8	32.0	30.9	25.8	–	102.0	4.3
	20-25	5.7	0	0	24.4	43.0	12.0	40.8	–	125.9	5.3
	15-20	13.8	0	0	27.2	45.0	6.6	24.9	–	117.5	4.9
	10-15	18.5	0	0	15.0	27.0	6.6	25.1	–	92.2	3.9
	5-10	29.6	0	0	3.5	15.5	5.9	24.9	–	79.4	3.3
	0-5	36.7	0	0	4.0	57.8	14.6	29.0	–	142.1	6.0
SEA LEVEL											
BELOW SEA LEVEL (feet)	0-6	36.9	0	0	42.4	100.5	14.4	0.5	5.5	194.7	8.2
	6-12	61.3	0	0	0	101.8	5.1	0	7.3	168.2	7.1
	12-18	0	0	0	0	37.0	0	0	10.5	37.0	1.5
	18-24	0	0	0	0	0	0	0	9.0	–	–
	24-30	0	0	0	0	0	0	0	14.8	–	–
	30-	–	–	–	–	–	–	–	–	–	–
	Shifting sand dunes*	0	0	0	8.5	2.3	0	0	–	10.8	0.5

†Data accuracy approximately 90 to 95 percent; area determined by point-count method and linear values determined by map-measuring wheel.
°Only part of each county lies within map area.
—Data not measured or unit not applicable.
*Area not included in other units above.

RESOURCE CAPABILITY: UTILITY IN LAND AND WATER MANAGEMENT

A basic goal of the Environmental Geologic Atlas of the Texas Coastal Zone is a regional inventory of the natural resources of the Zone. Flexible management of the Texas Coastal Zone should be based on the natural capability of resource and environment units. Such units were first termed *natural resource capability units* by Brown and others (1971). These units are derived from the maps included in this Atlas (table 13). The term *land and water resource unit* is a more appropriate name for these basic environmental elements. St. Clair and others (1975) define the units as follows: "Land and water resource units are mappable entities, either natural or man-made, that are defined by the physical, chemical, and biological characteristics or processes which govern the type or degree of use that is consistent with both their natural quality and productive utilization."

The concept of land and water resource units has been applied recently in a map of the 13-county area encompassed by the Houston-Galveston Area Council (St. Clair and others, 1975). A similar land and water resources map of the Coastal Bend Council of Governments region has been prepared (Kier and others, 1974). This 13-county map will soon be released for sale by the Bureau of Economic Geology.

Particularly important to the maintenance of environmental quality are those properties and characteristics of natural land resource units that limit their use for specific purposes or activities. Examples are: (1) flooding by hurricane surges or by overbanking rivers; (2) shrink-swell conditions; (3) corrosion of pipes and conduits placed in certain substrates; (4) degree of permeability, which determines the extent of transmission of pollutants into ground-water aquifers and nearby surface water bodies; (5) steep slopes, which are susceptible to gravity failure and extreme erosion from runoff; (6) extremely flat lands that are poorly drained and that pond water following heavy or prolonged rainfall; (7) impermeability, which exaggerates ponding and drainage problems; (8) persistent winds in arid areas, which result in wind erosion and migration of sediments in the form of dunes; (9) tidal flooding of broad, low-lying coastal flats by wind-driven water from bays, estuaries, and lagoons; (10) density of stabilizing vegetation on sand substrates, which maintains stability of sediments in high-energy wind and water environments; (11) wave energy dissipated along shorelines with resulting erosion and redistribution of sediments; (12) zones of active or potentially active faulting; (13) subsidence; and (14) erosional susceptibility of various sediments and soils to wind and water.

Evaluation of land and water resource units depends upon the human activities that result in the use of these units. Wide varieties of land and water use activities occur within the Coastal Zone (table 13); other activities will develop as population and urban-industrial expansion continues in the Zone. For each human activity or use, it is important to understand the qualitative and quantitative requirements that the activity will impose on any natural environment.

Land and water resource units display different capabilities and tolerances under the impact of human activities. For example, a highly permeable sand is a very poor host for a solid-waste disposal site simply because of its tendency to transmit wastes into aquifer systems, but the same permeable sand provides an excellent foundation for coastal structures. In turn, a relatively impermeable clay unit provides a secure host for solid-waste disposal without aquifer pollution, but it is a very unsatisfactory foundation material. A brackish-water marsh not only can tolerate but is in fact defined by its capacity to accommodate changes in salinity; salt-water marshes, by contrast, can tolerate little fresh-water influx. A washover channel on a barrier island is a natural outlet for hurricane surges; it is an exceedingly poor site for construction. Many land and water resource units and their capabilities for particular uses are obvious; others are more subtle. A resource unit, therefore, must be evaluated in terms of each coastal activity; that is, environmentally significant physical properties may indicate that the unit will be severely affected by one activity, while another activity may prove entirely compatible with these properties.

These examples show that in order to evaluate the impact of a specific coastal activity on a natural resource unit, it is necessary to evaluate the unit in terms of its limiting environmental capability properties. In this manner, an activity can be evaluated in terms of the environmental stress it exerts on the resource unit; if the limiting environmental capability properties are compatible with the activities, no unfavorable environmental impact will occur. On the other hand, if the activity adversely affects the resource unit because of the incompatibility of the activity and the limiting environmental capability properties, problems can be predicted and avoided or a solution properly engineered.

Historical monitoring analysis of land and water resource units in a given area adds another dimension to our understanding of these natural units. Delineating the direction and rate of changes in location and areal extent of natural resource units during a historical time

Table 13. Coastal Zone land and water resource units—use and capability. Evaluations are based on natural capability which can be improved by special planning and construction methods. Definition of land and water resource units, including limiting use factors and undesirable uses, are discussed in Brown and others (1971).

(shaded)	Not applicable
(blank)	Significant problems unlikely
X	Undesirable—significant problems likely
0	Possible problems
‡	Significant problems unlikely on vegetated barrier flat. Construction and recreation activities on fore-island dunes are undesirable.

LAND AND WATER RESOURCE UNITS \ ACTIVITIES			LIQUID-WASTE DISPOSAL			SOLID-WASTE DISPOSAL	SHORELINE CONSTRUCTION		COASTAL AND INLAND CONSTRUCTION				COASTAL, INLAND, AND OFFSHORE CONSTRUCTION									
			Surface disposal of untreated liquid wastes	Shallow subsurface disposal of untreated liquid wastes	Maintenance of feed lots	Disposal of solid-waste materials	Construction of jetties, groins, and piers	Construction of storm barriers and/or seawalls	Light construction	Construction of highways (excluding causeways)	Heavy construction	Flooding as a result of dam construction	Construction of production platforms and other oil well development activities	Placement of pipelines and/or subsurface cables	Dredging of canals and channels, and spoil disposal	Excavation, including extraction of natural materials	Filling for development	Draining of wetlands	Devegetation	Traversing with vehicles, including marsh buggies, air boats, dune buggies, and motorcycles	Light recreational activities, including hiking, nature trails, and pleasure boating	Use of herbicides, pesticides, insecticides
WATER RESOURCE UNITS	BAYS, ESTUARIES, AND LAGOONS	River-influenced bay, including prodelta and delta front	X	X		X	0	X					0	0	X		X					
		Enclosed bay	X	X		X	0	X					0	0	0		0					
		Living oyster reefs and related areas	X	X		X	X	X					X	X	X	X	X					
		Dead oyster and serpulid reefs and related areas	X	X		X	0	X					0	0	X	0	X					
		Grassflats	X	X		X	X	X					X	X	X		X		X	X		
		Mobil bay-margin sand	X	X		X	X	X					X	X	X	X	X					
		Open bay, lower end with tidal influence	X	X		X	0	X					0	0	X		X					
		Subaqueous spoil	X	X		X	0	0					0	0	0		0					
		Inlets and subaqueous tidal deltas	X	X		X	X	X					X	X	X		X					
		Tidal flats	X	X		X	0	0	X	X	X		0	0	0	X	X					
LAND RESOURCE UNITS	COASTAL WETLANDS	Salt-water marsh	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		Fresh-water marsh	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		Swamps	X	X		X			X	X	X	X	X	X	X	X	X	X	X	X	0	X
	COASTAL BARRIERS	Beach and shoreface	X	X		X	X	X	X	X	X		X	0	X	X	X			0		0
		Fore-island dunes and vegetated barrier flat	X	X	X	X		X	‡	‡	‡		‡	0	X	X	‡		X	X	‡	X
		Washover areas	X	X	X	X	X	X	X	X	X		X	X	X	0	X					0
		Blowouts and back-island dune fields	X	X	X	X			X	X	X		X	0	X	0			X	0		X
		Wind-tidal flats	X	X	X	X		0	X	X	X		0	0	0	0	X					0
		Swales	X	X	X	X			X	X	X		0		X	X	X	X	X	X		X
	MAN-MADE	Made land and spoil	X	X	X	X					0				0				X	0		0
	COASTAL PLAINS	Highly permeable sand	X	X	X	X						0	0		0	X			X			X
		Moderately permeable sand	X	X	X	X							0		0	X			X			X
		Impermeable mud	0						0	0	0			0								0
		Broad, shallow depressions with variable substrate	0	0	0	0			X	0	X		0									0
		Highly forested upland areas	0	0	0	0					0	X	0						X			X
		Steep lands, locally high relief	X	0	0	X			0	0	0		0	0		X			X			0
		Stabilized dunes	X	X	X	X			0	0	0		0		X	X			X	X		X
		Unstabilized, unvegetated dunes	X	X	X	X			X	X	X		X	0	X							0
		Fresh-water lakes, ponds, and sloughs, and playas containing fresh water	X	X		X							0	0	X		X	X				X
		Mainland beaches	X	X	X	X	X	0	X	X	X		X	0	X	X	X		0			0
		Areas of active faulting and subsidence	0	0	0	0		0	0	0	X	0	0	X			0	0				
	MAJOR FLOOD-PLAIN SYSTEMS	Point-bar sand	X	X	X	X			X	0	X	0	0	0	X	0	0		X			X
		Overbank mud and silt	X	X	X	X			X	0	X	0	0	0	0		0		X			X
		Water	X			X							X	0	X		X					X

interval helps in predicting such trends in the future and in determining the relative importance of natural versus man-induced changes. In addition, historical monitoring of land and water resource units augments our basic understanding upon which we can assess the environmental impact of proposed activities. Historical monitoring analyses have been applied to Gulf shorelines (Brown and others, 1974), bay and Gulf shoreline and marsh areas in the Matagorda Bay area (McGowen and Brewton, 1975), and northern Padre and Mustang Islands (White and others, in preparation).

Land and water resource unit maps derived from environmental geology maps inventory natural units and chart the distribution of natural resources. A schematic map of the Corpus Christi area (fig. 32) illustrates the nature and distribution of land and water resource units; detailed, cartographically accurate maps can be constructed (derived from the *Environmental Geology Map*) to chart these vital environmental units. In any area, these basic resource units can be evaluated in terms of current and projected human activities; the limits of their capabilities for various uses allow for the development of guidelines permitting maximum use and minimum environmental degradation.

A suite of special maps can be constructed from a basic land and water resource map by evaluating all the units of a region in terms of all possible uses or activities; each natural resource unit on the map, therefore, can be graded as to capability for each specific use, providing a basis for evaluating the potential impact of an activity. In this manner, potential environmental stresses can be predicted far in advance in order to provide a firm, logical, and just basis for environmental management and decisionmaking with the full realization of the economic, political, and social alternatives.

COASTAL PROBLEMS: OBSERVATIONS AND RECOMMENDATIONS

The present level of population and industry in the Corpus Christi area and its certain future growth point to accelerated use of available natural resources. Any use of resources results in some degree of alteration of the natural state. Several types of use occur: (1) use of finite and nonrenewable resources such as mineral deposits that leads to ultimate depletion; (2) certain human activities that place severe stress on natural environments; and (3) other human activities that are capable of completely destroying or permanently altering natural environments.

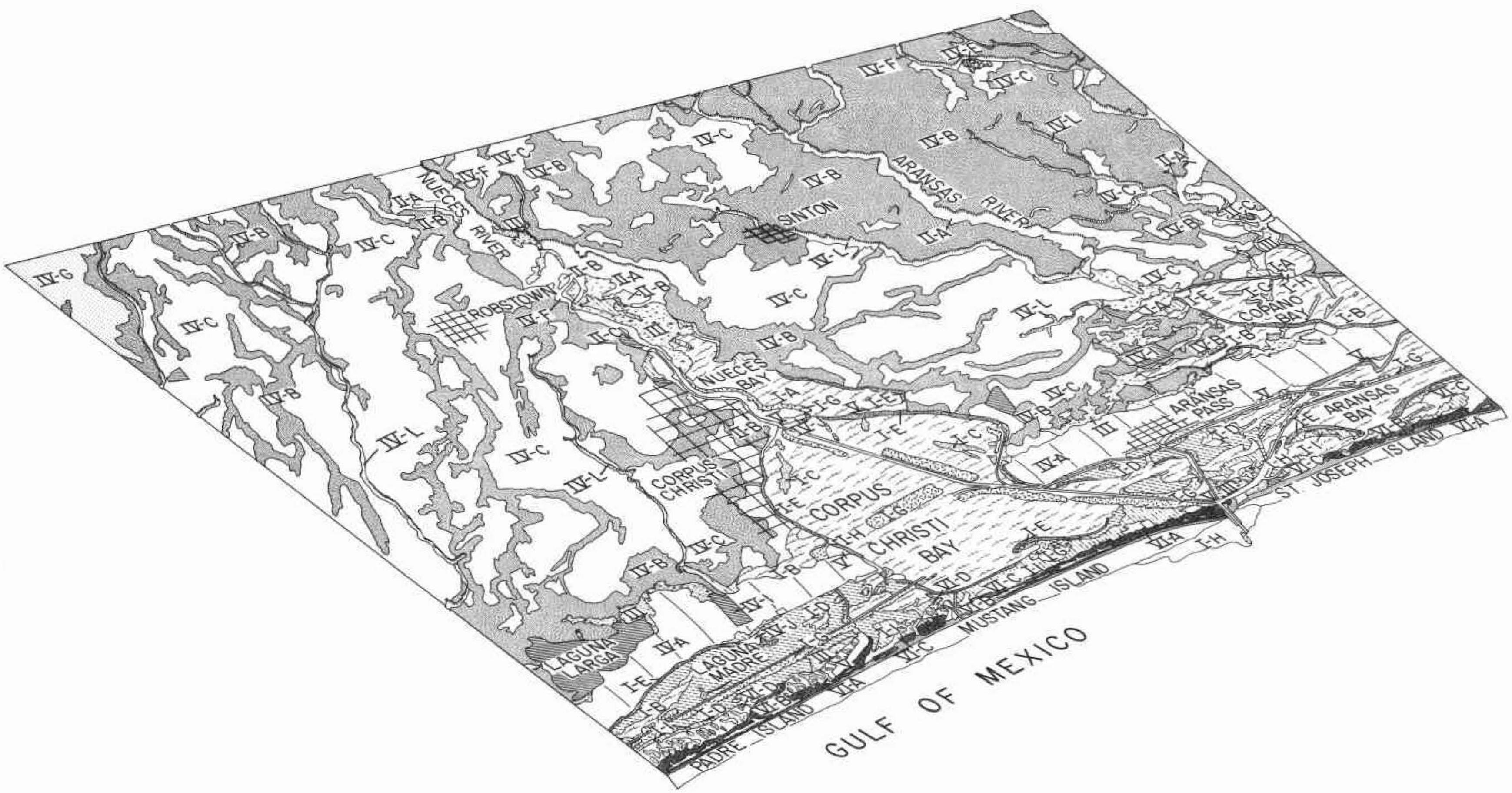
Many environmental problems associated with or arising from resource use or other human activities in the Coastal Zone have been recognized. Some coastal problems have been solved; others persist and are becoming increasingly critical. *Aside from some flagrant violations of existing statutes, many problems of long-term and far-reaching significance are products of currently legal and common coastal activities.* Other environmental problems in the Coastal Zone arise from natural processes and catastrophes, about which little can be done except to prevent exaggeration of the damage caused by unusual environmental stresses on the Zone through imprudent use of certain coastal resources.

It should be emphasized that the Environmental Geologic Atlas of the Texas Coastal Zone is addressed to problems directly involving the natural systems of the Zone. Environmental geology is related, at least indirectly, to most, if not all, coastal problems. Problems of sewage treatment, water quality, air pollution, and public health, for example, must be solved by science and engineering specialists in these fields. Likewise, certain critical problems arising from dense population, industrialization, and societal disorders will require the talents of economists, sociologists, and other urban social specialists. Even so, it is obvious that many of the current problems plaguing the growing metropolitan and industrial centers arise from imprudent use of land and water resources.

As population centers develop, they commonly do so without adequate attention to the natural limits imposed by the capabilities of the natural systems.

URBAN AND REGIONAL PLANNING SHOULD CONSIDER THE NECESSITY OF ORDERLY DEVELOPMENT COMPATIBLE WITH THE CAPACITY OR CAPABILITY OF THE NATURAL SYSTEMS.

The number of statutes designed to protect the quality of environmental resources is growing rapidly; enforcement of these standards is also making environmental protection a reality. Most citizens are aware of the consequences of impure water, improperly disposed sewage, and air pollution; accordingly, there is growing popular insistence for environmental quality. Unfortunately, many environmental problems, more subtle perhaps but just as critical, have not been clearly defined, and their consequences are generally not well known. These urgent problems of the Coastal Zone should be considered in prudent utilization of Coastal Zone resources.



COASTAL WATER BODY AND LAND CLASSIFICATION

I. Bays, lagoons, and estuaries

A. River-influenced bay
B. Enclosed bay
C. Reef and reef-related areas
D. Grassflats
E. Mobile bay-margin sands
F. Tidally influenced open bay (not illustrated)
G. Subaqueous spoil
H. Tidal inlet and tidal delta
I. Wind-tidal flats

II. Major river systems

A. Point-bar sands
B. Overbank muds and silts
C. Water (including related lakes and sloughs)

III. Coastal wetlands

Salt marsh, fresh-water marsh, swamps

IV. Coastal plains

A. Highly permeable sands
B. Moderately permeable sands
C. Impermeable muds
D. Broad, shallow depressions (absent)
E. Highly forested upland areas
F. Steep lands
G. Stabilized (vegetated) dunes and sandflats
H. Unstabilized (unvegetated) dunes (absent)
I. Fresh-water lakes, ponds, sloughs, playas
J. Mainland beaches
K. Areas of active faulting and subsidence (not illustrated)
L. Headward-eroding streams

V. Made land and spoil

VI. Coastal barriers

A. Beach and shoreface
B. Fore-island dunes and vegetated barrier flats
C. Washover areas
D. Active dunes
E. Tidal flats (not illustrated)
F. Swales (not illustrated)

Figure 32. Schematic map of land and water resource capability units, Corpus Christi map area. Modified from Brown and others (1971).

CHANNELIZATION

The establishment of intracoastal waterways, irrigation and drainage canals, and access channels has resulted in extensive channelization and attendant disposal of dredged spoil throughout the Texas Coastal Zone. Cuts have been made on land and in bays, estuaries, and tidal inlets. The major environmental consequences of channelization and disposal of spoil in piles and banks are: (1) tendency to dam shallow water bodies into isolated compartments, inhibiting natural circulation and altering temperature and salinity gradients; (2) alteration or modification of on-land drainage patterns; and (3) creation of unstabilized, easily eroded sediments that are reworked and redistributed by hurricanes, normal waves and currents, and stream runoff. Redistributed spoil in many cases covers organically productive, vital coastal environments such as grassflats and salt marshes, altering them indefinitely to barren, unproductive sandflats.

EXCESSIVE CUTTING OF CHANNELS AND CREATION OF SPOIL BANKS SHOULD BE AVOIDED. WHERE POSSIBLE, SPOIL SHOULD NOT BE PILED ON BAY BOTTOMS OR ALONG BAY MARGINS WHERE IT IS SUBJECT TO REWORKING, BUT SHOULD BE CARRIED INLAND OR DISPOSED OF OFFSHORE. CHANNELS NO LONGER USED SHOULD BE CLOSED AND FILLED TO RESTORE THE ORIGINAL LAND AND BAY-BOTTOM CONFIGURATIONS.

DEVEGETATION

Several resource uses or activities result in the destruction of vegetation and the natural erosional stability it provides. Common activities include development construction, road construction, off-road trails, and brine disposal. Devegetation of vegetated barrier flats and fore-island dunes renders these environments highly susceptible to erosion by wind and water, increasing the possibility of destroying a natural barrier by hurricane forces. Devegetation of marsh-bounded and stabilized bay shorelines commonly results in shoreline erosion and land loss. Disposal of brine in open pits or drainage ditches destroys stabilizing vegetation and results in loose, easily eroded sediment that is transported to the bay during periods of high runoff.

VEGETATION ALONG THE COAST PROVIDES A NATURAL BARRIER FOR STORM PROTECTION; IT STABILIZES COASTAL LAND MARGINS AND MINIMIZES LAND LOSS THROUGH SHORELINE EROSION. WHERE ACTIVITIES RESULT IN DEVEGETATION, SUBSEQUENT RESTORATION OF ORIGINAL VEGETATIVE STABILITY IS DESIRABLE.

SHORELINE CONSTRUCTION

Construction of groins, piers, and jetties has modified the circulation and sediment transport patterns within the bays and estuaries and along the Gulf coastline. The state of a shoreline, whether erosional, depositional, or in equilibrium, is largely controlled by natural processes. Chief among these are availability of a sediment source and intensity of wave activity. Shoreline construction, whether in the form of shoreline control or development, alters the natural balance. Each alteration in the natural process is compensated for in another place. For example, construction of a jetty or groin along an erosional shoreline will trap sediment immediately up longshore drift but may effect even more serious erosion at a point down longshore drift. In certain cases, specific local management or alteration of shoreline processes may be necessary, but modification cannot be effected on a regional basis.

PROPER MANAGEMENT AND USE OF SHORELINES WITHIN THE BAY AND ALONG THE OPEN GULF REQUIRE RECOGNITION OF THE CHARACTERISTICS OF A SPECIFIC SHORELINE AND THE PROCESSES THAT DETERMINE ITS NATURE. SHORELINE USES SHOULD BE IN ACCORDANCE WITH THE NATURAL STATE.

WASTE DISPOSAL

A significant activity in the populated and industrial area of the Texas Coastal Zone is waste disposal. Although certain wastes are treated and discharged directly into water bodies and others are incinerated, a large volume of wastes is disposed of beneath or on land. Without proper engineering, land disposal of waste may result in pollution of ground-water aquifers or surface water bodies, if the host soils and substrates are permeable and if the ground-water table is high. Of the currently operated land disposal sites for solid waste in the Texas Coastal Zone, approximately 30 percent are in hosts naturally capable of holding the waste securely, 20 percent are in very poor hosts, based on environmental mapping, and the balance are in sites of marginal suitability. Commonly, the more accessible and less expensive sites available for waste disposal are also the poorest hosts. Surface holding ponds for industrial wastes should be situated on secure, impermeable lands.

IN THE SELECTION OF WASTE DISPOSAL SITES, ECONOMIC FACTORS SHOULD BE CONSIDERED IN THE LIGHT OF ASSESSED PHYSICAL AND HYDROLOGIC CONDITIONS.

FILLING AND LAND RECLAMATION

Artificial filling of shallow coastal water bodies and low-lying marshes creates valuable shorefront development land or additional land for industrial expansion. The process also permanently destroys parts of vital natural environments, alters shoreline configuration, modifies natural patterns of circulation and sediment dispersal, and commonly creates unstabilized and easily erodable substrates. Fill materials are commonly more permeable than the parent sediments and for the most part are unsuitable for waste disposal and septic fields.

FILLING AND LAND RECLAMATION PROJECTS SHOULD BE CONSIDERED NOT ONLY IN TERMS OF THE VALUE OF THE NEWLY CREATED LAND BUT ALSO IN TERMS OF THE EFFECTS ON NATURAL SYSTEMS.

ARTIFICIAL PASSES

A number of artificial passes between inland bays and the Gulf have been cut in the barriers of the Texas Coastal Zone; additional artificial passes have been proposed. These, of course, increase access between the bays and Gulf. With the low tidal range of the Texas coast, only one pass per bay normally can be maintained by natural processes; additional passes reduce the tidal exchange through existing ones, necessitating increased dredging to maintain them. Artificial passes alter natural circulation patterns and subject the protected bays to greater effects of storm surges.

THE ECONOMIC BENEFIT OF ARTIFICIAL PASSES SHOULD BE WEIGHED AGAINST THE COST OF ADDITIONAL DREDGING REQUIRED FOR INLET MAINTENANCE AND INCREASED POTENTIAL DAMAGE FROM STORM SURGES.

NATURAL CATASTROPHES

Several kinds of major natural processes create particular problems in the Texas Coastal Zone. These include: (1) hurricanes, which, through high and intense flood surges, may breach barrier islands and flood low-lying coastal areas and, in addition, commonly produce high, damaging winds and excessive aftermath rainfall and inland flooding; (2) shoreline erosion under normal and storm conditions; (3) inland flooding along floodplains; and (4) surface faulting and land subsidence.

Hurricanes

Hurricanes and tropical storms, striking the coasts on an average of once every two years, pose one of the most significant problems for land use in the Coastal Zone of Texas. Hurricanes are natural phenomena and are fundamental natural processes of the Coastal Zone. The effects of hurricanes depend largely on their intensity, but other factors are also important. The amount of low-lying land in the area of hurricane landfall determines the extent of flooding. In addition, the configuration of the shoreline along the Gulf and bays modifies the height of storm-surge tides. Funnel-shaped bays, for example, tend to intensify the height of storm surges. Stability of the barrier islands is a critical factor; unvegetated, low-relief barriers provide less deterrent to storm surges than do stabilized, vegetated barriers.

Hurricanes can breach barrier islands, creating washover or storm channels. Hurricane-tidal surge reaches the bay through these storm channels, as well as through the normal tidal passes. Storm channels across the barriers become inactive after passage of the storm but exist as depressions in the barrier through which future surges may pass. The number of inactive storm channels activated during a hurricane depends on the severity of the storm. With increasing demand for ocean frontage along the barrier islands, construction may occur too near to and even within these washover channels. Proper land use should avoid these potentially hazardous sites at all costs to protect life and property.

A common adjunct of certain kinds of hurricanes striking the Texas Coastal Zone is excessive aftermath rainfall. In the low-lying Coastal Zone, runoff is normally slow. Any alteration of natural drainage patterns by on-land construction and damming increases the area of potential fresh-water flooding by aftermath rainfall.

Several factors should be considered when planning coastwise structures designed to prevent the destruction of property by hurricanes. Barrier islands are natural barriers to much of the surge effect and offer the most effective protection, if stabilizing vegetation is undisturbed. Neither natural nor artificial barriers prevent wind effects and runoff from torrential rainfall. Properly engineered artificial barriers may serve to lessen the effects of storm-surge flooding but may severely alter circulatory patterns within the bays and estuaries.

THE BEST KIND OF HURRICANE PROTECTION IS THROUGH MAINTENANCE OF STABILIZING NATURAL

ENVIRONMENTS AND DEVELOPMENT OF LAND USE AND BUILDING CODES IN HARMONY WITH NATURAL HURRICANE PROCESSES.

Shoreline Erosion

Open-ocean and bay shorelines of the Corpus Christi area exist in four states: erosional, depositional, naturally stabilized, and artificially stabilized. The state of a particular stretch of shoreline is largely a function of natural processes, chiefly the availability of sediment and the extent of vegetation. Modification of these natural processes can be effected only locally; generally, modification of one stretch of shoreline causes a corresponding, perhaps detrimental change in another shoreline area.

SHORELINE CONSTRUCTION OR MODIFICATION SHOULD BE UNDERTAKEN IN HARMONY WITH NATURAL PROCESSES WHEREVER POSSIBLE.

Inland Flooding

Most fresh-water flooding in the Coastal Zone is associated with hurricane-aftermath rainfall and runoff that flood the major fluvial systems. River flooding affects the low floodplain bordering the river. Inland dam construction along many of the major streams has significantly reduced the potential of river flooding below the reservoir but increases flood potential above the dam. Damming has reduced discharge of the streams into the bays, thereby modifying natural salinity and restricting the flushing effect of the flood surge. All coastal depressions and local low-lying areas are subject to flooding from hurricane-aftermath rainfall.

AREAS OF PREVIOUS FLOODING AS WELL AS NATURAL FLOODPLAINS AND AREAS OF POTENTIAL FLOODING ARE DELINEATED ON MAPS OF THIS ATLAS. LAND USE SHOULD BE CONSIDERED ACCORDINGLY.

Surface Faults and Land Subsidence

The entire Texas Coastal Zone is underlain by faults. Many of these are surface faults that are presently inactive; others show actual displacement at the earth's surface.

NONE OF THESE SURFACE FAULTS POSES A THREAT TO LAND USE PROVIDED THEY ARE EITHER RECOGNIZED AND AVOIDED OR PROPERLY CONSIDERED IN ENGINEERING DESIGN.

Principal effects of subsidence, largely triggered by withdrawal of underground water, are activation of surface faults, loss of ground elevation in critical low-lying areas already prone to flooding, and alteration of natural slope and drainage patterns.

LAND-SURFACE SUBSIDENCE, PARTICULARLY IN RESPONSE TO HEAVY WITHDRAWAL OF GROUND WATER, IS IRREVERSIBLE. WITHIN AREAS OF PRESENT OR PROJECTED SUBSIDENCE, SPECIAL ATTENTION SHOULD BE GIVEN TO PROBLEMS CAUSED BY LOSS OF GROUND ELEVATION AND ACTIVATION OF SURFACE FAULTS.

CONCLUSIONS

There are numerous land and water uses in the Corpus Christi map area; many are in direct competition, and some are incompatible. In the future, the extent of resource use and the degree of competition will surely increase. With increased and more competitive use of Coastal Zone lands and waters, voluntary or obligatory management policies must be developed. If these policies are to be prudent and fair, they must be based on an adequate inventory of natural resources, including composition and properties, related physical, chemical, and biologic processes, and natural capability to sustain varied and specific uses.

Through inventory and assessment, criteria may be established that will permit requisite environmental quality. A regional natural resource inventory, evaluation, and assessment, as portrayed in a series of basic maps with accompanying legends, descriptive text, statistical tables, and illustrations, are the prime goals of the Environmental Geologic Atlas of the Texas Coastal Zone.

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