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-

Port Lavaca 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

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Preface by
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Cover photo: Wind-sculptured live oak (*Quercus virginiana*) on the Pleistocene Ingleside Sand at the north end of Live Oak Peninsula.

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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 and submerged land topographic and 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—

PORT LAVACA AREA

J. H. McGowen, C. V. Proctor, Jr.,[1] L. F. Brown, Jr., 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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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 25 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 distinct properties and composition; (2) units displaying a variety of natural processes, including storm channels,

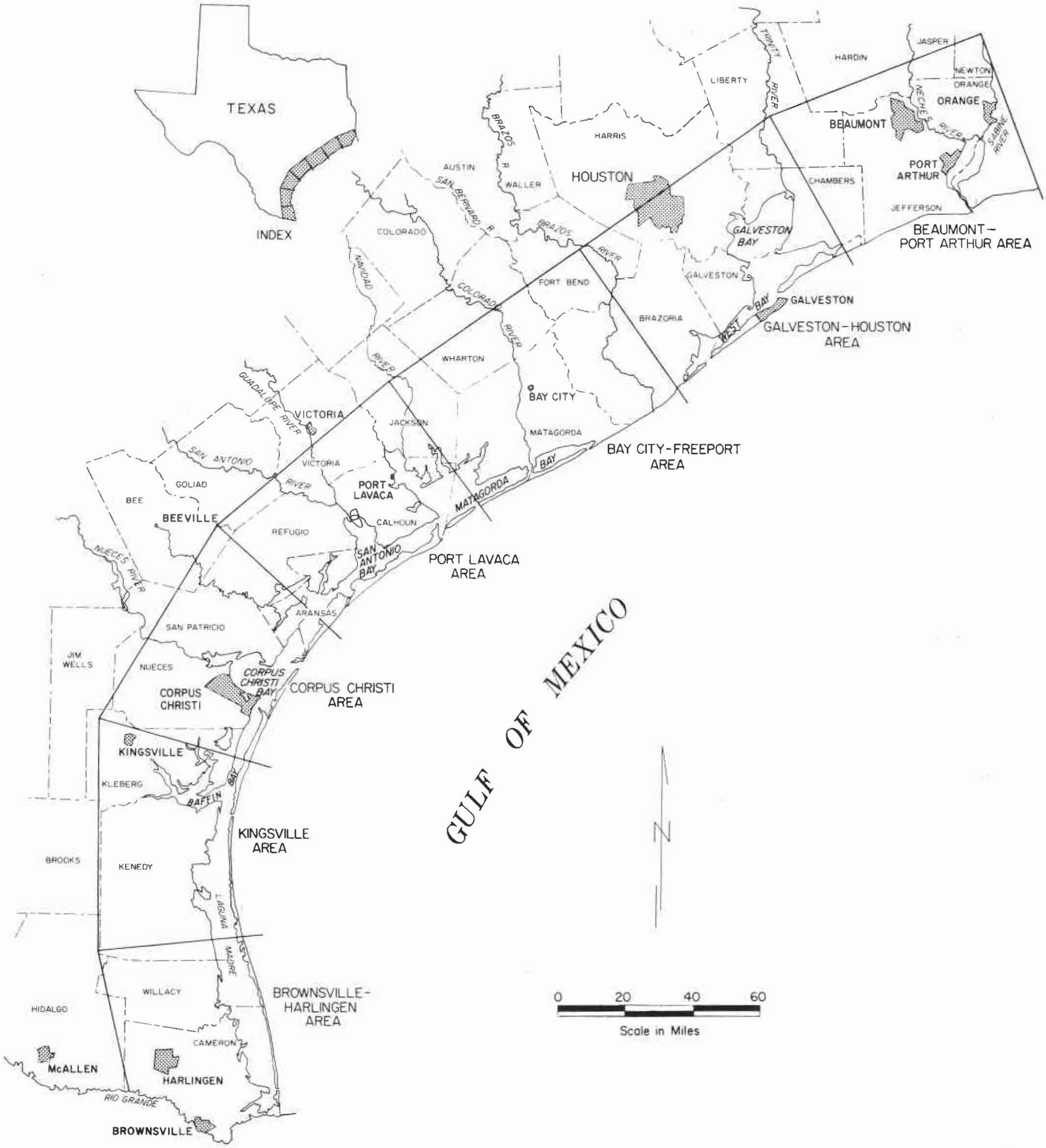

Figure 1. Index of the Environmental Geologic Atlas of the Texas Coastal Zone.

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 135 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, marsh-swamp, 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.

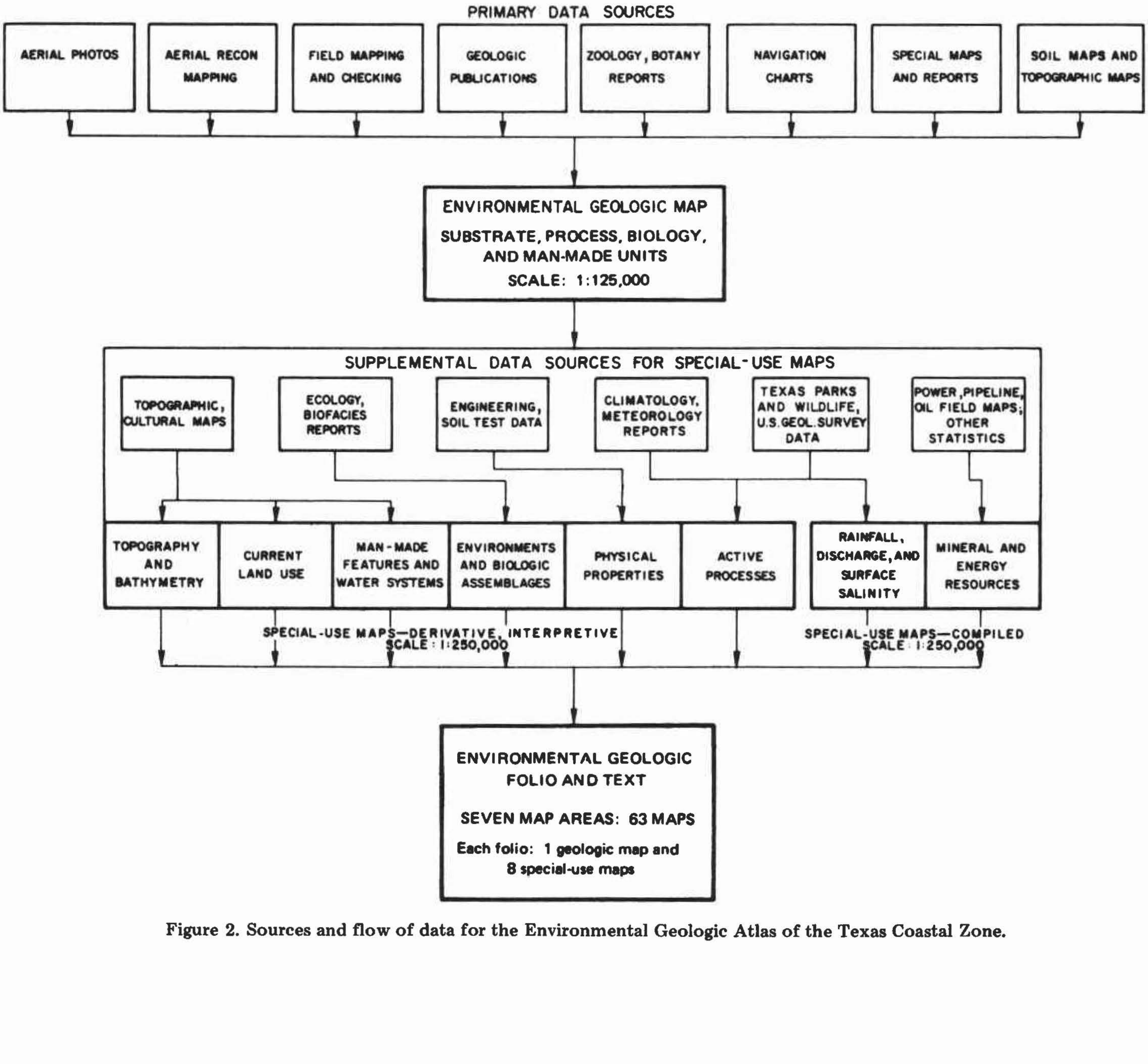

Figure 2. Sources and flow of data for the Environmental Geologic Atlas of the Texas Coastal Zone.

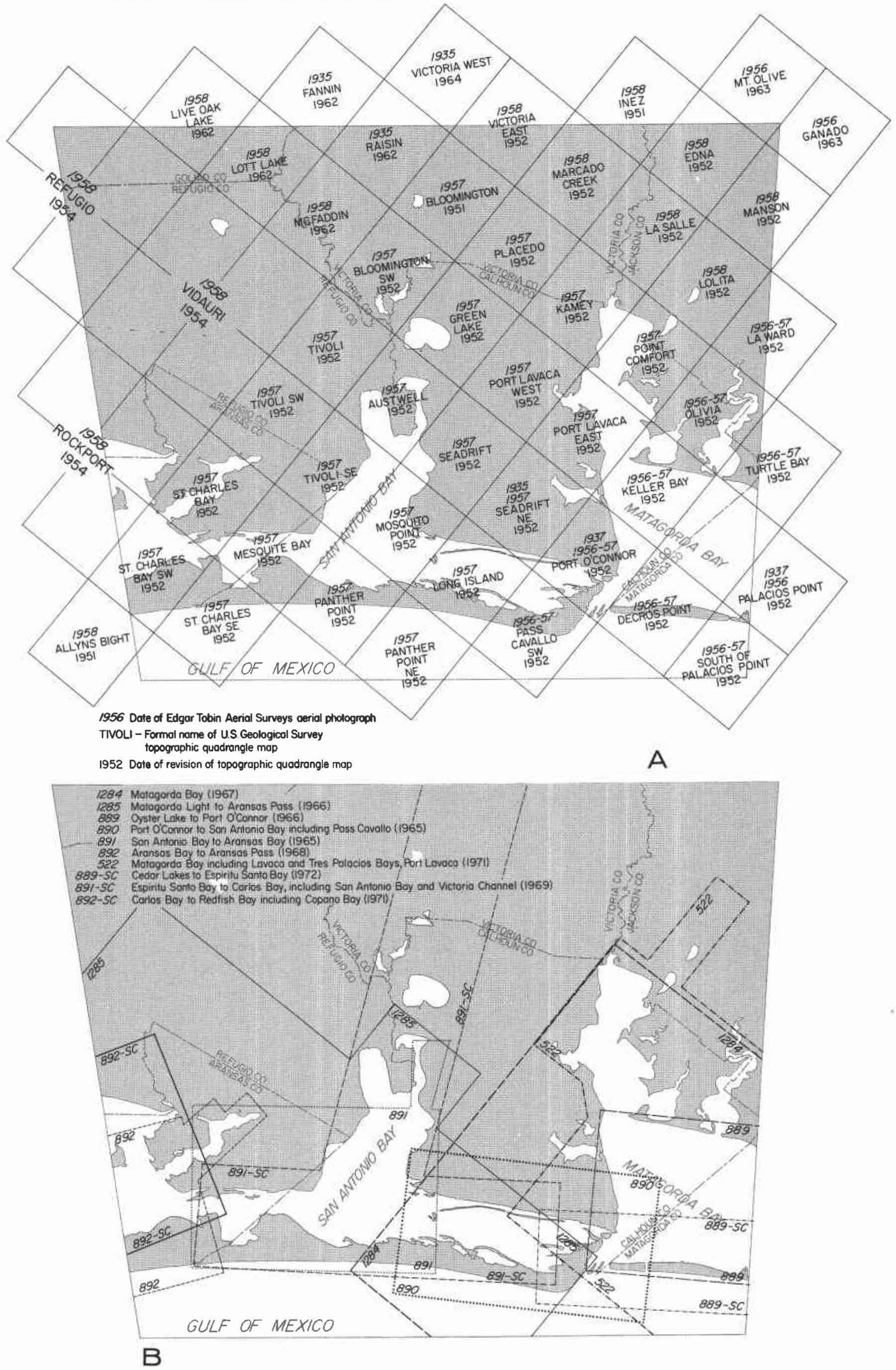

Figure 3. Source and dateline for principal data used in mapping the Port Lavaca map area. (A) U. S. Geological Survey topographic maps and Edgar Tobin Aerial Surveys photographic mosaics showing name, date of map revision, and date of aerial photography. (B) U. S. Coast and Geodetic Survey nautical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

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 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, and wind-tidal flats; (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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Edgar Tobin Aerial Surveys, San Antonio, Tex.

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PORT LAVACA AREA

GENERAL SETTING

The Environmental Geologic Atlas of the Port Lavaca area covers a region of approximately 2,709 square miles, excluding offshore areas. Included in the map area are parts of Aransas, Bee, Calhoun, Goliad, Jackson, Matagorda, Refugio, and Victoria Counties, Texas. The area includes the cities, towns, and small hamlets of Austwell, Bloomington, Dacosta, Dernal, Edna, Guadalupe, Inez, Lolita, Long Mott, Magnolia Beach, Matilda, McFadden, McGill, Placedo, Point Comfort, Port Lavaca, Port O'Connor, Refugio, Seadrift, Tivoli, and Vanderbilt.

Approximately 2,098 square miles of land occur within the Port Lavaca map area. Broad areas of relatively flat coastal prairies occur inland from extensive bays and coastal marshes. Coastal prairies are broken into several segments by northwest-trending Lavaca and San Antonio Bays and by the Lavaca and Navidad Rivers, Garcitas Creek, the Guadalupe and San Antonio Rivers, and Melon and Blanco Creeks. Water-tolerant hardwoods extend along the upper reaches of these major fluvial systems.

The coastal plain is gently inclined gulfward at about 2 to 3 feet per mile; in many areas, slopes are less than 2 feet per mile. Maximum elevations of more than 130 feet above mean sea level (MSL) occur in the northwestern part of the area near Bundick Lake in Goliad County.

Marshes are present on the bayside of barrier islands and peninsulas and along mainland shorelines. The most extensive marshes are situated on the Lavaca, Garcitas, and Guadalupe delta plains. Marshlands are developed from 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) inland for 3 to 15 miles along major river valleys (fresh-water marsh). Swamps are not well developed in the map area; small swamps are present on the Guadalupe River floodplain about 13 miles inland from the distal part of the delta plain. Marshes and swamps are commonly flooded during hurricanes.

Four major river valleys, the Lavaca, Navidad, Guadalupe, and San Antonio, are incised into the coastward-sloping land surface. From 15 to 20 feet of local relief occurs along the margins of the Lavaca and Navidad river valleys; steepest areas occur above the confluence of the Lavaca and Navidad Rivers. Local relief along the valley walls of the lower Lavaca River valley is about the same as the relief of valley walls in the upper parts of the river system. Relief along the lower Guadalupe River valley is 25 to 30 feet with steepest slopes occurring along the lower part of the river valley. Maximum relief of about 60 feet occurs along the valley of the Guadalupe River from near its confluence with the San Antonio River to about 6 miles south of the northern limit of the map area, across the valley from Dernal. Maximum relief along the valley of the San Antonio River is about 40 feet along the right bank adjacent to Lott Lake.

Approximately 37 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 15 feet occur along a northeast trend from Aransas and Copano Bays to the west shore of Matagorda Bay, occupying about 4 percent of the map area. St. Joseph Island,[3] Matagorda Island, and the western part of Matagorda Peninsula are representative of highly permeable sand and shell bodies having maximum elevation of about 30 feet above MSL and ranging in thickness from 15 to 60 feet. The valleys of Garcitas Creek, Lavaca, Navidad, Guadalupe, and San Antonio Rivers are filled with sand, muddy sand, and mud. Other sand and muddy sand deposits represent ancient river courses that trended south to east-southeast. Width of these preserved river deposits is about 0.5 to 1.0 mile for single systems; the systems coalesce in some areas to form belts up to 7 miles wide. These ancient river courses generally display less than 5 feet of relief.

Carancahua, Keller, Lavaca, Matagorda, Espiritu Santo, San Antonio, Mesquite, Aransas, St. Charles, and Copano Bays occupy about 570 square miles of the area. Bays are generally less than 6 feet deep with maximum depth of approximately 14 feet in Matagorda Bay. Dredged channels are maintained at various depths by the U. S. Army Corps of Engineers for deep-water access to major ports. Three natural passes connect the bays and the Gulf of Mexico: Greens Bayou, Pass Cavallo, and Cedar Bayou. Greens Bayou (located on Matagorda Peninsula near the west edge of the map area) is presently closed. Maximum depth of water in Pass Cavallo is about 35 feet, and water depth in Cedar Bayou is from 2 to 9 feet. Matagorda Ship Channel is a man-made pass that cuts through Matagorda Peninsula; depth of the channel is 38 feet. On the Gulf side of

[3] Subsequent to printing of the Port Lavaca Atlas maps, the name of St. Joseph Island was changed to San Jose Island.

Matagorda Peninsula and Matagorda Island, the sea floor slopes gulfward at about 36 feet per mile from 0 to 3 fathoms, about 17 feet per mile from 3 to 5 fathoms, and about 5 feet per mile from 5 to 8 fathoms.

RESOURCE ACTIVITIES

Land use within the area is divided principally among cropland, rangeland, urban-residential and urban-commercial land, recreational land, marsh-covered land with abundant wildlife, and land utilized for industry, military installations, and formally designated wildlife preserves. 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 Point Comfort area, north of Long Mott, and east of the Guadalupe River between Bloomington and Dernal. The aluminum plant at Point Comfort is the major industrial complex in the map area, and petrochemical plants (north of Long Mott and north of Bloomington) represent another important industry. Oil and gas fields are distributed throughout most of the area. Railroads, highways, dredged channels, pipelines, and major power transmission systems are rather uniformly distributed throughout the area.

Natural ponds and lakes are present in the valleys of the Guadalupe River, Garcitas Creek, and the Lavaca River, and in the western part of the map area bounded by the San Antonio River to the north and the Missouri Pacific Railroad to the southeast. Large holding ponds have been constructed in the Point Comfort, Long Mott, and Dernal areas. Artificial surface reservoirs have been constructed on the floodplain of the Guadalupe River at Burgentine Lake on Blackjack Peninsula, and south of Magnolia Beach near Indianola Island. An intricate irrigation and drainage network exists throughout much of the area except the western quarter bounded by State Highway 35 on the southeast and the Guadalupe River on the northeast.

Rice cropland and coastal marshlands constitute the most important waterfowl habitats along the Texas Gulf coast. Rice provides a principal food supply for the migratory fowl; the marshlands provide nearby nesting sanctuaries. The Aransas National Wildlife Refuge provides an extensive, legally protected sanctuary.

Dredge spoil occurs along the Intracoastal Waterway, Ferry Channel, Matagorda Ship Channel, Victoria Channel, Port Lavaca Channel, and associated channels such as those connecting Palacios (off mapped area to northeast) and Seadrift with the Intracoastal Waterway. With the exception of the Matagorda Club airfield on Matagorda Peninsula, there are no large airfields available to the private citizen within the map area. Small airstrips are situated near Port Lavaca, Port O'Connor, Tivoli, Austwell, and Refugio.

Resources produced in the area include oil and gas, oyster shell, sand, clay, and gravel. Agricultural products include cattle, rice, grain sorghums, cotton, corn, soybeans, and lesser grain and truck crops. Refineries, petrochemical plants, and facilities for aluminum processing, agricultural milling, starch production, and fish processing are situated near ship channels in the Port Lavaca-Point Comfort area. Matagorda Ship Channel and Pass Cavallo provide access to the open Gulf for recreational and commercial fishing. A large tonnage of both deep-water and intracoastal shipping flows into and out of the Port Lavaca-Point Comfort area.

The bay and estuary waters of the Port Lavaca 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, oil and gas, and oyster shell.

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 marsh-swamp systems 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 ancient sediments were deposited by the same natural processes that are active in 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 flood deposition.

Active and relict coastal systems in the Port Lavaca 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 following the last glacial period of the Pleistocene between about 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 (e.g., 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

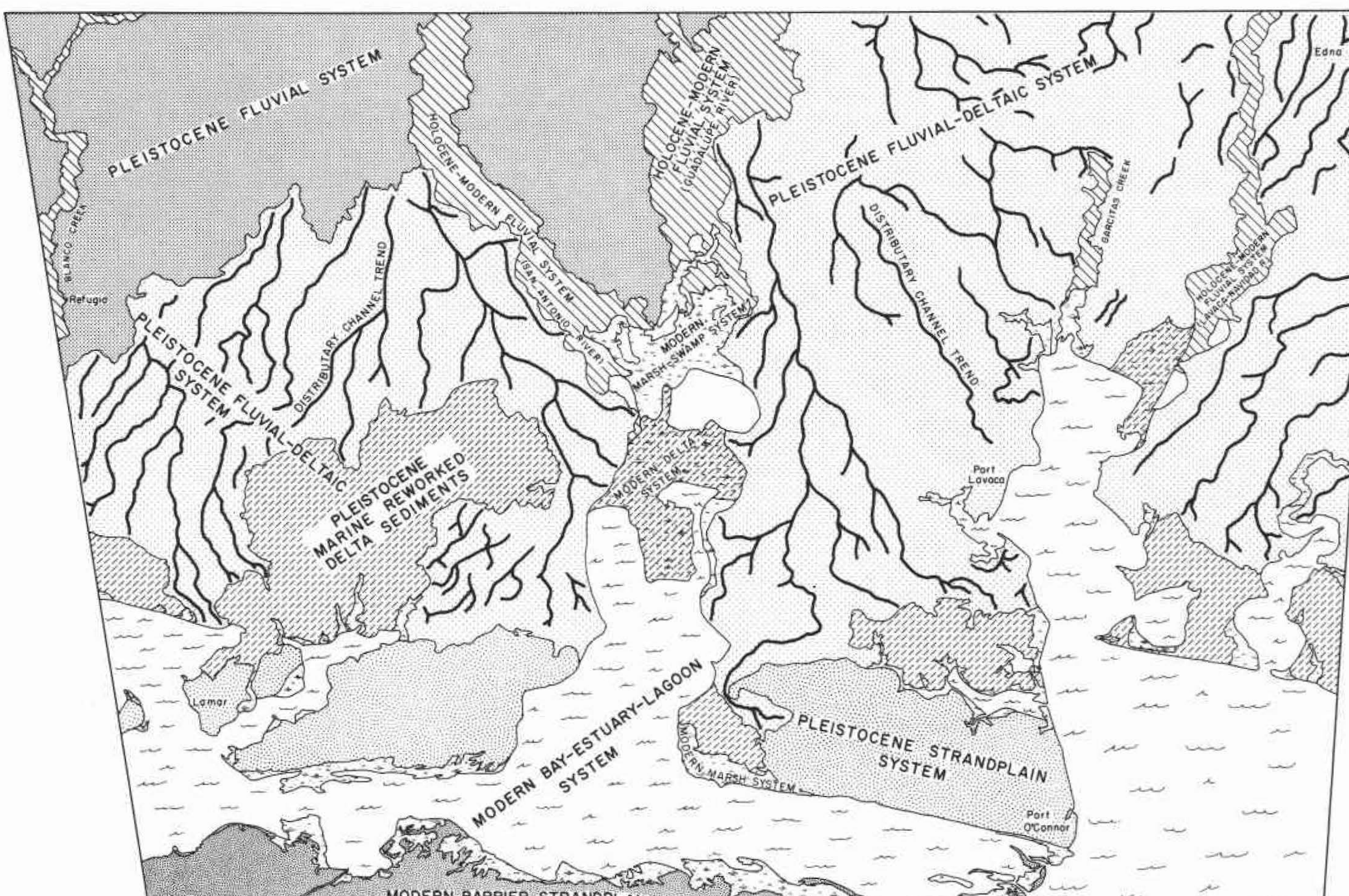
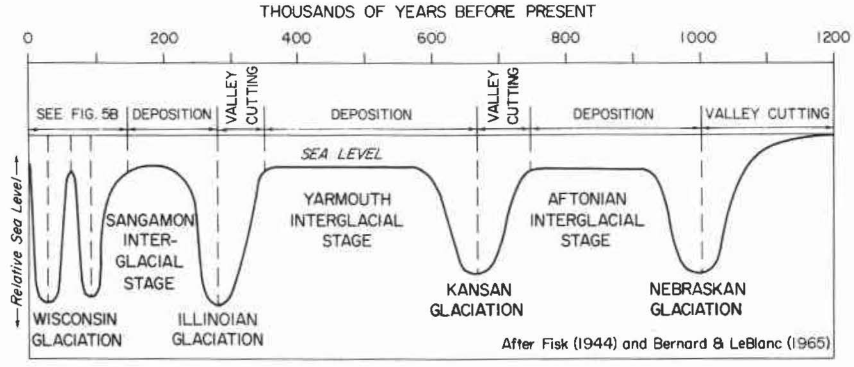
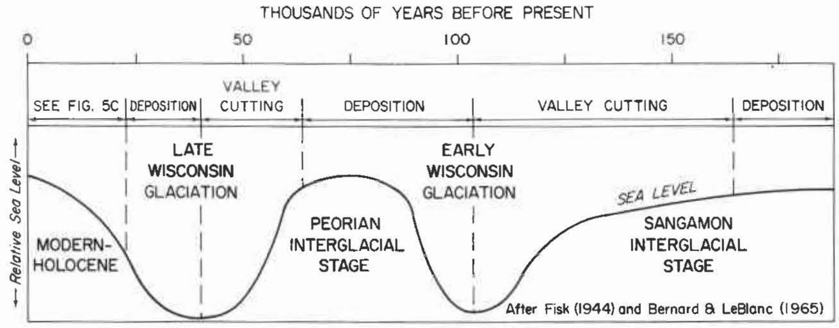


Figure 4. Natural systems defined by environmental mapping in the Port Lavaca area. These systems are composed of genetically related environments, sedimentary substrates, biologic assemblages, areas of significant physical processes, and man-made features. Simplified from the *Environmental Geology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





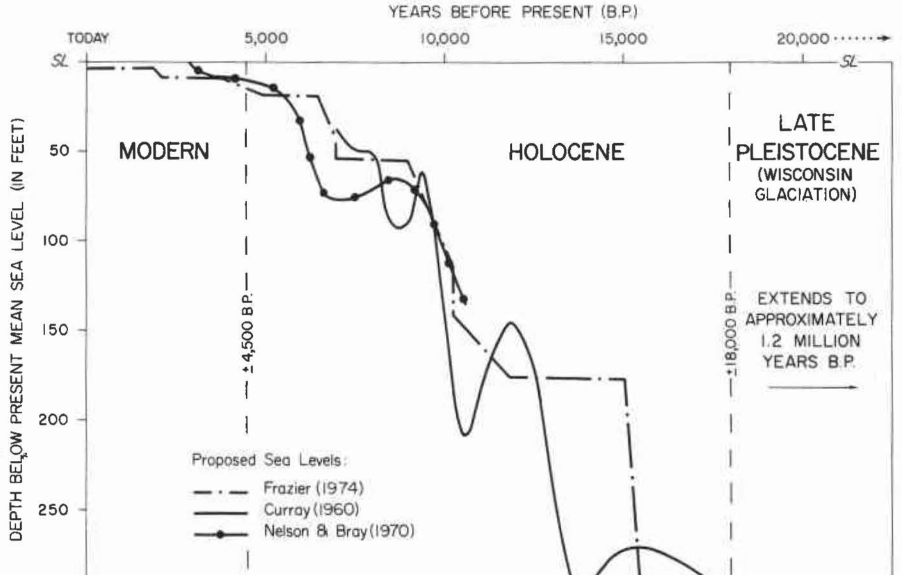


Figure 5. Sea-level changes related to glacial and interglacial stages. (A) Generalized Pleistocene sea-level variations and associated erosional and depositional episodes. (B) Generalized sea-level changes during Late Wisconsin glaciation. (C) Proposed sea-level changes during the last 20,000 years;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

punctuated by numerous stillstands and even some reversals. 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 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 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 have 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 left 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 floodplain mud deposits are presently exposed over about 266 square miles of the inland part of the Port Lavaca map area (fig. 4). These ancient river sand and mud deposits extend from the Guadalupe River southwest to the limit of the map area and are bounded, generally, on the southeast by State Highway

35. Pleistocene meanderbelt sands are elongate in a south to southeast direction; continuity of these sand bodies is broken by the Guadalupe and San Antonio Rivers and Melon and Blanco Creeks. Associated with Pleistocene fluvial sands are patches of overbank mud and large, natural lakes such as Willow Lake and Sharps Lake (dry).

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 the delta lobe into broad embayments, building land at the expense of the ancient Gulf embayment. Currents redistributed some of the deltaic sand and mud, but most of it 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 salt- to brackish-water 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.

Several coastward-trending segments of ancient delta distributaries are still exposed at the surface within the coastal upland prairies of the Port Lavaca map area (fig. 4). Some of the channel-mouth sandbars and prodelta mud deposits are now buried beneath younger floodbasin mud and silt; others extended somewhat beyond the Modern Gulf shoreline and are now partly exposed on the shoreface and inner shelf. The sand-filled distributary channel bodies are slowly subsiding into underlying delta mud, so that some segments are discontinuous and have been partially covered by later deposits. The course of relict distributary streams is marked principally by higher levee deposits that still stand a few feet above the old deltaic and fluvial plain. Abandoned, mud-filled river meanders or oxbows represent relict streams that supplied the prograding delta distributary courses. Almost 955 square miles, or 35 percent of the map area (fig. 4), are underlain by Pleistocene interdistributary and floodbasin mud and sandy distributary deposits. Fertile soils that developed on these deposits support extensive agriculture.

The principal ancient deltas presently exposed in the Port Lavaca area are part of the late Pleistocene Colorado and Guadalupe-San Antonio systems. The Pleistocene Colorado delta is bounded on the southeast by Matagorda Bay and on the west by Lavaca Bay and Garcitas Creek (fig. 4). Distributaries of this delta trend mostly to the south. The Pleistocene Guadalupe-San Antonio delta occupies most of the upland area. There is an overall change in direction of trend of its distributaries from southeast along Garcitas Creek and Lavaca and Matagorda Bays to the south in the Refugio-Copano Bay area. These Pleistocene deltas extended beyond the present Gulf shoreline (Wilkinson, 1973).

The Pleistocene Colorado and Guadalupe-San Antonio deltas are probably of Sangamon age (Wilkinson and others, 1975). Deltaic deposits are overlain by Pleistocene strandplain sand bodies (Lamar Peninsula, Blackjack Peninsula, and the Seadrift-Port O'Connor area). Strandplain sands occur primarily between Port O'Connor and Lamar and from the northwest shores of Espiritu Santo and Mesquite Bays inland for about 8 miles (fig. 4). Following deposition of sediment composing the Pleistocene Colorado and Guadalupe-San Antonio deltas, sea level was lowered during one of the Wisconsin interstadials (fig. 5B), and a soil was developed on the Sangamon deltaic deposits. Sea level rose again to approximately its former position. Instead of rivers building deltas during the Wisconsin interstadial, they constructed extensive strandplains, as waves and currents striking the coast and carrying sediments along the shoreline dispersed sediment carried to the coast by the rivers. Vertebrate fauna collected from time-equivalent strandplain sand in the vicinity of Ingleside, about 18 miles southwest of mapped area, are said to be post-Sangamon (Lundelius, 1972). Depositional grain, characterized by ridge-and-swale topography, is well preserved on parts of this strandplain sand body, indicating rapid seaward accretion. Ridges are up to 15 feet above MSL, but average ridge height is about 7 feet. Throughout the Port Lavaca area, the strandplain sand rests on a red soil and displays a remarkably uniform thickness. Distinction of shoreface, beach, or other facies cannot be made in these predominantly well-sorted, uniformly fine-grained terrigenous sands. Approximately 178 square miles of Pleistocene strandplain sand crops out within the map area. These strandplain sand bodies are the youngest Pleistocene deposits in the Port Lavaca map area. Sediment data obtained from the Matagorda Island area indicate that Pleistocene strandplain sand extended at least as far seaward as the present Gulf shoreline (Wilkinson, 1973). These Pleistocene strandplain sand bodies, at the time of their deposition, resembled the present-day strandplain of Mazatlan, Mexico (Curray and others, 1969).

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 Lavaca, Navidad, Guadalupe, and San Antonio Rivers record this dramatic event. Depth of scour of the Pleistocene Lavaca-Navidad fluvial system was up to 100 feet below present MSL in the area of southern Lavaca Bay. Scour within this same valley was greater than 125 feet in the Port O'Connor area. Many of the smaller bays (e.g., Keller and Carancahua Bays) are underlain by valleys that were tributary to the dominant Lavaca-Navidad system. San Antonio Bay represents the partially filled Pleistocene valley that was scoured by the Guadalupe-San Antonio fluvial system. These two river systems, Lavaca-Navidad and Guadalupe-San Antonio, eroded valleys across the present continental shelf and discharged their sediment load at the Wisconsin shoreline which was 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). During the sea-level rise between 18,000 and about 4,500 years B. P., rivers continued to meander within their incised valleys, and point-bar sand bodies and overbank muds were deposited.

The deeply incised lower reaches of the Lavaca-Navidad and Guadalupe-San Antonio valleys and lesser valleys filled slowly with brackish to marine water as sea level rose. These extensive bay-estuary systems occupied submerged valleys that now lie beneath parts of Lavaca, Matagorda, San Antonio, Copano, and Aransas Bays. Parts of the Lavaca-Navidad and Guadalupe-San Antonio river valleys remained unfilled. 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 the temporary position of the Holocene strandline (Frazier, 1974).

Estuaries received sediment from the various fluvial systems and from the Gulf of Mexico. Holocene deposits that have partly filled the drowned river valleys and underlie the present bay bottom consist of terrigenous sand and mud associated with a variety of depositional environments. The valley fill is dominated by sediment deposited under transgressive conditions. Frazier (1974) has established that during the Holocene transgression there were four periods of stillstand: (1) at 48 fathoms (18,500-15,500 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 Lavaca-Matagorda and San Antonio Bay systems. Seismic-reflection data and core data in the Lavaca-Matagorda Bay area plus data from the inner continental shelf (Frazier, 1974) suggest that during the stillstand at 9 fathoms, the Gulf could have extended inland along the incised river valleys as far as 26 miles from its present shoreline. With renewed rise in sea level (about 7,500 years B. P.), the Lavaca-Navidad and Guadalupe-San Antonio river valleys were definitely inundated by the Gulf of Mexico.

Subbottom profiling, washdown drilling, and core data from Lavaca, Matagorda, San Antonio, and Aransas Bays have been utilized to determine the configuration of the Pleistocene erosional surface on which Holocene and Modern bay sediment accumulated (Fagg, 1957; Shepard and Moore, 1960; Behrens, 1963; Bouma and Appelbaum, 1973). Maximum depth of scour by the Lavaca-Navidad River in the southern Lavaca Bay area was in excess of 100 feet, and near Port O'Connor, scour was greater than 125 feet. San Antonio Bay was scoured to about 80 feet below MSL (Shepard and Moore, 1960; Bouma and Appelbaum, 1973). Mission River, which lies to the west of the Port Lavaca area, entrenched itself at least 80 feet below MSL in the area of Aransas Bay (Behrens, 1963).

The history of sedimentation in San Antonio and Aransas Bays was similar during the Holocene transgression. The Lavaca-Navidad River scoured a deeper valley than has been recorded in Aransas and San Antonio Bays. The sea invaded the lower Lavaca-Navidad valley at least 1,000 years before San Antonio and Aransas Bays began to develop (fig. 5). Marine invasion of the deeper parts of San Antonio Bay probably began about 9,500 years B. P. (Shepard and Moore, 1960). Sediment in Lavaca Bay, at 85 feet below

MSL (40 feet above the Lavaca-Navidad valley floor), has a radiocarbon age of 9,330 to 9,530 years B. P. (Byrne, 1975).

The valley of the Guadalupe-San Antonio system had a trend approximately north-south to a point opposite McMullen Lake where the trend became southeast (fig. 6). The valley axis, estimated to be about 80 feet below present MSL, underlies Matagorda Island about 3.5 miles northeast of the center of a large inactive tidal delta (Wilkinson, 1973). Ancient tributary valleys parallel the north shores of Espiritu Santo and Ayres Bays.

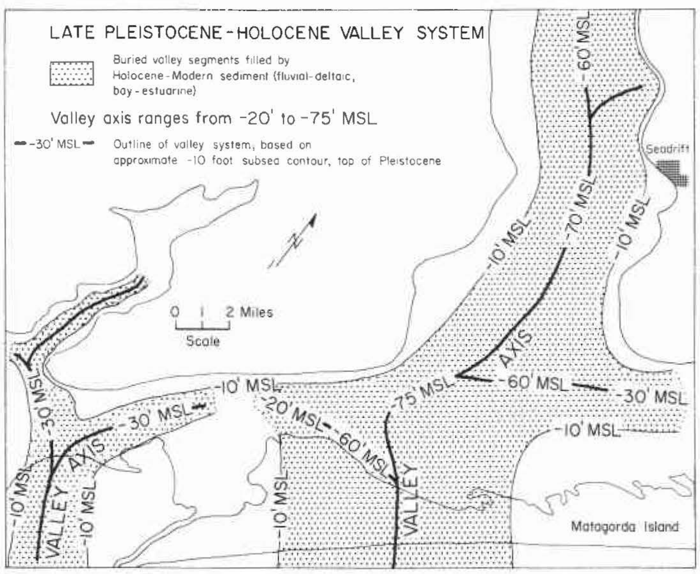


Figure 6. Late Pleistocene-Holocene valley system, San Antonio-St. Charles Bay area. Valleys were incised during last glaciation (low sea level) and progressively filled by Holocene and Modern fluvial, estuarine, tidal, and open-marine sediments. Data from Bouma and Appelbaum, 1973, and Shepard and Moore, 1960.

The Pleistocene surface underlying Matagorda Bay is characterized by many valleys and divides (fig. 7). Recent subbottom profiles indicate that the valley depicted by stations 2, 3, and 4 (idem) is more than 125 feet deep in the vicinity of Port O'Connor.

Shoreline features similar to Modern ones were constructed when there was a stillstand at about 9 fathoms between 10,000 and 7,500 years B. P. (Frazier, 1974). A sand body that probably represents a relict barrier or peninsula occurs some 3 miles seaward of St. Joseph Island (figs. 8 and 9) and up to 6 miles seaward of Matagorda Island. The stillstand at 9 fathoms probably lasted some 2,500 years (comparable to the age of the Modern shoreline). Estuarine sedimentation occurred in most of the valleys, and bayhead deltas were developed by rivers flowing into these estuaries. During this stillstand, walls of drowned valleys were eroded by waves, and the estuaries were widened.

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 a relative rise in sea level of probably less than 10 to 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 approached its present level, 2,800 to 2,500 years B. P., several natural changes began along the mainland and Gulf coastline of the Port Lavaca area: (1) Matagorda-Lavaca and Guadalupe-San Antonio estuaries continued to fill with sediment eroded from the walls of drowned valleys, with sediment supplied by rivers and streams, and with sediment derived from the Gulf of Mexico and transported into the bays through tidal passes; (2) headward erosion of short streams continued within Pleistocene interdistributary areas; (3) Matagorda, Espiritu Santo, San Antonio, and Aransas Bays were developed behind Matagorda Peninsula and Matagorda and St. Joseph Islands; (4) prograding bayhead deltas began to fill Lavaca and San Antonio estuaries; and (5) erosion of bay shorelines by waves continued to enlarge the bays and estuaries.

Development of the Modern Gulf Shoreline

Sea level rose to approximately its present position by about 2,500 years B. P. As sea level rose, sand was transported landward in the Matagorda-St. Joseph Island area, and at stillstand, incipient islands were formed (Wilkinson, 1973). These islands formed in the same areas that Pleistocene strandplains had formed, and part of the sand comprising these incipient islands was derived from these older sand bodies. The incipient islands were separated by tidal channels which closed with time due to spit accretion across channel mouths. Tidal channels situated over Pleistocene valleys remained active for relatively long periods of time, and large flood-tidal deltas developed in these areas. These tidal deltas are shown as large salient features on the bayside of Matagorda and St. Joseph Islands.

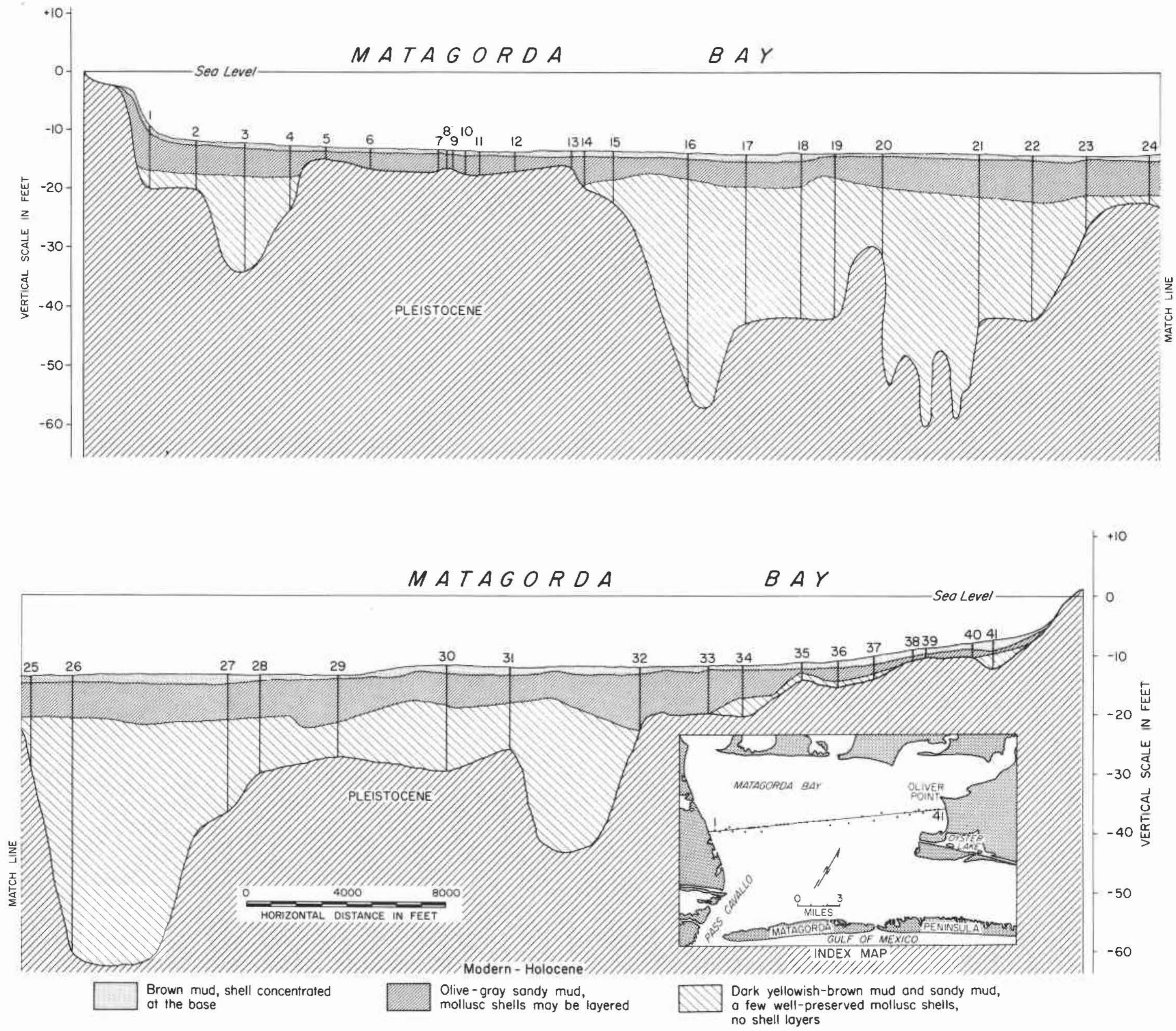


Figure 7. Cross section of Late Pleistocene-Holocene valley system, west Matagorda Bay area. Valleys were incised during last glaciation (low sea level) and progressively filled by Late Pleistocene-Holocene fluvial and deltaic sediments and Holocene estuarine sediments. Development of Matagorda Peninsula resulted in the subsequent filling of the ancient river valleys with Recent bay sediments. Data from Fagg, 1957.

Matagorda Peninsula probably did not exist as a continuous sand body until the Brazos and Colorado Rivers, located northeast of the Port Lavaca area, filled their common estuary about 1,800 years B. P. and riverborne sand became available for redistribution by longshore currents. Shell beaches and berms situated along the north and west shores of Matagorda Bay probably formed prior to development of Matagorda Peninsula and creation of Matagorda Bay. Shell derived from Gulf species constitutes a significant part of these mainland beaches (e.g., the surf clam *Donax* occurs in shell beaches of the north Matagorda Bay shoreline). The presence of these Gulf species indicates that marine conditions existed in the area prior to the development of Matagorda Bay.

After tidal passes closed, Matagorda and St. Joseph Islands accreted. However, Matagorda Island and St. Joseph Island are currently entering an erosional phase; Matagorda Peninsula, in contrast, has been in an erosional phase for at least the past 119 years (McGowen and Brewton, 1975).

Estuarine Deposition and Mainland Shoreline Changes

After the sea reached its present level, the bays began to take on a Modern aspect. Configuration of the bay shoreline changed as promontories were smoothed by wave erosion and the more shallow tributary bays (such as Carancahua and Keller Bays and Powderhorn Lake) were isolated, in part, by spit accretion across their entrances. Bays and estuaries continued to fill chiefly with riverborne sediment.

About 2,000 years B. P., the Guadalupe delta began prograding into San Antonio Bay (Shepard and Moore, 1960). Rate of growth was initially slow, becoming more rapid as the bay became shallower. Average rate of growth over the past 2,000 years has been 40 feet per year (Donaldson and others, 1970). Initial progradation began about 15 miles inland from the present deltaic shoreline.

The Lavaca and Navidad Rivers have filled their estuary since stillstand, and the delta has prograded about 2.7 miles into Lavaca Bay (McGowen and Brewton, 1975). Distribution of Modern depositional environments indicates that initial deltation began about 9 miles inland from the present position of the Lavaca River mouth. If initiation of delta building in the Guadalupe-San Antonio estuary and Lavaca-Navidad estuary was contemporaneous, the Lavaca River delta prograded at a rate of about 24 feet per year. Present rate of progradation is only 4 feet per year. Apparently, once the Lavaca-Navidad estuary was filled and the Lavaca River began discharging directly into Lavaca Bay, progradational rates decreased considerably.

As the bayhead deltas filled their estuaries and continued to prograde southward, they were succeeded by fluvial deposits. From a point about 7 miles upstream of the delta shoreline, these fluvial deposits overlie and cut the Guadalupe delta inland for 8 miles along the Guadalupe and San Antonio Rivers. When the width of meanders of the Modern Guadalupe and San Antonio Rivers is compared with the width of incised meanders cut into the valley walls, it is obvious that Modern streams are significantly smaller than their Pleistocene predecessors.

A meandering channel pattern characterizes the Modern Lavaca and Navidad Rivers above their confluence. Below their confluence, the pattern is sinuous. In this same area, the late Pleistocene-early Holocene pattern was highly meandering; meander scars are preserved in the bluffs adjacent to Menefee Flat and Redfish Lake. Predominance of fluvial sediments extends to within approximately 9 miles of the shoreline of Lavaca delta; the intervening area between the shoreline and fluvial sediments consists of deltaic deposits.

Headward-Eroding Streams

Erosion of the relict Pleistocene fluvial, deltaic, and strandplain deposits has been principally concentrated within about 31 square miles of headward-eroding, commonly ephemeral streams and bayous. Streams such as Keller Creek, Garcitas Creek, Placedo Creek, and the streams which eroded the valleys now occupied by Powderhorn Lake and St. Charles Bay began developing by headward erosion when Late Wisconsin sea level began to drop during a final glacial episode. The small streams incised valleys with steep gradients that connected with the broader valleys of the Lavaca-Navidad and Mission Rivers. The stream which eroded the Powderhorn Lake valley, for example, incised a deep valley that now extends beneath the western end of Matagorda Bay to join the buried Lavaca-Navidad valley about 6 miles north of Port O'Connor.

Since sea level reached its Modern position, headward-eroding streams have continued cutting into Pleistocene coastal plain sediments. The streams are fed principally by runoff from the highly impermeable deltaic coastal plain. Some alluvium and marshland occur along the streams, especially along the lower

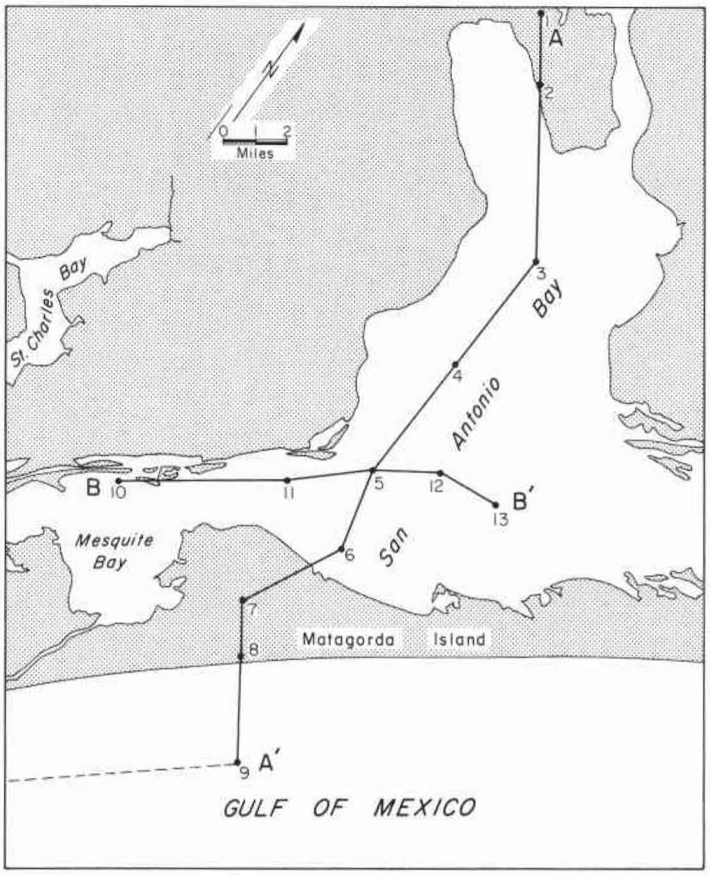


Figure 8. Index of cross sections for figure 9, San Antonio Bay area. Data for boring 9 from Humble well offshore of St. Joseph Island, about 12 miles west of location shown (*see* Shepard and Moore, 1960, fig. 16, for exact location).

reaches, but upper reaches are principally erosional. Wooded areas have commonly developed where sandy sediment and increased moisture are available.

Marshes and Swamps

The largest marshes in the Port Lavaca map area are associated with bayhead deltas. A variety of marsh types, ranging from salt- to fresh-water marsh, characterize the Lavaca, Garcitas, and Guadalupe deltas. Marsh areas expand as these deltas continue to grow.

Generally there is a succession, from the bay margin inland, of salt marsh, brackish marsh, and fresh-water marsh. Swamps are not common in the Port Lavaca area, but generally occur along the lower reaches of fluvial systems and the upper parts of bayhead deltas, particularly along lake margins; some swamps grade laterally into fresh-water marsh.

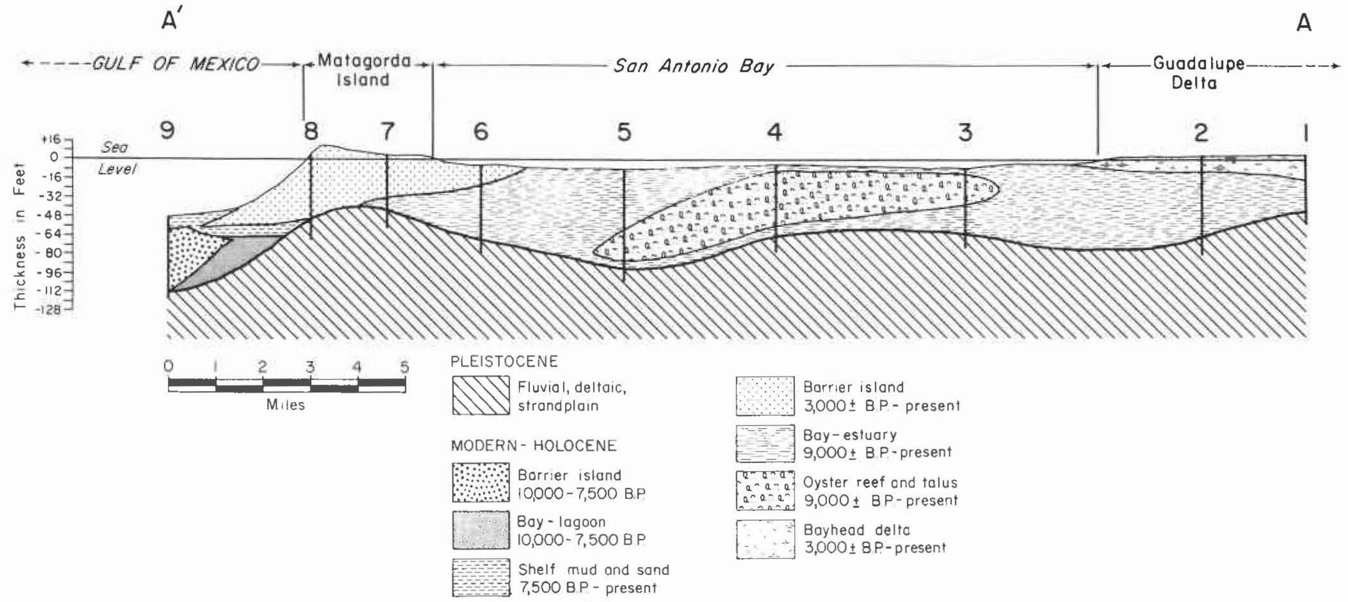
HISTORICAL SUMMARY

The Port Lavaca coastal prairies 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. An old shoreline, marked by beach and shoreline sands, lies along the northwest shores of Espiritu Santo, San Antonio, and Mesquite Bays, between Port O'Connor and Lamar. This is the youngest Pleistocene deposit in the area and was probably constructed during a Wisconsin interstadial episode.

About 30,000 years B. P., sea level was again lowered about 450 feet in response to continental glaciation, resulting in the erosion of deep valleys by rivers such as the ancestral Lavaca-Navidad and Guadalupe-San Antonio; lesser headward-eroding streams that occupied Powderhorn Lake also incised deeply into underlying sediments. When sea level reached its lowest point, rivers extended through deep valleys across many miles of exposed continental shelf to the temporary shoreline.

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 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. This sediment originates from wave erosion of valley walls, transportation by rivers and small, headward-eroding streams, and movement through tidal inlets into the bay-estuary system. Between 3,000 and 2,500 years B. P., barrier-island nuclei had developed in the area between Pass Cavallo and the southwestern map limit. These nuclei coalesced, by spit accretion and filling tidal passes, to form Matagorda and St. Joseph Islands, thereby creating Aransas, San Antonio, Espiritu Santo, and associated bays and lagoons. Initial sand source for Matagorda and St. Joseph Islands was offshore. Subsequent accretion of barrier islands was fed by longshore transport of riverborne sediment from the Colorado-Brazos delta area to the northwest. Some 1,800 years or so after stillstand, Matagorda Bay was cut off from the Gulf of Mexico by spit accretion forming Matagorda Peninsula.



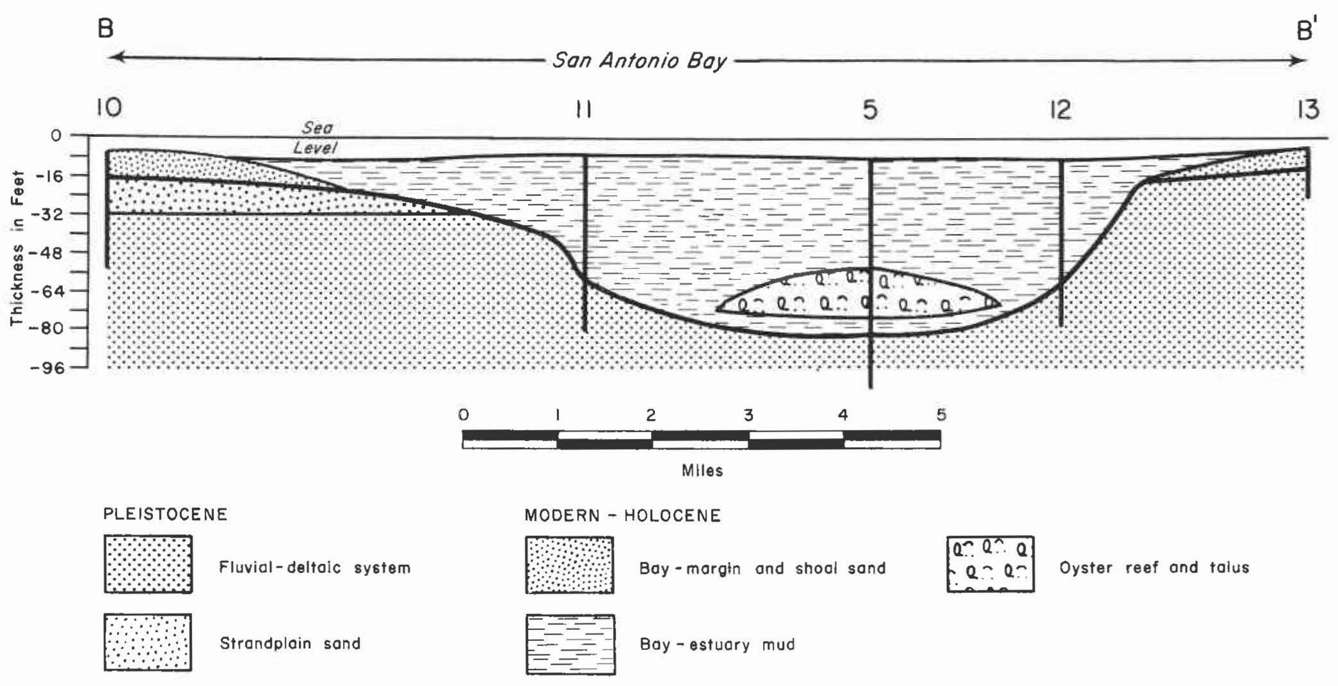


Figure 9. Cross sections of Modern-Holocene barrier island and bay-estuary deposits. Locations of borings shown on fig. 8. (A) A-A' cross section extends north-south from the delta of the Guadalupe River across San Antonio Bay and Matagorda Island into the offshore area. (B) B-B' cross section extends northeast-southwest across the lower (coastward) portion of San Antonio Bay into the area of Mesquite Bay. Data for cross sections from Shepard and Moore, 1960.

The history of Matagorda Peninsula has been one of migration toward the mainland over the deposits of Matagorda Bay. Early history of Matagorda and St. Joseph Islands was rapid accretion, followed by equilibrium. Both have recently entered an erosional phase. 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; resulting discharge of sediment into bays has modified natural circulation patterns. Sediment supplied by human activities during the past few decades has far surpassed the volume of sediment supplied by natural erosion; 20.3 square miles of bay-bottom spoil in the Port Lavaca area is presently being redistributed, while 9.3 square miles of spoil is now piled above sea level and is eroding and entering 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.

Increasing the volume of ground-water withdrawal in the Port Lavaca area could possibly result in land subsidence (Winslow and Wood, 1959; Baker, 1965; Baker and Follett, 1973). Although subsidence to date is slight, Brown and others (1974) indicate that 0.2 to 1.0 foot of subsidence has occurred in Jackson County north of latitude 28°45′. Ground-water use and oil and gas production may result in subsidence and should be monitored carefully to avoid increasing hurricane and rainfall flooding in populated and industrialized areas.

Though most bays in the Port Lavaca area have low mean tidal range (0.25 foot in San Antonio Bay to 0.7 foot in Lavaca Bay), they are still flushed adequately to remove some industrial waste by river flooding and hurricane storm surge. Because tidal range is low in the Gulf of Mexico and lower still in bays and estuaries, tidal exchange alone is insufficient to flush pollutants from the bays into the Gulf of Mexico. At present, there are no major reservoirs on those streams that contribute fresh water to the bays and, therefore, fresh-water flushing is still operative. Hurricanes significantly aid in flushing water and some sediment from the bay system, renewing the bay water and reducing the threat of growing pollution. Man-made structures designed to block hurricane storm surge may severely affect this bay-flushing mechanism. Similarly, the placement of oil-field sludge pits and solid-waste disposal sites on sandy substrates is a threat to ground-water purity; leachate from solid-waste disposal sites also poses a threat to surface-water systems.

A steady trend toward filling or draining of marshes, swamps, and 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. Unusual care should be exercised in casing, cementing, and maintaining these kinds of disposal wells.

CONCLUSIONS

The natural environments of the Port Lavaca 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; for this reason, therefore, caution will be required to maintain a satisfactory level of environmental quality during coming decades. 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. A principal factor is 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. The angle at which hurricanes strike the coast, likewise, 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, just as longshore drift smooths the seaward side of strandplains 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 is 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 (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 PORT LAVACA AREA

Average annual rainfall along the coast in the Port Lavaca area ranges from 35.5 inches in Aransas County to 39 inches in Matagorda County. Inland, average annual rainfall extends from 32 inches in Bee County to 38 inches in Jackson County. Victoria County, near the center of the map area, averages 36.2 inches of precipitation annually. The average annual rainfall from 1931 to 1960 shows a progressive increase eastward across the area from 32 inches in the extreme northwest to 39 inches in the southeast corner of the map area (fig. 10A).

Precipitation values alone are not necessarily significant until compared with precipitation deficiency (fig. 10C). Between 1931 and 1960, the Port Lavaca area had a precipitation deficit of about 3 to 16 inches. Coupled with this deficient rainfall budget is a 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 45°F in Bee County to a July or average summer maximum of 95°F in Bee County; a high of 94°F was recorded in Goliad County. Counties along or nearer to the Gulf of Mexico, such as Aransas, Calhoun, and Matagorda Counties, registered ranges from an average winter minimum of 47°F to an average summer maximum of 92°F. Between 1931 and 1960 (fig. 10B), the average annual mean free-air temperature in the Port Lavaca area was between 70° and 71°F.

The importance of two 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 Port Lavaca area than to the east. Fore-island dunes are continuous along west Matagorda Peninsula, Matagorda Island, and St. Joseph Island, except at Greens Bayou (an ephemeral pass 7.3 miles east of the Matagorda Ship Channel jetties), Decros Point (the western tip of Matagorda Peninsula), and Cedar Bayou. Density of vegetation cover of the sandy shorelines of the Port Lavaca area is intermediate between the south and east

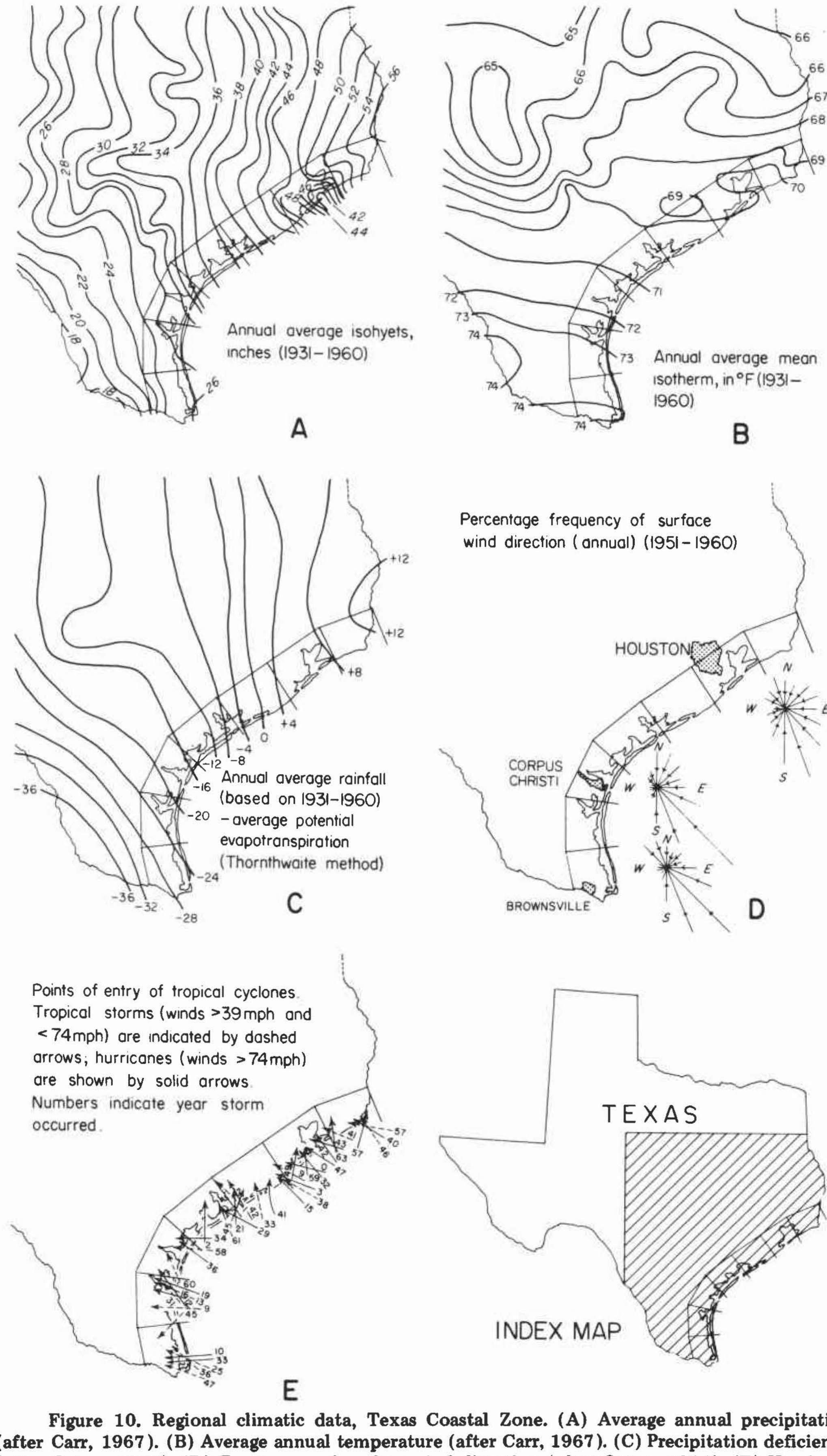


Figure 10. Regional climatic data, Texas Coastal Zone. (A) Average annual precipitation (after Carr, 1967). (B) Average annual temperature (after Carr, 1967). (C) Precipitation deficiency (after Orton, 1969). (D) Frequency of surface-wind direction (after Orton, 1964). (E) Hurricane tracks across Texas coastline (after Hayes, 1967).

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 November and short-lived but strong northerly winds from December through February. The surface-wind pattern (fig. 11) for Victoria (1941-1945 and 1953-1956) illustrates the percentage frequency of various wind directions characteristic of the Port Lavaca 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.

During passage of a severe polar front, for example, a north wind may blow for 24 hours, but at average wind velocities of perhaps 30 to 40 miles per hour. Therefore, 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 effective-

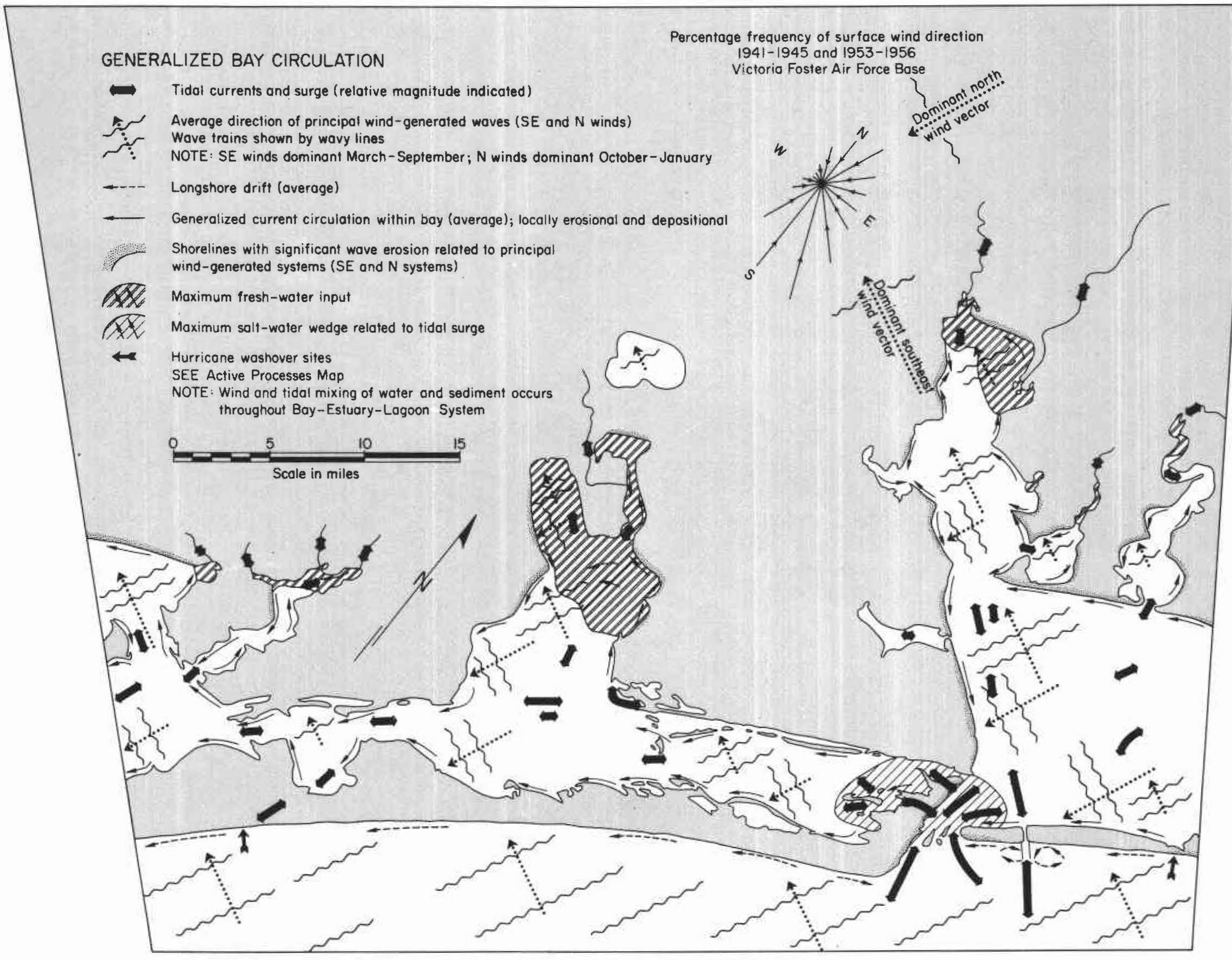


Figure 11. Circulation, waves, sediment transport, and other physical processes, bay-estuary-lagoon and offshore systems, Port Lavaca map area.

ness; 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-driven tides.

Persistent Southeasterly Winds

Prevailing winds from the southeast develop wave trains that are translated into extensive breakers as the waves contact the bottom of the smooth, gently sloping inner shelf and shoreface (fig. 11). These wave trains result in secondary waves and currents that control deposition and erosion along barrier island and peninsula beaches. Wave crests oriented northeast-southwest move northwestward across the shoreface where they refract to strike the coastline almost at a 90° angle. 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 the wave trains cross the shoreface at a slight angle, a net southwestward longshore drift is generated. This net southwestward drift results in sediment being repeatedly moved onshore and offshore, but with a slight southwestward drift or vector resulting from the slight angular wave approach (fig. 11). 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 along the shoreline and from the sea floor 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 in the absence of sufficient sand nourishment, normally shift landward during their development. 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 Matagorda, Lavaca, Espiritu Santo, San Antonio, Aransas, and Copano Bays. Shorelines of Matagorda Bay are affected most 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 along east-west shorelines and northward along north-south shorelines. Wind stress on the water surface causes a general lowering of water level along the bayside of peninsulas and barrier islands and flooding of low-lying mainland shorelines that lie in the downwind direction. 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 net southwest longshore drift 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); erosional shorelines can be recognized by increased shell content. During the last 3,000 years, the Gulf shoreline from Pass Cavallo to the southwestern map limit has been chiefly accretionary. However, recent observations and historical shoreline monitoring data indicate that the Gulf shorelines of Matagorda and St. Joseph Islands have begun to erode. Currently, the Gulf shoreline of Matagorda Peninsula is chiefly erosional; indeed, Matagorda Peninsula has been erosional during much of its history. Sediment composing Matagorda Peninsula was derived from the Brazos and Colorado Rivers and from offshore Pleistocene and Holocene deposits. During early development of Matagorda and St. Joseph Islands, most of the sand supplied to these coastal features was derived from offshore Pleistocene strandplain sand. Sediment supply for all the Gulf shorelines in the map area has diminished over the past few years. Dams on major rivers and jetties at the Matagorda Ship Channel intercept sand that would normally be delivered to Gulf beaches.

Northerly Winds

During December, January, and February, 15 to 20 northers (rapidly moving polar fronts) pass through the coastal area. 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. 11). 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 Pass Cavallo and Matagorda Ship Channel. Resuspended mud in Espiritu Santo, San Antonio, Aransas, and Copano Bays is transported toward the south bay shore and southwestward through Cedar Bayou and Lydia Ann Channel (14 miles southwest of map area).

Wind stress on the water surface 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 parts of Matagorda Bay. Parts of the south bay shores (baysides of Matagorda Peninsula and Matagorda and St. Joseph Islands) are inundated by wind tides created by northers, and wind-tidal flats are progressively better developed from northeast to southwest.

Coincident with the rise in water level along the south 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 excessively high ebb-current velocities through tidal inlets. Pass Cavallo and Cedar Bayou are oriented approximately 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 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 poorly understood for the bays and nearshore marine environment. Current velocities and the general role in sediment transport are known for tidal channels.

There are three natural passes in the Port Lavaca area—Greens Bayou, Pass Cavallo, and Cedar Bayou. Greens Bayou is only intermittently open. Pass Cavallo is a major tidal pass which, prior to 1965, was the only avenue of water exchange between the Gulf of Mexico and the Matagorda Bay system. Cedar Bayou lies between Matagorda Island and St. Joseph Island, some 30 miles to the southwest of Pass Cavallo. In the past, Cedar Bayou was the principal tidal channel between the San Antonio Bay system and the Gulf of Mexico. Since historical records have been maintained, Cedar Bayou has been alternately opened and closed.

Pass Cavallo has been open continuously since historical records have been maintained. Tidal currents and sediment move freely through this pass. Highest velocities are attained in the winter when northers create excessively high water at the south corner of Matagorda Bay.

Mean tidal range at Pass Cavallo is 1.4 feet (U. S. Dept. Commerce, 1973a). Tidal currents are probably greater during ebb than flood (Harwood, 1973) because ebb tide is of shorter duration than flood tide. Ebb currents are stronger than flood currents in Sabine Pass and Bolivar Pass (U. S. Dept. Commerce, 1973b). Because tidal currents are asymmetrical, most of the sediment that moves into the bay 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. A large volume of sand that constitutes flood deltas accumulated under storm conditions when currents through the passes were abnormally strong and tides were exceptionally high.

Prior to the dredging of Matagorda Ship Channel in 1965, Pass Cavallo was approximately 1.8 miles wide, and the channel through the pass was about 2,000 feet wide and 20 to 42 feet deep (Simmons and Rhodes, 1966). Water depths throughout most of the pass area were generally less than 6 feet. Since 1965, the inlet tidal prism has been 5.7 billion cubic feet (this is for mean tidal range during half the tidal period) and 4.3 billion cubic feet at Matagorda Ship Channel (Harwood, 1973). In 1856, the tidal prism through Pass Cavallo was 12.4 billion cubic feet. Discharge through Pass Cavallo (same tidal conditions as given for the tidal prism) in 1856 was 274,000 cubic feet per second, and since 1965 it has been about 135,000 cubic feet per second (Harwood, 1973).

Matagorda Ship Channel has reduced the volume of water exchanged through Pass Cavallo between the Matagorda Bay system and the Gulf of Mexico; however, volume of water exchanged is still sufficient to maintain the estuarine environment.

Cedar Bayou is about 3 miles long and has a maximum depth of about 9 feet. When open, the depth of the pass at the Gulf of Mexico is approximately 2 feet. The pass is opened when high discharge through the Guadalupe River coincides with strong north winds (Simmons and Hoese, 1959). Much of the fresh-water discharge from the Guadalupe River flows southwestward along the Intracoastal Waterway into Aransas Bay. Water movement through Cedar Bayou is greatest when high river discharge and north winds coincide. Flow through Cedar Bayou does not always reflect tidal cycle conditions. Water sometimes flows continuously from the Gulf through Cedar Bayou for as many as 5 days (Simmons and Hoese, 1959). Similarly, sustained outflow occurs in the winter as a consequence of persistent, high-velocity north winds. Tidal currents acting alone are not adequate to maintain Cedar Bayou.

RIVER DISCHARGE

Within the Port Lavaca map area, four significant streams discharge into the bays. Lavaca River and Garcitas Creek discharge at the head of Lavaca Bay. San Antonio Bay receives water and sediment from the Guadalupe River. Mission River, just off the map to the southwest, contributes fresh water and some sediment to Copano and Aransas Bays. 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.

Some of the suspension load derived from Lavaca River and Garcitas Creek reaches the Gulf of Mexico through Pass Cavallo. Mud contributed to San Antonio Bay may reach the Gulf of Mexico through Cedar Bayou; much of the fresh water and suspended sediment load flows toward Aransas Bay along the Intracoastal Waterway. A large part of the suspension load of the Mission River is trapped in Mission Bay (southwest of mapped area).

River flooding changes the salinity of bay water; thus, a salinity gradient is produced during flooding. In the Matagorda Bay area, salinity may range from 0 parts per thousand ($^{\circ}/_{\circ\circ}$) near the heads of bays to about $20^{\circ}/_{\circ\circ}$ at Port O'Connor. The Guadalupe River has a pronounced effect on the salinity of San Antonio Bay. Fresh water virtually replaces bay water as far south as the Intracoastal Waterway. When river flooding and northers coincide, salinity at the mouth of Cedar Bayou may be as low as $11^{\circ}/_{\circ\circ}$. Espiritu Santo Bay, on the other hand, is not significantly affected by river flooding.

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. 10). 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, deltaic headlands, or chenier ridges, 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. 12A).

The storm approach is marked by rising tides and increased wind velocities (fig. 12B). 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 peninsula shoreline; these tides are known to reach 22 feet above sea level. The storm surge deposits sand and shell berms on beaches, pushes shelf sand onto the shoreface, erodes fore-island dunes, and may breach the

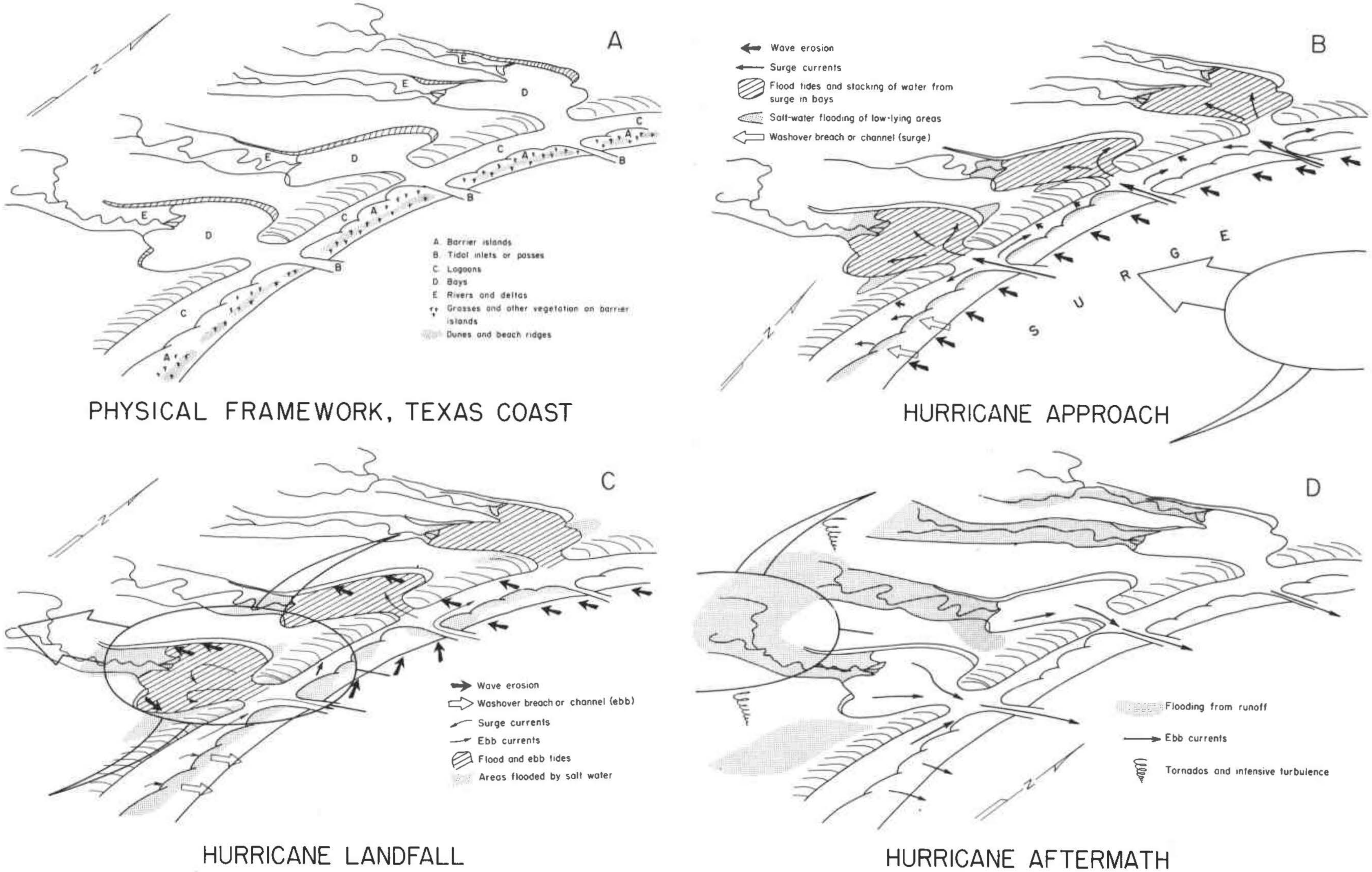


Figure 12. Schematic model of hurricane effects on the Texas Coastal Zone. (A) Physical features characterizing the Texas coast. (B) Effect of approaching hurricanes. (C) Effect of hurricanes upon impact with the coast. (D) Aftermath effects of hurricanes. After McGowen and others, 1970.

barrier island or peninsula through storm or washover channels. Strong southwestward currents along the shoreface result from the counterclockwise wind circulation.

As the storm passes over the shoreline, the counterclockwise winds generate unique currents within the bays (fig. 12C). 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. 12D). Water stacked in bays during the storm approach and impact suddenly begins to drain gulfward through passes and storm channels. Heavy rains, which may exceed 30 inches over a period of 2 days or so, 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) breached Matagorda Peninsula and widened Greens Bayou more than 1 mile. Fore-island dunes were eroded on both Matagorda Peninsula and Matagorda and St. Joseph Islands. Neither Matagorda nor St. Joseph Island was breached; washovers occurred in the Cedar Bayou-Vinson Slough area. As the storm moved inland, storm surge increased from 14 feet at Port O'Connor to 22 feet at Port Lavaca (U. S. Army Corps Engineers, 1962). Low-lying areas were extensively flooded. Storm surge flooded the Lavaca and Navidad river valleys a distance of about 14 miles from the head of Lavaca Bay. Flooding extended a distance of about 12 miles inland along the Guadalupe and San Antonio Rivers. Total area inundated by Hurricane Carla storm surge was about 495 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, 1974, personal communication).

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: 96°15′ and 97°15′. The 96°15′ longitude line, for example, is 96 degrees and 15 minutes west of the Prime Meridian at Greenwich, England. In the Port Lavaca area, 1 degree of longitude equals about 62 miles, or 1 minute of longitude equals about 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: 28°00′, 28°15′, and 29°00′. The 28°00′ latitude line is 28 degrees and 00 minutes north of the Equator. One degree of latitude equals about 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 Port Lavaca area within the Coastal Zone.

Magnetic declination in the center of the Port Lavaca area during 1972 was approximately 9 degrees 15 minutes easterly; magnetic North Pole is thus 9 degrees 15 minutes east of the geographic North Pole in the area. This simply means that a compass will read 9 degrees 15 minutes more easterly or clockwise than true or geographic North. Nine degrees 15 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 Port Lavaca 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 number 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 cultural and natural features 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 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 Port Lavaca 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 Port Lavaca 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 Port Lavaca 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 Port Lavaca area, he can evaluate the sites based on the properties at each location (*Physical Properties Map*) and determine the percentage. Interpretation 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.

Table 1. Index of map units, Port Lavaca map area, Texas.

In the following alphabetical list of map units used in the Port Lavaca 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

Table 2. Environmental subject index, Port Lavaca 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

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 other 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 from the standpoint of 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, 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 these products of man's activity have 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 Port Lavaca 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 Port Lavaca 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 Port Lavaca 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 2,500 years B. P.; and (2) deposits and landforms developed during the past 2,500 years, during which time sea level has been approximately at its present position.

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 are basic to considerations of resource evaluation and use since they determine the main features, composition, and character of the natural units. Natural systems delineated in the Port Lavaca area (fig. 4) include: (1) fluvial-deltaic system, a series of relict Pleistocene substrates and Modern environments and substrates formed by older 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 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; and (5) bay-estuary-lagoon system, consisting of Modern subaqueous or submerged estuarine environments (e.g. Matagorda, Lavaca, and San Antonio Bays) occurring inland from barrier islands and peninsulas and connected with the Gulf via Matagorda Ship Channel, Pass Cavallo, and Cedar Bayou. Certain specific environments or mapped units may occur in more than one natural system, for example, marshes and swamps which also form 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 Port Lavaca area (fig. 4). These include a fluvial-deltaic system and a barrier-strandplain system formed prior to 40,000 or 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 5 feet above present sea level. Individual units within the Pleistocene systems are distinguished largely by composition of geologic substrates and overlying soils, trend and distribution of sediments, and local occurrence of relict landforms.

Fluvial-Deltaic System

There are 12 principal units defined within the Pleistocene fluvial-deltaic system. These include units

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

		ENVIRONMENTAL GEOLOGIC MAP UNITS	Aransas°	Bee°	Calhoun°	Goliad°	Jackson°	Matagorda°	Refugio°	Victoria°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Port Lavaca map area (excluding offshore area)	Percentage of Port Lavaca map area covered by map unit (excluding offshore area)
PLEISTOCENE SYSTEMS	FLUVIAL-DELTAIC SYSTEM	Meanderbelt sand, sparsely tree-covered, little grain preserved	0	2.7	0	52.5	0	0	62.0	54.0	–	171.2	6.3
		Floodplain, overbank mud, including mud-filled abandoned channels and mud-veneered meanderbelt sand	0	0	0	9.0	0	0	14.0	3.5	–	26.5	1.0
		Floodplain, mud veneer over meanderbelt sand, little grain preserved, grass-covered	0	0	0	14.5	0	0	17.0	37.0	–	68.5	2.5
		Distributary and fluvial sand and silt, including levee and crevasse splay deposits	10.5	0	90.0	0	78.5	0	133.0	90.5	–	402.5	14.9
		Interdistributary mud with sand veneer, including bay and floodbasin facies	6.9	0	35.0	0	36.0	0	86.5	39.0	–	203.4	7.5
		Interdistributary mud, including bay, floodbasin, and locally abandoned channel facies	0.5	0	101.0	0	102.0	0	40.5	105.0	–	349.0	12.9
		Upland oak mottes on distributary and fluvial sand	0	0	1.7	0	3.0	0	0.8	5.0	–	10.5	0.4
		Circular to irregular depressions on distributary-fluvial sand, may be mud-, sand-, or water-filled (Pleistocene-Modern)	0.5	0	1.0	1.0	2.5	0	3.4	4.0	–	12.4	0.5
		Lakes and ponds along coast, and heart-shaped lakes on inland meanderbelt sand, mud- and sandy mud-filled (Pleistocene-Modern)	0	0	0.5	0	0	0	4.0	0	–	4.5	0.2
		Beach ridge and berm, along margins of inland lakes, abandoned, sand and shell, grass-covered (Pleistocene-Modern)	0	0	0	0	0	0	0.5	0	–	0.5	0.01
		Swales between beach ridges along margins of inland lakes, grass-covered, mud-filled (Pleistocene-Modern)	0	0	0	0	0	0	0.3	0	–	0.3	0.01
		Marine deltaic sand, delta-front and reworked delta facies, may be veneered by thin marsh or lacustrine mud	10.0	0	31.5	0	2.5	0.3	49.0	0	–	93.3	3.4
		Mud veneer distributed locally over marine deltaic sand, delta-front and reworked delta facies (Holocene)	23.0	0	21.0	0	4.0	0	17.5	0	–	65.5	2.4
		Abandoned channel and course, mud-filled (Pleistocene-Modern)	0	0	7.5	11.0	9.5	0	40.5	10.0	–	78.5	2.9
		Abandoned channel and course, fresh-water marsh-covered, mud-filled (Pleistocene-Modern)	0	0	0.3	0	0	0	0.5	0.3	–	1.1	0.04
		Tidal creek, fresh-water marsh-covered, mud-filled (Modern)	0.5	0	0.7	0	0	0	0	0	–	1.2	0.04
		Tidal creek, grass-covered, mud-filled (Pleistocene-Modern)	5.0	0	4.0	0	0	0	20.5	0	–	29.5	1.1
		Beach sand, thin veneer at edge of marine deltaic sand (Holocene)	0.8	0	4.2	0	0.1	0	0	0	–	5.1	0.2
	BARRIER-STRANDPLAIN SYSTEM	Barrier-strandplain sand, tree-covered	11.0	0	0.3	0	0	0	0.8	0	–	12.1	0.4
		Barrier-strandplain sand, grass-covered	43.5	0	52.6	0	0	0	2.0	0	–	98.1	3.6
		Live-oak-covered beach ridge, relict, barrier-strandplain, sand and shell	2.0	0	0	0	0	0	0	0	–	2.0	0.07
		Well-stabilized dune sand, dense live-oak mottes (Modern)	1.0	0	0.3	0	0	0	0	0	–	1.3	0.04
		Swales between beach ridges, including minor drainage courses developed in lows, grass-covered, mud-filled (Pleistocene-Modern)	5.3	0	0	0	0	0	0	0	–	5.3	0.2
		Swales between beach ridges, including minor drainage courses developed in lows, fresh-water marsh-covered, mud-filled (Modern)	3.0	0	7.5	0	0	0	0	0	–	10.5	0.4
		Sheet sand, locally mud-veneered, along back side of Pleistocene strandplain, wind- or sheetwash-derived, sparsely grass-covered, overlies partly filled lagoon, embayment, or linear depression	8.5	0	32.5	0	0	0	8.0	0	–	49.0	1.8

MODERN-HOLOCENE SYSTEMS	FLUVIAL-DELTAIC SYSTEM	Small active headward-eroding streams, tree-covered, alluvium, sand, silt, and mud, alluvium absent locally	1.2	0	2.5	3.0	9.0	0	6.5	9.0	–	31.2	1.2
		Point-bar sand, tree-covered, along active streams	0	0	0.5	0	0.3	0	0.3	0.3	–	1.4	0.05
		Point-bar sand, bare or sparsely grass-covered, along active streams	0	0	0	0.2	0.3	0	0	0.5	–	1.0	0.03
		Levee and local crevasse splay deposits, silt, mud, and sand, sparsely grass-covered	0	0	9.0	0	0.5	0	2.5	1.7	–	13.7	0.5
		Levee and local crevasse splay deposits, silt, mud, and sand, tree-covered	0	0	4.7	0	0	0	0.8	4.0	–	9.5	0.4
		Levee deposits, silt, mud, and sand, fresh-water marsh-covered	0	0	0.5	0	2.0	0	0.3	0.5	–	3.3	0.1
		Meanderbelt sand without prominent grain, tree-covered, locally overbank muds, inactive, within an entrenched valley (Holocene)	0	0.5	0.3	4.0	10.0	0	10.5	29.5	–	54.8	2.0
		Meanderbelt sand and silt, sparsely grass- and shrub-covered, inactive, within an entrenched valley (Holocene)	0	0.3	1.7	4.0	12.0	0	9.0	27.0	–	54.0	2.0
		Floodbasin, overbank mud, grass-covered, inactive, within an entrenched valley	0	0	0.1	0.7	0.3	0	2.0	16.0	–	19.1	0.7
		Interdistributary silt and mud, includes locally bay, lacustrine, and crevasse splay facies	0	0	5.0	0	0.8	0	0	1.5	–	7.3	0.3
		Abandoned channel and course, mud-filled	0	0	*	*	*	0	*	*	–	*	*
		Abandoned channel and course, swamp-covered, mud-filled	0.1	0	0.3	0.5	0.5	0	0	0	–	1.4	0.05
		Abandoned channel and course, fresh-water marsh-covered, mud-filled	0	0	*	0	0	0	*	*	–	*	*
		Marsh, salt-water, mud and locally sand substrate	*	0	*	0	*	*	*	*	–	*	*
		Marsh, fresh- to brackish-water, mud and locally sand substrate	0	0	*	0	*	0	*	0	–	*	*
		Marsh, fresh-water, mud and locally sand substrate	0	0	*	*	*	0	*	*	–	*	*
		Swamp, mud and locally sand substrate	0	0	*	0	*	0	*	*	–	*	*
		Tidal creek, fresh- to brackish-water marsh-covered, mud-filled	1.2	0	1.5	0	0	0	0	0	–	2.7	0.09
		Tidal creek, mud-filled	0	0	*	0	0	0	0	0	–	*	*
		Delta-plain mud and sand, grass-covered	0	0	6.5	0	2.5	0	3.5	0	–	12.5	0.5
		Delta-plain mud and sand, sparsely grass-covered	0	0	0.5	0	0.3	0	1.0	0	–	1.8	0.06
		Prodelta mud and silt	0	0	6.5	0	0	0	0	0.5	–	7.0	0.3
		Delta-front sand (abandoned and active)	0	0	2.0	0	0	0	0	0	–	2.0	0.07
	BARRIER-STRANDPLAIN AND OFFSHORE SYSTEMS	Shelf mud and sand with shell, mottes	–	–	–	–	–	–	–	–	–	–	–
		Shoreface, sand and muddy sand, burrowed	–	–	–	–	–	–	–	–	56.5	–	–
		Beach, sand and shell	0.5	0	6.0	0	0	2.5	0	0	–	9.0	0.3
		Fore-island dune ridge, sand	0.3	0	3.5	0	0	0.5	0	0	–	4.3	0.2
		Beach ridge and barrier flat, sand and shell, grass-covered (fore-island dunes discontinuous and beach ridges rare northeast of Pass Cavallo)	0.8	0	24.0	0	0	5.0	0	0	–	29.8	1.1
		Stabilized blowout dune complex, sand, grass-covered, hummocky, ramplike	2.8	0	6.0	0	0	0	0	0	–	8.8	0.3
		Marsh, salt-water, mud and locally sand substrate	*	0	*	0	*	*	*	*	–	*	*
		Washover channel, sand-filled, normally inactive	0.5	0	1.2	0	0	0	0	0	–	1.7	0.06
		Washover distributary channel, sand, active	6.5	0	0	0	0	0	0	0	–	6.5	0.2
		Washover fan, sand, subaerial, vegetated	5.0	0	2.0	0	0	0	0	0	–	7.0	0.3
		Washover distal fan, sand, subaerial, barren, active (St. Joseph Island), normally inactive northeast of Vinson Slough	7.5	0	0	0	0	0	0	0	–	7.5	0.3
		Fore-island blowout dunes and back-island dunes on washover fan surface, sand, active	0.3	0	0.5	0	0	0	0	0	–	0.8	0.02
		Tidal channel, sand, active	0.3	0	7.0	0	0	1.3	0	0	1.5	8.6	0.3
		Tidal channel, mud- and sand-filled, inactive	0	0	0	0	0	0.1	0	0	–	0.1	0.003
		Flood-tidal delta, sand, subaqueous, proximal to major channel, and small bay-margin tidal deltas, both flood and ebb, mostly sand	0	0	6.0	0	0	0.8	0	0	–	6.8	0.3
		Flood-tidal delta, mud and sand, subaqueous, distal to channel	0	0	2.2	0	0	0.8	0	0	–	3.0	0.1
		Ebb-tidal delta, sand, subaqueous, proximal to channel	0	0	0.7	0	0	0.3	0	0	4.0	1.0	0.03
		Ebb-tidal delta, mud and sand, subaqueous, distal to channel	0	0	1.5	0	0	0	0	0	14.6	1.5	0.05
		Inlet-related shoal and bars on tidal flats, sand	0	0	2.2	0	0	0.5	0	0	0.7	2.7	0.09

MODERN-HOLOCENE SYSTEMS	MARSH-SWAMP SYSTEM	Marsh, salt-water, mud and locally sand substrate	13.0	0	29.0	0	5.0	0.5	4.5	2.0	–	54.0	2.0
		Marsh, fresh- to brackish-water, mud and locally sand substrate	0	0	0.5	0	0.5	0	0.8	0	–	1.8	0.06
		Marsh, fresh-water, mud and locally sand substrate	0	0	8.5	0.5	1.3	0	0.5	1.7	–	12.5	0.5
		Swamp, mud and locally sand substrate	0	0	0.3	0	0.1	0	0.3	0.5	–	1.2	0.04
	BAY-ESTUARY-LAGOON AND LAKE SYSTEMS	Bay-margin sand and shell berms, beaches, and active spits, accretionary, subaerial, relict depositional grain, locally vegetated	0.3	0	5.0	0	0.3	0.3	0	0	–	5.9	0.2
		Beach ridge and berm, abandoned, grass-covered, sand and shell	0.3	0	0.3	0	0	0	0.1	0	–	0.7	0.02
		Wind-tidal flat, sand and mud, barren to sparsely vegetated, subaerial, burrowed	5.3	0	14.0	0	0	1.3	0.5	0	–	21.1	0.8
		Grassflat, muddy sand with shell	1.8	0	9.5	0	0	0.5	0	0	–	11.8	0.4
		Bay-margin sand, muddy sand and shell, bare to sparsely marine grass-covered, subaqueous	13.2	0	44.0	0	0.4	2.0	1.7	0	–	61.3	2.3
		Bay and bay-margin sandy mud, mottled, some shell	0.5	0	76.0	0	0	15.2	0	0	–	91.7	3.4
		Bay sand with mixed shell, probably thin veneer over Pleistocene ridge or mound	0.3	0	4.5	0	0	0.5	0	0	–	5.3	0.2
		Delta-front sand (abandoned and active)	0	0	*	0	0	0	0	0	–	*	*
		Prodelta mud and silt	0	0	*	0	0	0	0	*	–	*	*
		Bay mud, mottled, some mixed shell	25.0	0	192.0	0	4.0	45.5	1.0	0	–	267.5	9.9
		Oyster reef	3.0	0	6.0	0	0	0.5	0.3	0	–	9.8	0.4
		Oyster reef flank, sand or mud, abundant shell	6.9	0	14.5	0	0	0.5	0.3	0	–	22.2	0.8
		Bay sand and muddy sand, locally with oyster shell	26.0	0	8.5	0	0.8	0	2.5	0	–	37.8	1.4
		Interreef mud with oyster shell	8.5	0	0.7	0	0	0	1.0	0	–	10.2	0.4
		Lakes and ponds along coast and on inland meanderbelt sand, mud- and sandy mud-filled (Pleistocene-Modern)	0	0	*	0	0	0	*	0	–	*	*
		Beach ridge and berm along margins of inland lakes, abandoned, sand and shell, grass-covered (Pleistocene-Modern)	0	0	0	0	0	0	*	0	–	*	*
		Swales between beach ridges, along margins of inland lakes, grass-covered, mud-filled (Pleistocene-Modern)	0	0	0	0	0	0	*	0	–	*	*
OTHER MAP UNITS		Point-bar (fluvial) accretion	–	–	–	–	–	–	–	–	–	–	–
		Beach ridge (barrier-strandplain) accretion	–	–	–	–	–	–	–	–	–	–	–
		Spoil heap or mound, subaerial	1.0	0	6.0	0	0	0.3	0	0	–	7.3	0.3
		Reworked spoil, subaerial	0.5	0	1.0	0	0.5	0	0	0	–	2.0	0.07
		Spoil, subaqueous	2.8	0	13.0	0	0	4.5	0	0	0.7	20.3	0.7
		Made land	0	0	0.3	0	0	0	0	0	–	0.3	0.01
TOTAL		Total land area+	179.1	3.5	532.8	100.9	284.3	10.8	543.9	442.5	–	2097.8	77.4
		Total land and water area, excluding offshore area+	273.0	3.5	946.6	102.1	294.0	85.0	554.7	450.0	–	2708.9	100.0
		Total water area (natural and artificial) excluding bay, lagoon, and open ocean	5.6	0	17.0	1.2	4.5	1.3	4.0	7.0	–	40.6	1.5
		Total bay and lagoon area	88.3	0	396.8	0	5.2	72.9	6.8	0.5	–	570.5	21.1

†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 Port Lavaca map area.

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

that are entirely Pleistocene, those that were created during the Pleistocene (e.g., lakes and abandoned channel segments) and are receiving some sediment today, and Modern-Holocene features (e.g., tidal channels, beaches, and oak mottes) that modify fluvial-deltaic deposits. Pleistocene and younger units include: (1) meanderbelt sand, (2) floodplain-overbank mud and mud veneer over meanderbelt sand, (3) distributary and fluvial sand and silt, (4) interdistributary mud and interdistributary mud with sand veneer, (5) upland oak mottes, (6) circular to irregular depressions on distributary-fluvial sand, (7) lakes and ponds, (8) beach ridges and swales associated with inland lakes, (9) marine deltaic sand and marine deltaic sand with mud veneer, (10) abandoned channel and course, either mud filled or incompletely filled and now occupied by fresh-water marsh, (11) tidal creeks, either mud filled or incompletely filled and now occupied by fresh-water marsh, and (12) beach sand at the terminus of marine deltaic sand. The principal natural systems in the Port Lavaca area are shown in figure 4. Pleistocene meanderbelt sand and mud have, in part, been called Montgomery and Bentley Formations, as well as Lissie Formation, by some workers; similarly, Pleistocene deltaic units (distributary channels and interdistributary mud) and barrier-strandplain-chenier units are commonly termed Beaumont Formation or, in part, Prairie Formation (Bernard and LeBlanc, 1965).

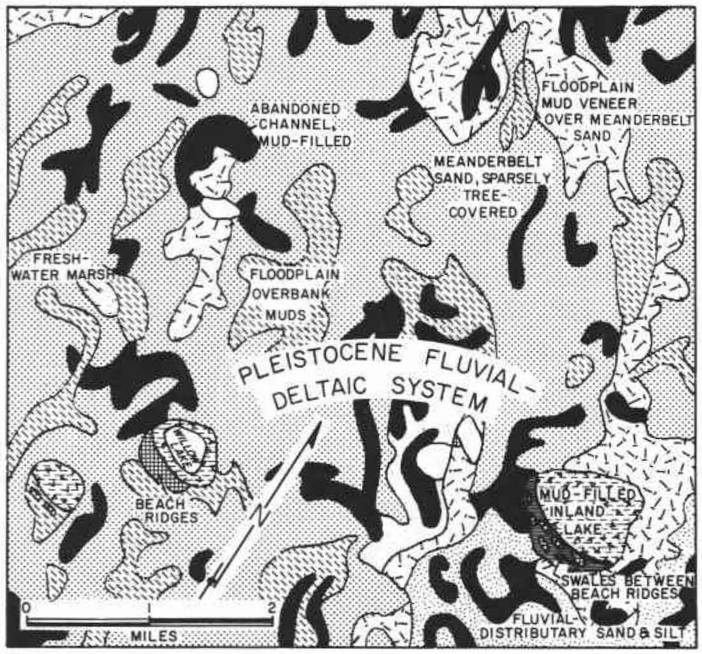


Figure 13. Pleistocene meanderbelt sand and floodplain mud in the vicinity of Refugio, Port Lavaca map area. Abandoned fluvial-deltaic distributary channels are mud filled. Shallow lakes are sand and mud filled, contain fresh-water marsh, or are under water; prominent beach ridges formed downwind from dominant north winds.

Meanderbelt sand.—Meanderbelt sand, the channel and point-bar deposits of Pleistocene meandering streams, occurs as 171 square miles of high-terrace deposits which cover broad inland areas flanking the Guadalupe and San Antonio Rivers and Blanco Creek (fig. 13). They form relatively low-relief surfaces on which original depositional topography and grain (point-bar accretion and channel abandonment) are locally, though vaguely, displayed. Associated with meanderbelt sand are a few inland lakes—Sharps Lake (dry), Willow Lake, Ninemile Flat, South and North St. Nicholas Lakes, Flat Lake, and Bundick Lake. Beach ridges, berms, and swales are situated to the south of these lakes, which range from 0.7 mile to 2.0 miles in diameter. These lakes are analogous to Modern ones associated with the Lavaca and Guadalupe deltas. Some of the lakes contain water, others have been filled with sand and mud. Meanderbelt sand is permeable and well drained, supporting mixed chaparral, live-oak, and post-oak vegetation and developing relatively mature soils.

Floodplain mud.—Broad and local inland areas are underlain by a total of 95 square miles of muddy or clayey deposits and soils. In some areas, these deposits are relatively thick; in others, they are a veneer of mud deposited on meanderbelt sand. These represent preserved overbank or floodbasin deposits of streams that formed the associated meanderbelt sand (fig. 13). The Pleistocene overbank mud forms localized prairies vegetated by grasses and scattered trees.

Distributary and fluvial sand and silt.—The coastal uplands of the Port Lavaca area, especially north of Matagorda and Espiritu Santo Bays, west of the San Antonio River, and south of U. S. Highway 77, are characterized by a series of narrow, elongate sand bodies, totaling about 403 square miles, that generally trend normal to the present coastline. They represent deposition by distributary channels, flanking levees, and crevasse splays on extensive, late Pleistocene delta plains. Individual sand bodies are up to 30 miles long, range in width from 0.25 mile to 5.0 miles, and may be as much as 60 feet thick (figs. 14, 15, 16, and 17). They are composed of very fine- to fine-grained sand with admixtures of silt and clay. Locally, the sand has been partly replaced by caliche. Areas underlain by the channel sand bodies are slightly higher than surrounding areas on the coastal uplands. The channel sand is characterized on the surface by pimple mounds and pockmarks, by a distributary or branching pattern, and by numerous abandoned channel loops and courses. The channel loops were abandoned during the Pleistocene, though infilling continues to the present; the abandoned channels are largely filled with mud and organic (plant) debris, in contrast to the sands on which they are superimposed. A few of the abandoned channels presently pond water.

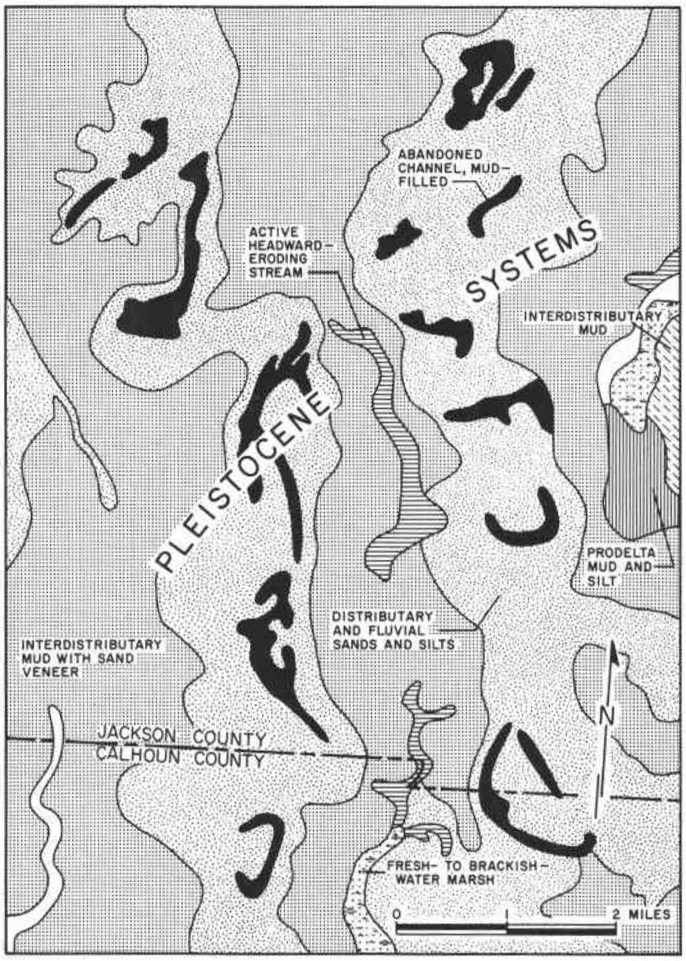


Figure 14. Pleistocene fluvial-deltaic facies, coastal uplands in the vicinity of Point Comfort, Port Lavaca map area. Fluvial-deltaic facies composed of distributary and fluvial sands and silts and interdistributary muds. Abandoned fluvial and distributary channels are locally mud filled. Modern-Holocene headward-eroding stream, in part filled with fresh- to brackish-water marsh, is gradually eroding these Pleistocene facies. Modern prodelta muds and silts at head of Carancahua Bay also present.

Interdistributary mud.—Extensive areas of the Pleistocene coastal uplands occurring between distributary channel sand bodies are characterized by broad, flat to slightly depressed areas of mud and clay substrates, mud with sand veneer, and associated clay soils (figs. 14, 15, 16, and 17). These fine-grained muddy and clayey sediments represent floodbasin or overbank deposition on the Pleistocene delta plain or a Holocene mud veneer over marine deltaic sand. They occupy the greatest areal extent (618 square miles) of any map unit. Soils developed on interdistributary and floodbasin clay are dark and fertile; these fine-grained deposits support highly productive agricultural lands.

Upland oak mottes.—Live-oak (*Quercus virginiana*) mottes are sparsely distributed in the Port Lavaca map area. They occur in the vicinity of the confluence of Navidad and Lavaca Rivers, south and west of Matilda, at Inez, south of Dernal and Bloomington, and southwest of Tivoli (north of State Highway 35). Live-oak mottes are situated on distributary and fluvial sand, meanderbelt sand, and marine deltaic sand. Total area comprised by upland oak mottes is about 10 square miles.

Circular to irregular depressions on distributary-fluvial sand.—Circular to irregular depressions are widely distributed throughout the map area. They occur most frequently on distributary-fluvial sand; they are also associated with meanderbelt and marine deltaic sand units. Depressions are incompletely filled with mud or muddy sand and have characteristics different from the associated sand units. Sediment contained in depressions has low permeability and retains water several days subsequent to rains. Depressions, characterized by dark tones on aerial photographs, constitute 12 square miles of the Port Lavaca map area.

Lakes and ponds.—Numerous Pleistocene lakes and ponds occur in the Port Lavaca map area. Most of the lakes are situated southwest of the San Antonio River, east of U. S. Highway 183, and northwest of State Highway 35. Total area occupied by these lakes is about 4 square miles. Origin of the lakes is not clear, but they appear to have formed in the same manner as the Modern Green and Mission Lakes which are components of the Guadalupe delta. Lakes display a wide range of sizes and shapes. Some have been completely filled with mud and sand; others are incompletely filled and are commonly encircled by fresh-water marsh. The larger lakes are characterized by beach ridges and swales situated along the south shores.

Beach ridges and swales.—The larger Pleistocene lakes, such as Sharps Lake (dry), Willow Lake, and Ninemile Flat, have well-developed beach ridges (some with swales) which comprise an area of 0.8 square mile. Ridges consist predominantly of sand, and swales are underlain by mud.

Marine deltaic sand.—Certain of the distributary channel sand bodies terminate gulfward in broad sand sheets. These represent delta-front deposits where the

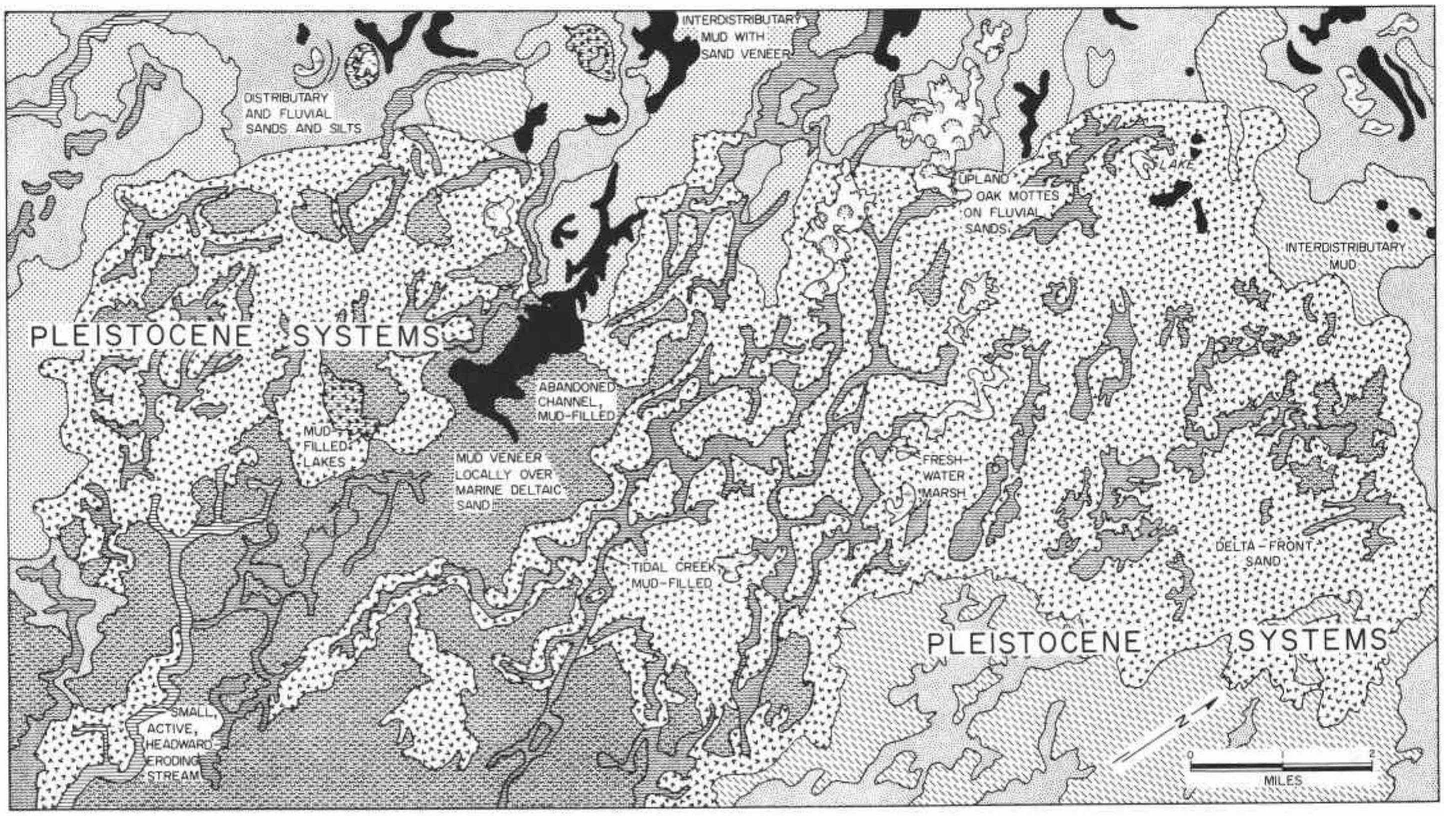


Figure 15. Pleistocene fluvial-deltaic and delta-front facies in the vicinity of Austwell, Port Lavaca map area. Mud-veneered marine deltaic sands and delta-front sands truncate fluvial-deltaic sands, silts, and muds and are in turn truncated by slightly younger Pleistocene fluvial-deltaic facies to the northeast. Mud-filled tidal creeks cover much of the older fluvial-deltaic and deltaic facies.

Pleistocene channels debouched and dropped their bed load into standing bodies of water. Later reworking by marine currents after the delta was abandoned may also account for some of these sand sheets. A rather extensive marine deltaic body was developed during the Sangamon interglacial stage but was locally removed by erosion during the Wisconsin glacial stage. Remnants of the marine deltaic sand (totaling 93 square miles) occur in the Carancahua and Keller Bays area, north of Powderhorn Lake (fig. 18), southeast of Seadrift, and west of Austwell (fig. 15). Locally, this sand belt is veneered by a Holocene mud deposit.

Mud veneer over marine deltaic sand.—Throughout the Port Lavaca area, marine deltaic sands are partly obscured by a Holocene mud veneer (a total of 65 square miles). Properties of this mud are similar to those of interdistributary mud.

Abandoned channel and course.—Modern rivers and distributaries frequently alter their courses in response to sedimentation within the channels, flow characteristics, and stream gradient. Meander cutoffs, which subsequently become oxbow lakes, are indications of a change in course of a meandering river. Another means of altering a stream's course is avulsion, whereby long stream segments are abandoned when the stream takes a shorter, higher gradient route to the sea. Channels abandoned by avulsion become sluggish or stagnant water bodies in which mud and plant debris accumulate. Relict meander cutoffs are displayed in the area west of San Antonio River and northwest of U. S. Highway 77 (fig. 13). These are characteristic of Pleistocene meanderbelt sand. Abandoned channel courses are prominent features of certain distributary and fluvial sand, for example, between Placedo and Lavaca Bay and north of Point Comfort (fig. 14). Most of the Pleistocene abandoned channels and courses are mud filled; a few are occupied by fresh-water marsh. Total area consisting of abandoned channel and course is 78 square miles.

Tidal creeks.—Modern tidal creeks are cut into Pleistocene deposits that form bay shorelines. Examples are the tidal creeks at the head of Keller Bay and along the northwest shore of St. Charles Bay. Some tidal

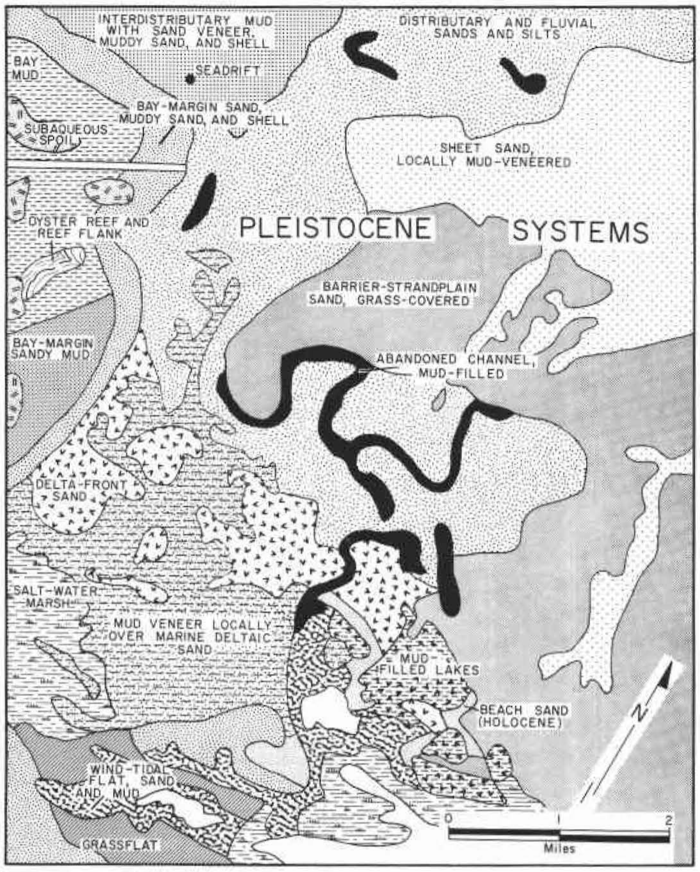


Figure 16. Pleistocene fluvial-deltaic and barrier-strandplain systems in the Seadrift region, Port Lavaca map area. Diversity of environmental geologic units including Pleistocene fluvial-deltaic, barrier-strandplain, and marine deltaic facies; Modern-Holocene bay-estuary-lagoon environments; and Modern-Holocene subaerial facies, including salt marsh and beach sand.

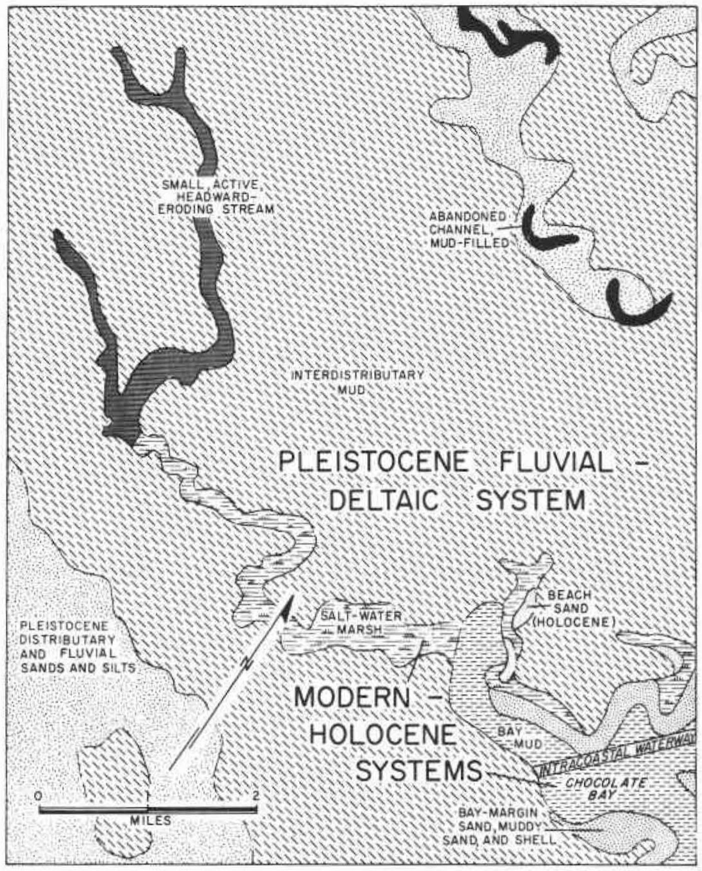


Figure 17. Pleistocene fluvial-deltaic system, large area of interdistributary overbank mud in the Chocolate Bay vicinity, Port Lavaca map area. Modern-Holocene headward-eroding stream is gradually eroding the low-lying Pleistocene interdistributary mud regions between slightly higher elevated fluvial and distributary sands. Lower reaches of headward-eroding streams are subject to salt-water inundation and support salt marsh vegetation.

creeks have been filled with mud (30 square miles); these are mostly relict Pleistocene features. Fresh-water marshes are associated with some of the Modern tidal creeks (1 square mile).

Beach sand.—Holocene-Modern beach sand occurs adjacent to Pleistocene marine deltaic sand. Beach deposits (5 square miles) are thin, transitory features which range in sediment size from sand to gravel and in composition from terrigenous quartz sand to shell and caliche.

Barrier-Strandplain System

Most of the Modern Texas coast is characterized by a series of barrier islands, formed seaward of extensive bay and lagoon systems by the gulfward outbuilding of beach ridges and shorefaces. A series of marine sand bodies that are preserved inland of the present coastline throughout much of the Texas Coastal Zone has been considered by some geologists to represent a Pleistocene counterpart of Modern barrier islands. Many of these ancient sand deposits may have formed along shorelines where erosion and redeposition of deltaic sand resulted in extensive strandplain deposits.

In the Port Lavaca area, parts of this ancient barrier-strandplain system are well preserved. The system, which covers approximately 178 square miles, occurs in the south and southwestern parts of the area extending from Port O'Connor to the west map boundary. A large part of the area between Port O'Connor and Seadrift is composed of strandplain sand (figs. 16, 18, and 19). Blackjack Peninsula (fig. 20), Lamar Peninsula, and the peninsula directly across the

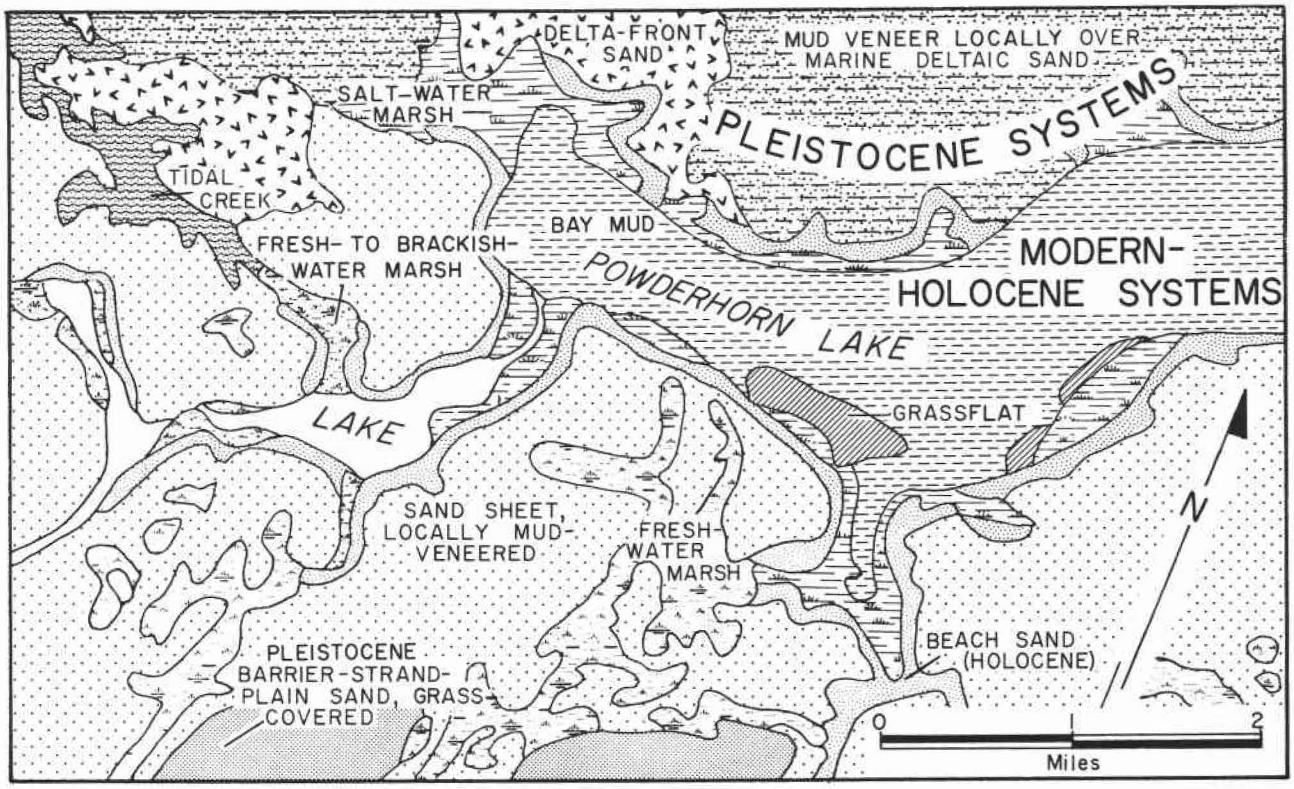


Figure 18. Pleistocene strandplain and marine deltaic sands, Powderhorn Lake vicinity, Port Lavaca map area. Powderhorn Lake represents a small estuary now filling with sand and mud and separated from Matagorda Bay by shell spits covered with salt-water marsh.

bay from Lamar constitute the remaining parts of the Pleistocene strandplain. The dominant trend of this system throughout most of the Texas Coastal Zone is roughly parallel to the present coast.

Strandplain sand commonly overlies and is bounded landward by Pleistocene deltaic sand, mud, and clay. These sand bodies form local, shallow aquifers, commonly with perched water tables. Locally, original depositional topography (beach ridges and swales) is indicated by the linear grain observed on aerial photographs. Some swales contain water; others are partly filled with sand and mud. Depositional grain is well developed on Blackjack Peninsula (fig. 20).

The barrier-strandplain system is composed of seven morphologic and vegetational units: tree- and grass-covered barrier-strandplain without apparent accretionary grain, live-oak-covered beach ridges, stabilized dune sand (Modern-Holocene), vegetated swales covered with grass or fresh-water marsh, and sheet sand.

Barrier-strandplain sand.—Large areas of strandplain sand, which display little relict depositional grain and are grass- or tree-covered, are grouped into the category of barrier-strandplain sand, which covers an area of 110 square miles. Live oak (*Quercus virginiana*) is the dominant tree, and prairie grasses dominate the grass-covered areas.

Beach ridges.—Live-oak-covered beach ridges are elongate parallel to the trend of the strandplain; they mark former positions of the Pleistocene shorelines. Beach ridges are 10 to 15 feet above mean sea level, as is much of the strandplain system. Concentration of live oak along the ridges is the chief criterion for their recognition. Beach ridges are underlain by root-mottled, highly permeable, fine- to very fine-grained terrigenous sand. The area underlain by these ridges is approximately 2 square miles.

Well-stabilized dune sand.—Sand dunes stabilized by grasses overlie strandplain sand along the northeast end of Blackjack Peninsula. Dune crests are approximately 25 to 35 feet above mean sea level and can be 45 to 50 feet high. The dune field is aligned approximately parallel to the shore of San Antonio Bay. Most of the dunes are discontinuous; however, the northernmost

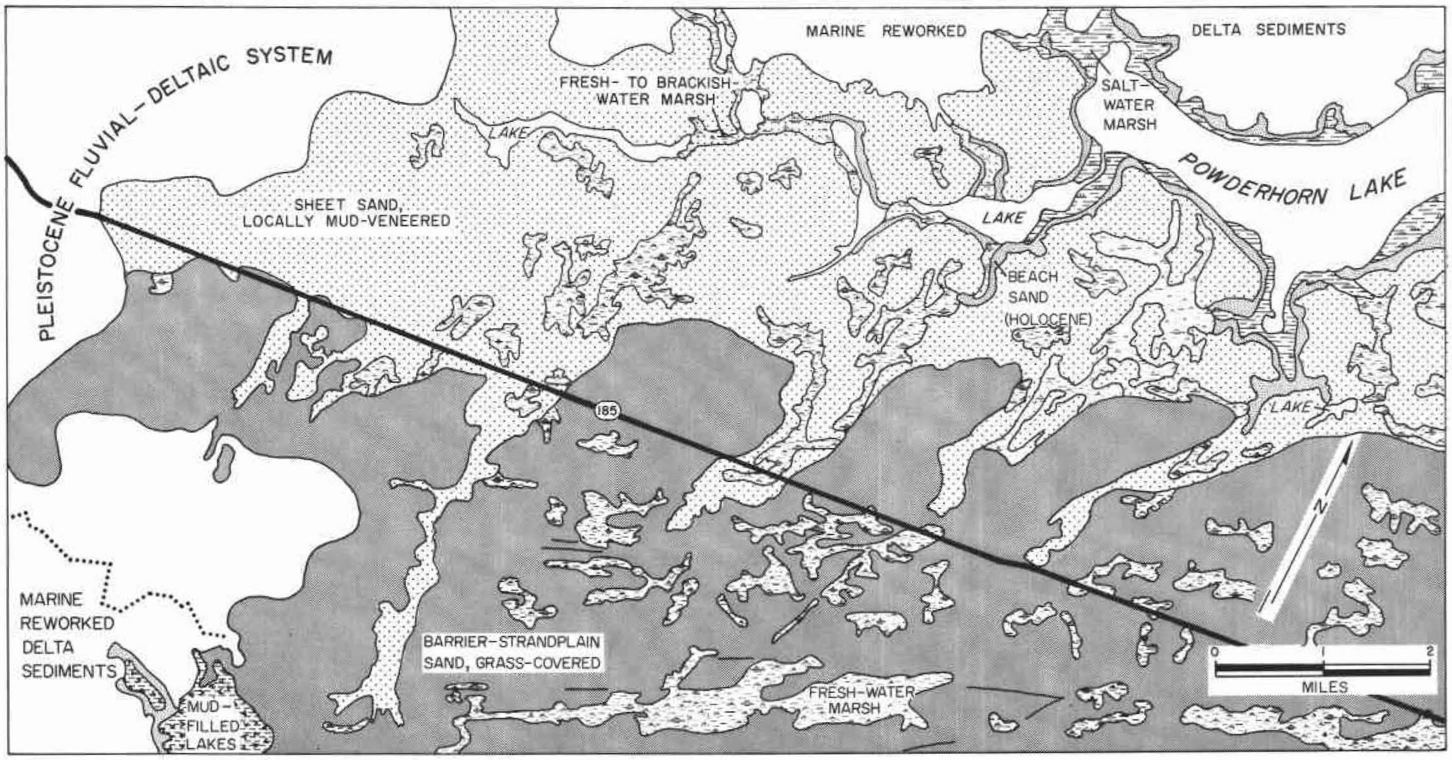


Figure 19. Pleistocene barrier-strandplain sands between Port O'Connor and Seadrift, Calhoun County, Texas. Fresh-water marsh occupies elongate swales in grass-covered strandplain sands. Sheet sands are derived from barrier-strandplain sands and cover older Pleistocene fluvial-deltaic facies; they are locally covered by fresh- to brackish-water marsh. Barrier-strandplain sands are locally reworked into Holocene beach deposits along Powderhorn Lake estuary shorelines.

dune has a rather continuous crest with a southeast-northwest alignment. Dune sand is derived from the adjacent Pleistocene strandplain. The area comprised by these Modern, stabilized dunes is approximately 1.3 square miles.

Swales between beach ridges.—Swales, like beach ridges, cannot be distinguished by topography alone. Ridges have been subdued through time by erosion. Part of the sand eroded from the ridges now resides in the partly to completely filled swales. Swales are filled with a combination of sand, mud, and plant debris. Fresh-water marsh occupies remnant swales and relict drainage systems that were cut into the strandplain sand. Marshes in remnant swales are aligned parallel to elongation of the strandplain. Combined area of marsh- and sediment-filled swales is 16 square miles.

Sheet sand.—The north-northwest side of the strandplain system is represented by sheet sand (49 square miles) derived from outwash and sand blown from the strandplain. The sheet sand overlies distributary and fluvial sand, interdistributary mud, and marine deltaic sand. The sheet sand thins northward away from the strandplain; in the Powderhorn Lake area, it is approximately four feet thick. Texturally, the sand is muddy to well-sorted, very fine sand; it is highly to moderately permeable.

MODERN-HOLOCENE SYSTEMS

Four major natural systems are currently active in the Port Lavaca area. 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 of the area include: (1) fluvial-deltaic system, (2) barrier-strandplain and offshore systems, (3) marsh-swamp system, and (4) bay-estuary-lagoon and lake systems. Forty-eight distinct and separate environments are delineated and mapped within these four major systems (see *Environmental Geology Map*). Specific environments are recognized by floral and faunal assemblages, physiographic expression, depositional grain and morphology, and dominant active processes.

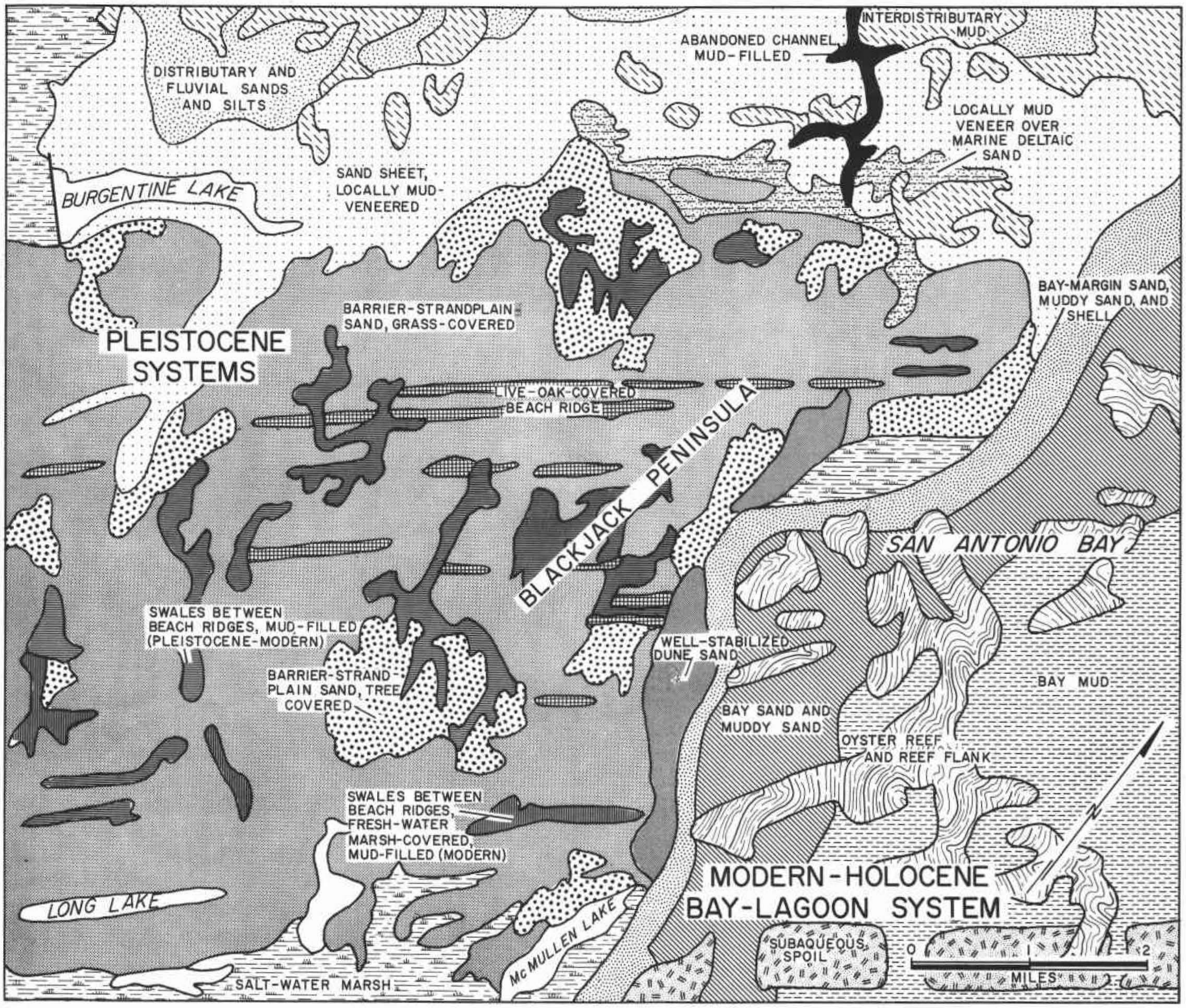


Figure 20. Pleistocene strandplain sand and Modern-Holocene bay facies, Aransas National Wildlife Refuge, San Antonio Bay region, Port Lavaca map area. Barrier-strandplain system includes relict beach ridges covered by live oak and locally truncated by mud-filled swales, as well as mud-veneered sheet sands located inland (northwest) of the main strandplain sand body. Variety of bay environments includes mud, muddy sand, and sand, bay-margin sand and shell, and oyster reef and reef-associated deposits.

Fluvial-Deltaic System

The major Modern-Holocene fluvial systems of the Port Lavaca area include the Navidad, Lavaca, San Antonio, and Guadalupe Rivers and Garcitas and Blanco Creeks. Lesser streams, Keller and Carancahua Creeks, occur in the northeast part of the map area. All are developed within entrenched or incised valleys (fig. 4), and most are fine-grained meanderbelt systems. They are characterized by sinuous courses, lateral accretionary grain, a few meander cutoffs (some of which support swamps and marshes), relatively high mud loads, and narrow to broad floodbasins (fig. 21). The present-day rivers are underfit.

Most smaller streams in the Port Lavaca area are eroding headwardly into the Pleistocene coastal uplands (fig. 17). They are not in adjustment and are actively

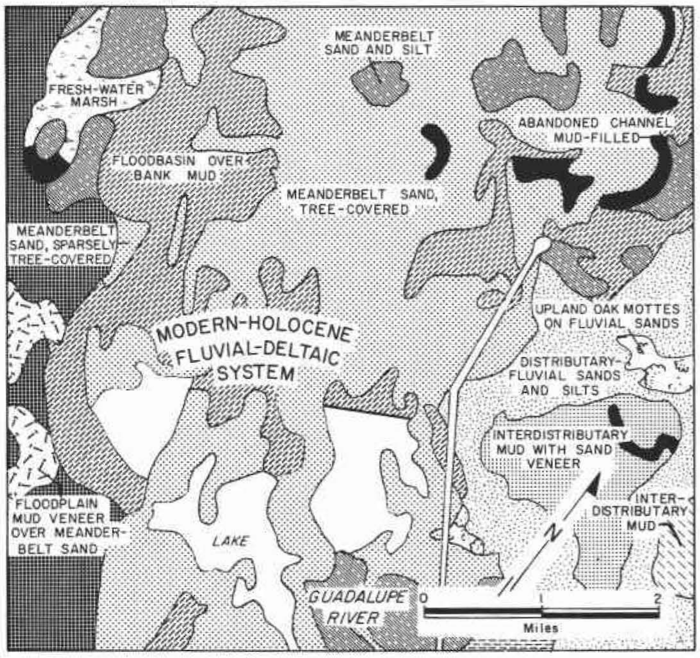


Figure 21. Modern-Holocene meanderbelt sand and associated floodbasin muds, and Pleistocene meanderbelt and fluvial-deltaic facies, vicinity of Dernal, Port Lavaca map area. Modern-Holocene sands and floodbasin muds occupy narrow valleys incised into similar Pleistocene facies.

cutting their valleys, at least in their upper drainage basins. Examples include Placedo, Copano, and Melon Creeks. These smaller streams have well-drained valleys, and some of them support areas of dense tree vegetation.

The Lavaca and Navidad Rivers and the San Antonio and Guadalupe Rivers join a few miles from the heads of Lavaca and San Antonio Bays, respectively. These rivers have constructed bayhead deltas; the Guadalupe delta in San Antonio Bay is one of the largest bayhead deltas in the Texas Coastal Zone. Garcitas Creek is constructing a small delta in its estuary; it has not yet prograded into Lavaca Bay.

Fluvial Environments

Within the Port Lavaca area, there are six significant Modern-Holocene fluvial environments. These are meanderbelt sand, floodbasin and overbank mud, active point bars, levee deposits, abandoned channels, and small headward-eroding streams. Each fluvial environment is not a component of a single river or smaller stream. For example, Blanco Creek exhibits well-developed point bars which are not associated with most of the other streams, and only the San Antonio and Guadalupe Rivers have extensive meanderbelt sand and floodbasin-overbank mud.

Some of the Modern-Holocene fluvial units mapped in the Port Lavaca area include those formed during the past 18,000 years, as well as presently active river environments (fig. 4). These include relict sand and mud deposited by older and larger meandering Holocene rivers, and Modern floodplain features.

Meanderbelt sand.—There are two types of meanderbelt sand within the Port Lavaca map area: (1) sand without prominent depositional grain, locally veneered with overbank mud, and tree covered; and (2) sand and silt, sparsely grass- and shrub-covered. Meanderbelt sand is the product of both active and relict systems (fig. 21). There are terraces within the valleys of Navidad, Lavaca, Guadalupe, and San Antonio Rivers and Garcitas Creek that represent Holocene meanderbelt deposits of these streams. Meander scars and cutoffs are prominently displayed in the Guadalupe valley between the Missouri Pacific Railroad and U. S. Highway 77.

Meanderbelt sand terranes are relatively flat with minor local relief resulting from original depositional topography. They are marked by some accretionary grain and a few meander cutoffs. Meanderbelt sand supports dense stands of water-tolerant hardwoods. Along the lower parts of the Lavaca, Guadalupe, and San Antonio valleys, the meanderbelt sand and floodbasin mud are locally veneered by areally restricted marshes and swamps.

The meanderbelt sand of the Navidad, Lavaca, Guadalupe, and San Antonio Rivers and Garcitas, Melon, and Blanco Creeks is a group of low terraces that occur near the elevation of the rivers. Accordingly, meanderbelt sand floors about 99 square miles of the floodbasin of the present streams and is normally veneered by thin deposits of overbank mud. The Holocene terraces composed of this meanderbelt sand in the Texas Coastal Zone are commonly called the Deweyville terrace, which formed during the last rise in sea level or between 18,000 and 4,500 years B. P. (Bernard and LeBlanc, 1965).

Floodbasin mud.—Associated with the Modern-Holocene meanderbelt sand of the major river systems are very small to large, isolated mud and clay deposits totaling 19 square miles. These deposits represent overbank or flood deposition by the same streams that formed the meanderbelt sand bodies. Some of the overbank mud areas support water-tolerant hardwoods, although the vegetation is not as dense as on meander-belt sand.

Active point bars.—Major fluvial systems within the map area have sinuous or meandering patterns. Meanders are unstable features that migrate laterally and downstream. Coincident with meander migration is a change in shape; meander loops sometimes approach each other and may ultimately meet, forming a meander cutoff or oxbow lake. As 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 bank are shown by accretionary grain, which consists of alternating ridges and swales, developed on point-bar deposits. Active point bars occupy 2.4 square miles in the Port Lavaca map area.

Point-bar deposits consist of gravelly sand along the lower part, sand at about midpoint, and fine sand and mud where the bar grades into the floodplain. Point-bar deposits are predominantly well-sorted gravel and sand and are highly permeable. Although the sediment characteristics of all point bars are similar, there are some surficial differences. Some point bars are tree covered (for example, those along Blanco Creek), and others are bare or sparsely grass covered (for example, point bars on Garcitas Creek north of the Missouri Pacific Railroad). Willows are common along the upper parts of point bars.

Meandering streams move back and forth across their valleys. As they migrate, they deposit gravel and sand (point bars) and clay and silt (overbank deposits). The combined accumulation of thick point-bar and thin overbank deposits has developed the meanderbelt deposits of the major fluvial systems in the Port Lavaca area.

Levee deposits.—Streams subject to frequent overbank flooding deposit fine sand, silt, and mud (levees) adjacent to their channels. Levees (approximately 6 square miles in the Port Lavaca area) are prominent along the lower reaches of the San Antonio and Guadalupe Rivers. These levees are sparsely grass or tree covered.

Levee deposits are thickest and stand topographically highest immediately adjacent to the river channel; they thin and slope away from the channel into flanking floodbasins, marshes, or swamps. Levees are mostly vegetated; older levees are covered by willow, cottonwood, and cane, but younger levees are sparsely to densely covered with grasses and locally covered with marsh plants.

Abandoned channels.—Former meandering channels of the Navidad, Lavaca, Guadalupe, and San Antonio Rivers and Garcitas and Blanco Creeks are now abandoned. Most of these are semicircular loops reflecting the original meandering courses of the rivers. Abandoned channels and courses form topographic depressions on the river floodplains; some pond water at the present time, forming oxbow lakes. Most of the abandoned channels and courses are filled with mud from overbanking river waters and slopewash; these are largely void of vegetation. Other abandoned channel courses support either swamp or fresh-water marsh vegetation.

Headward-eroding streams.—An area of approximately 31 square miles of Pleistocene coastal uplands in the Port Lavaca area is dissected by small to moderately large streams. Examples include Placedo Creek, Chocolate Bayou, Copano Creek, and Melon Creek (fig. 17). Where streams are entrenched into the Pleistocene uplands, they have developed alluvium-mantled slopes. The alluvium is composed chiefly of slopewash sediments derived from the Pleistocene deposits into which the streams are cut. These slope sediments and the soils they support are well drained and, accordingly, are sparsely to densely vegetated with hardwoods.

Deltaic Environments

Two major fluvial systems, the Lavaca-Navidad and San Antonio-Guadalupe Rivers, and two minor systems, Garcitas and Carancahua Creeks, have built deltas into Lavaca Bay, San Antonio Bay, Garcitas Cove, and Carancahua Bay, respectively (fig. 4). These river systems occupy valleys that were entrenched during the last low-level stand of Gulf waters, approximately between 60,000 and 18,000 years B. P. (fig. 5B). With rise in sea level beginning about 18,000 years B. P., the entrenched river valleys became drowned, and the upper ends have subsequently been filled in part by prograding deltas. These deltas, prograding from the heads of bays, are termed bayhead or estuarine deltas.

The two principal bayhead deltas of the Port Lavaca area are the Guadalupe (fig. 22) and Lavaca. Lesser deltas are the Carancahua and Garcitas. The Guadalupe delta has been studied extensively (Shepard and Moore, 1960; Donaldson and others, 1970). Data on the facies distribution and thickness of the other deltas do not exist at this time.

Transition from chiefly fluvial to deltaic environments occurs about 8, 5, and 3 miles inland along the Guadalupe River, Lavaca River, and Garcitas Creek,

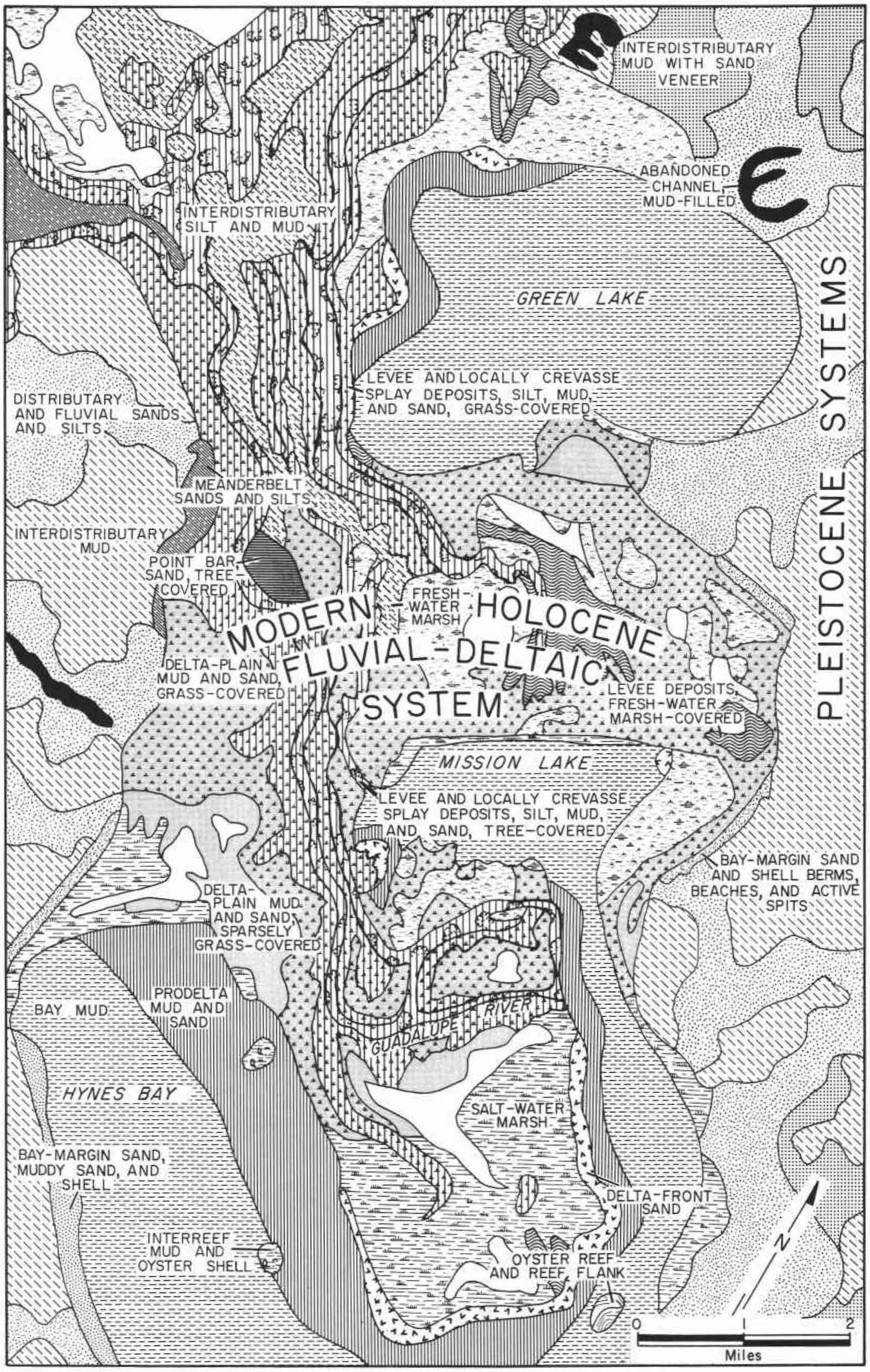


Figure 22. Modern Guadalupe delta in the Tivoli-Austwell-Seadrift-Long Mott region, Port Lavaca map area. Delta-associated facies extend into San Antonio Bay as a bayhead delta. Modern delta is analogous to deltas that helped fill incised Pleistocene river valleys following the last glaciation and subsequent rise of sea level.

respectively. The subaqueous parts of the deltas consist of *delta front* (2 square miles) representing deposition of river sand at a point where a stream discharges into a bay and *prodelta* (an area of about 7 square miles) in the upper parts of bays which receive the fine-grained suspended load of streams (fig. 11). Continued deposition at the river mouth results in successive outbuilding of the delta into the bay, a process called progradation. Inland from the channel mouth, the subaerial part of the delta (*delta plain*) is built up chiefly by deposition within the main channels and by deposition between channels during floods. Here the delta, like associated fluvial systems, builds up by aggradation.

The delta plains of the Guadalupe, Garcitas, Lavaca, and Carancahua deltas are not shown as single units on the Port Lavaca map, but are represented by the following component environments: (1) lakes, such as Green Lake associated with the Guadalupe delta and Swan Lake associated with Lavaca delta, (2) swamps, (3) vegetated levees, (4) grass-covered and sparsely grass-covered delta plain, (5) interdistributary silt and mud, and (6) fresh, brackish, and salt marshes. Extensive *lakes* associated with bayhead deltas are environments of low physical energy receiving water and sediment from rivers during flood and occasionally from bays during storms or when wind tides are excessive. These lakes have several origins. Some have formed as the delta plain foundered; others, such as Green Lake, represent segments of bays that were bypassed as the delta filled the drowned river valley.

For the most part, *interdistributary silt and mud* occur in the Guadalupe River valley generally to the northwest of Mission Lake. The interdistributary environment, approximately 7 square miles, is a low-lying area bounded by natural levees. Sediment in this environment is silt and mud deposited by river flooding, crevasse splays, and bay and lacustrine processes.

Grass-covered and sparsely grass-covered delta-plain mud and sand (14 square miles) are restricted to the Lavaca and Guadalupe deltas. The grass-covered delta plain generally occupies the higher parts of the delta between the levees and the barren to sparsely grass-covered delta plain; *Phragmites communis* (common reed) is locally associated with this facies on the Guadalupe delta, particularly in the Mission Lake area. The sparsely grass-covered delta plain is generally near mean high tide elevation and, consequently, is often inundated by bay water. Sediment constituting the delta plain is derived from river flooding and from bays.

Modern-Holocene fluvial and deltaic deposits of the Lavaca-Navidad and San Antonio-Guadalupe Rivers and Carancahua and Garcitas Creeks occur in valleys eroded during the last low stand of sea level. Pleistocene deposits underlie the distal delta plains of the Lavaca and Guadalupe deltas at depths of 80 and 60 feet, respectively. The drowned valleys have been partly filled by river and delta deposits since sea level reached its present position. Since that time, the Lavaca delta has prograded approximately 9 miles down the valley and into the bay, and the Guadalupe delta has prograded about 15 miles.

Barrier-Strandplain and Offshore Systems

A major and very important natural system within the Port Lavaca 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 immediate offshore area constituting the barrier shoreface and the inner part of the continental shelf (figs. 4 and 23).

The seaward extension of the barrier-strandplain system is called the *shoreface*. The shoreface averages about 1.25 miles 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 the 5-fathom depth, shoreface sediment is mud and muddy sand; here the shoreface merges with inner continental *shelf*, which is predominantly mud.

From the Gulf of Mexico across the barriers and peninsulas and into the bays, components of the barrier-strandplain and offshore systems are shelf mud and sand, shoreface sand and muddy sand, beach sand and shell, fore-island dune ridge sand, beach ridge and barrier flat sand, barren wind-tidal flat sand and mud, salt marsh underlain by mud and sand, and marsh-covered shell spits.

Included as components of the Modern barrier-strandplain system are washover channels and fans and the various specific environments constituting the tidal inlet, flood and ebb deltas, and accretionary spits.

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 Matagorda Peninsula and barrier islands to the west and the innermost part of the continental shelf, in addition to the previously mentioned ebb-tidal delta.

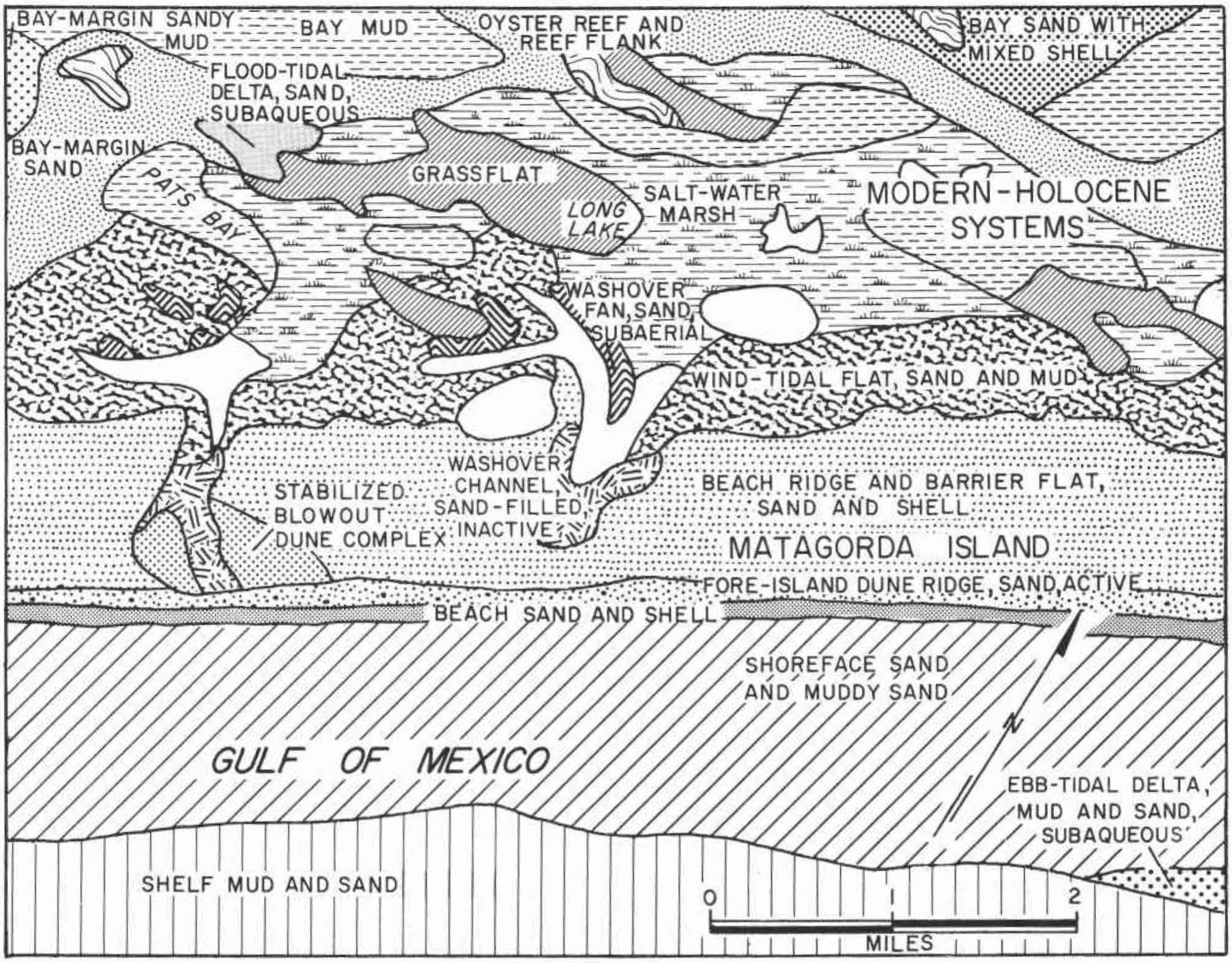


Figure 23. Modern inner continental shelf, shoreface and barrier island environments, Matagorda Island Bombing and Gunnery Range area, Calhoun County, Texas. Modern barrier island complex bordered on bayside by bay-margin sands, grassflat, wind-tidal flat, salt-water marsh, and other bay-related environments.

The *shelf mud and sand* environments of the inner continental shelf extend seaward from about the 30-foot or 5-fathom line (fig. 23). The inner shelf is a transitional area where sands and muds of the lower shoreface and inner shelf are mixed through the activities of burrowing animals. It is an area of considerable erosion and resedimentation during the hurricane season. The inner shelf in the Port Lavaca area is floored locally by relict Pleistocene and Holocene deposits (Frazier, 1974; Wilkinson, 1973; McGowen and Brewton, 1975), but most of the surface sediment is Modern-Holocene mud. The sand-mud boundary lies between 1.8 and 2.6 miles offshore from Matagorda Peninsula and is farther from shore near Pass Cavallo. The sand-mud boundary averages 3.2 miles offshore along Matagorda and St. Joseph Islands.

The *shoreface* is the gulfward extension of the peninsula and barrier islands. The shoreface extends seaward from mean sea level to about the 5-fathom line, or to the boundary with the shelf mud and sand (fig. 23). Off the Port Lavaca area, width of the shoreface averages about 1.0 mile to 1.1 miles, with a maximum of approximately 2.0 miles west of Matagorda Ship Channel. Locally there is only a veneer of Modern sediment resting on relict Holocene and Pleistocene deposits.

The shoreface, especially the part affected by breaking waves, is a zone of high physical energy. 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, and the lower shoreface consists largely 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 may be observed on the upper shoreface. These result in the formation of breaker bars, which may be parallel or at an angle to the shoreline. The innermost breaker bar is generally tied to the lower forebeach.

Barrier-Strandplain System

Beach.—About 9 square miles of Gulf beach occur between low tide and the first inland line of vegetation, which is generally situated at the toe of the fore-island dunes (fig. 23). Beaches consist primarily of terrigenous sand with local high concentrations of shell along Matagorda Peninsula. Sand beaches exhibit two distinct zones: forebeach, the seaward-sloping smooth part of the beach that is affected daily by swash, and back-beach, which may be separated from the forebeach by a berm. The backbeach slopes gently seaward but in places may slope landward. Most of the beaches of Matagorda Peninsula are undergoing erosion and have been doing so for at least 119 years (McGowen and Brewton, 1975). Beaches of Matagorda Island were in equilibrium until recently. Erosion is now dominant along Gulf beaches in the Port Lavaca area.

Fore-island dunes.—Fore-island dunes are well developed on Matagorda Peninsula from Greens Bayou to the vicinity of Matagorda Ship Channel. West of Pass Cavallo, fore-island dunes are continuous throughout the map area with the exception of the vicinity of Cedar Bayou and Vinson Slough. Total area of fore-island dunes is about 4 square miles. Dunes consist of very well-sorted, fine-grained sand; they are highly permeable and locally provide a source of fresh water. Average dune height is about 15 feet, and maximum height is about 30 feet (Wilkinson, 1973).

Where overgrazing has not occurred, dunes are stabilized by vegetation. Vegetation is zoned on the seaward side of dunes. Marshhay (*Spartina patens*), morningglory (*Ipomoea*), and sea purslane (*Sesuvium portulacastrum*) generally occur at lower dune elevations, and sea-oats (*Uniola paniculata*), *Panicum*, and *Croton* occur along the middle and upper parts of dunes. Seacoast bluestem (*Andropogon scoparius littoralis*) is common on the back sides of dunes.

Active and stabilized blowout dune complex.—Where vegetation cover has been damaged or removed from dunes, eolian blowouts tend to develop. Blowouts are gaps in the dune field that are commonly deflated down to the water table. Sand is removed from the fore-island dune field and transported bayward by the wind as blowout dunes. Active blowout dunes (0.8 square mile) are present at several localities along Matagorda Island, such as near Pass Cavallo and adjacent to Cedar Bayou. The bayward migration of blowout dunes ceases when a vegetation cover develops that is sufficiently dense to impede movement of sand by eolian processes. Blowout dunes are stabilized chiefly by grasses. Stabilized blowout dunes (8.8 square miles) are present on the southwest part of Matagorda Peninsula and are sparsely distributed throughout the entire length of Matagorda Island; they cover large areas of southwestern Matagorda and northeastern St. Joseph Islands.

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

Beach ridge and barrier flat.—The beach ridge and barrier flat comprise the major environment of the barrier system in the Port Lavaca area, totaling 30 square miles on Matagorda Peninsula, Matagorda Island, and St. Joseph Island. On Matagorda Peninsula, accretionary grain in the form of low-relief ridges and swales, which were produced by spits that migrated toward Pass Cavallo, is well preserved in the area of the Matagorda Club (see *Environmental Geology Map*).

The terrain on Matagorda and St. Joseph Islands is characterized by a series of subparallel *beach ridges and swales* generally oriented along the main trend of the barrier island (figs. 23 and 24; *Environmental Geology Map*). Each ridge represents a position of the shoreline during earlier stages of barrier development. Ridges begin at Pass Cavallo where their number is greatest; the area of beach ridges and barrier flats is widest near tidal passes. Ridge height is generally about 5 to 10 feet above mean sea level. Individual beach ridges may extend for several miles. Certain of the beach ridges on Matagorda Island are sharply curved toward the bay and represent spit accretion into tidal passes that subsequently have been filled. Spit migration, as indicated by the trend of curved beach ridges, was

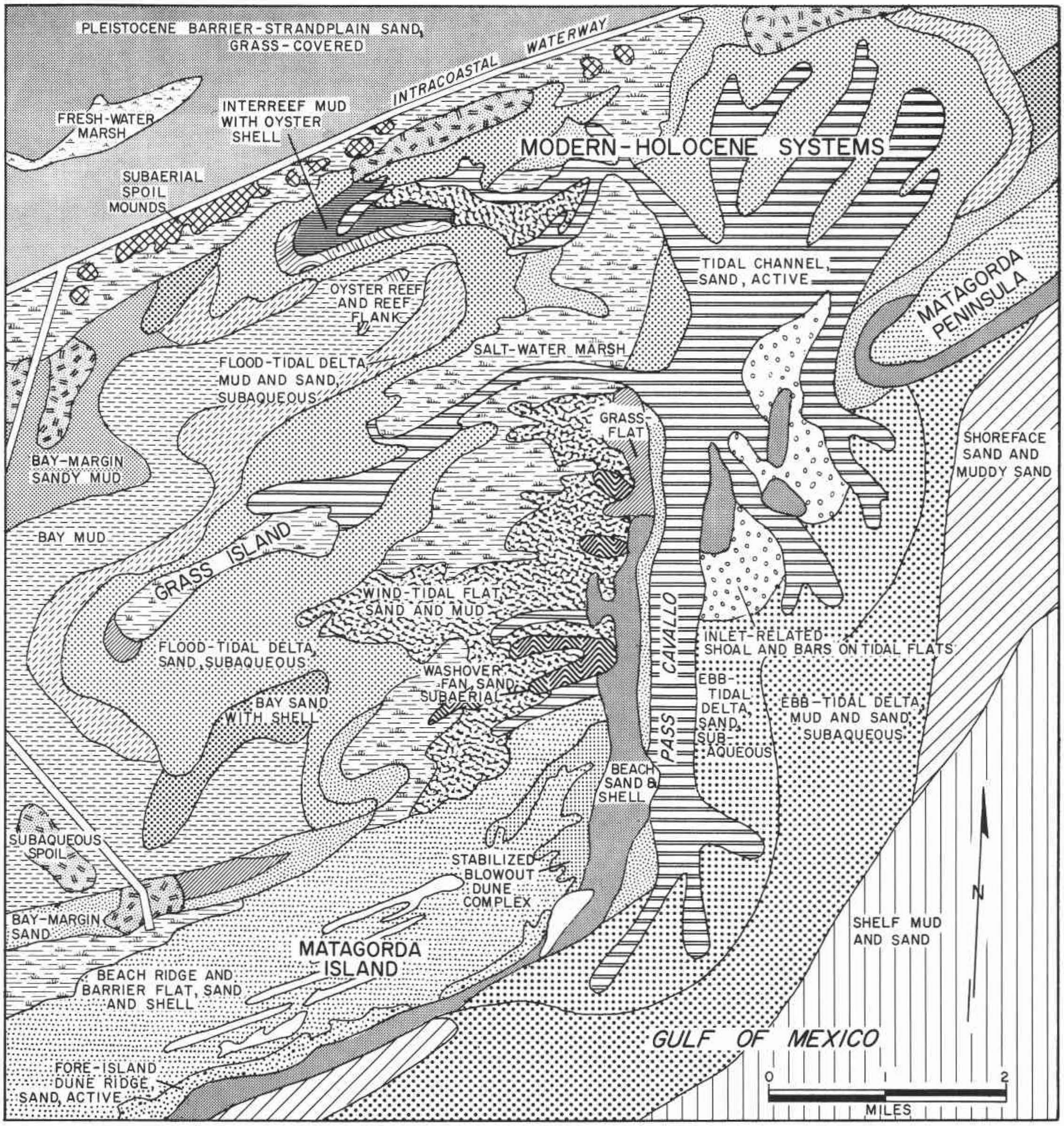


Figure 24. Modern tidal-delta facies, Pass Cavallo, Matagorda Bay, Calhoun and Matagorda Counties, Texas.

southwestward in the direction of present net longshore drift. When the tidal pass between Matagorda and St. Joseph Islands was open, there was a downdrift offset (to the southwest) between the two islands just as there is today between Matagorda Peninsula and Matagorda Island. With the closing of the tidal pass in the vicinity of Cedar Bayou, erosion of the northeast end of St. Joseph Island straightened the Gulf shoreline and narrowed the island. Thus, the ridge-and-swale physiographic unit on the northeast part of St. Joseph Island is considerably narrower than the same unit on Matagorda Island.

The growth of beach ridges 5 to 10 feet above sea level is a function of several interacting coastal processes. Sand and shell material with which the ridges have been constructed were derived from offshore and moved onshore by wind-generated currents (fig. 11). 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.

Situated between the beach and the wind-tidal flat are also areas in which there are no obvious beach ridges and swales. These areas constitute the *vegetated barrier flat* (fig. 23). The barrier flat lies between mean sea level and 5 feet above MSL. The surface of the barrier flat dips gently bayward. Vegetation on the flat, as well as on the beach ridges, is predominantly grasses that are tolerant to salt spray and occasional flooding by storm-tidal surge.

Salt marsh.—Salt marshes (characterized by a specific plant community) occupy the bay margins of barrier islands and peninsulas that are inundated daily by astronomical and wind tides (details of salt marshes are presented in the section on the marsh-swamp system). These areas are relatively flat, increasing in elevation away from the bay margin and grading into the virtually barren wind-tidal flat (wind-tidal flat is included in the section on bay-estuary-lagoon and lake systems).

Marshes are indented on the bayside by tidal channels that are curved to the west by the general westerly longshore drift along the back side of barrier islands. During northers, some shell of oysters and other bay species is washed into the marsh, developing thin, narrow, and discontinuous beaches. With the exception of the shell beaches, sediment underlying the marshes becomes coarser or sandier from the bay margin toward the higher parts of the marsh. Sediment underlying low marshes is generally dark gray mud or muddy sand intensely burrowed by worms, crustaceans, and molluscs, and mottled by penetration of plant roots. Sediment underlying higher marshes is mud and muddy sand but locally may be dominantly sand; 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 erode channels through the barrier and carry sand to the bayside of the barrier where it is deposited as a washover fan. The northern end of St. Joseph Island and the Greens Bayou area are frequently washed over by hurricane storm surge (fig. 11; *Active Processes* and *Environmental Geology Maps*). Most of northern St. Joseph Island is a washover fan (fig. 25) which was studied by P. B. Andrews (1970). 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. 25).

With the passage of some hurricanes across the Coastal Zone, *washover channels* (1.7 square miles) are scoured 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 seaward ends by sediment transported onshore by waves and parallel to shore by longshore currents. Channel fill is a mixture of sand and shell near the base of the channel. Shell content decreases upward in the channel, and the upper fill is primarily very fine- to fine-grained terrigenous sand. Water remains in the unfilled segments of washover channels, and windblown sand and mud derived primarily from the bays accumulate in these channels. Channels may be closed at their bayward terminus by sand.

The *washover distributary channels* (about 7 square miles) are features of large washover fans such as the one situated along the northeast part of St. Joseph Island. These channels bifurcate away from major washover channels. Sediment moves from the major washover channels into the distributary channels which deposit sediment in a radial pattern or fan. Distributary channels are relatively shallow and become progressively more shallow bayward. At their proximal ends, they are partly filled with sand and shell; deeper parts of these channels become ponds after the passage of hurricanes.

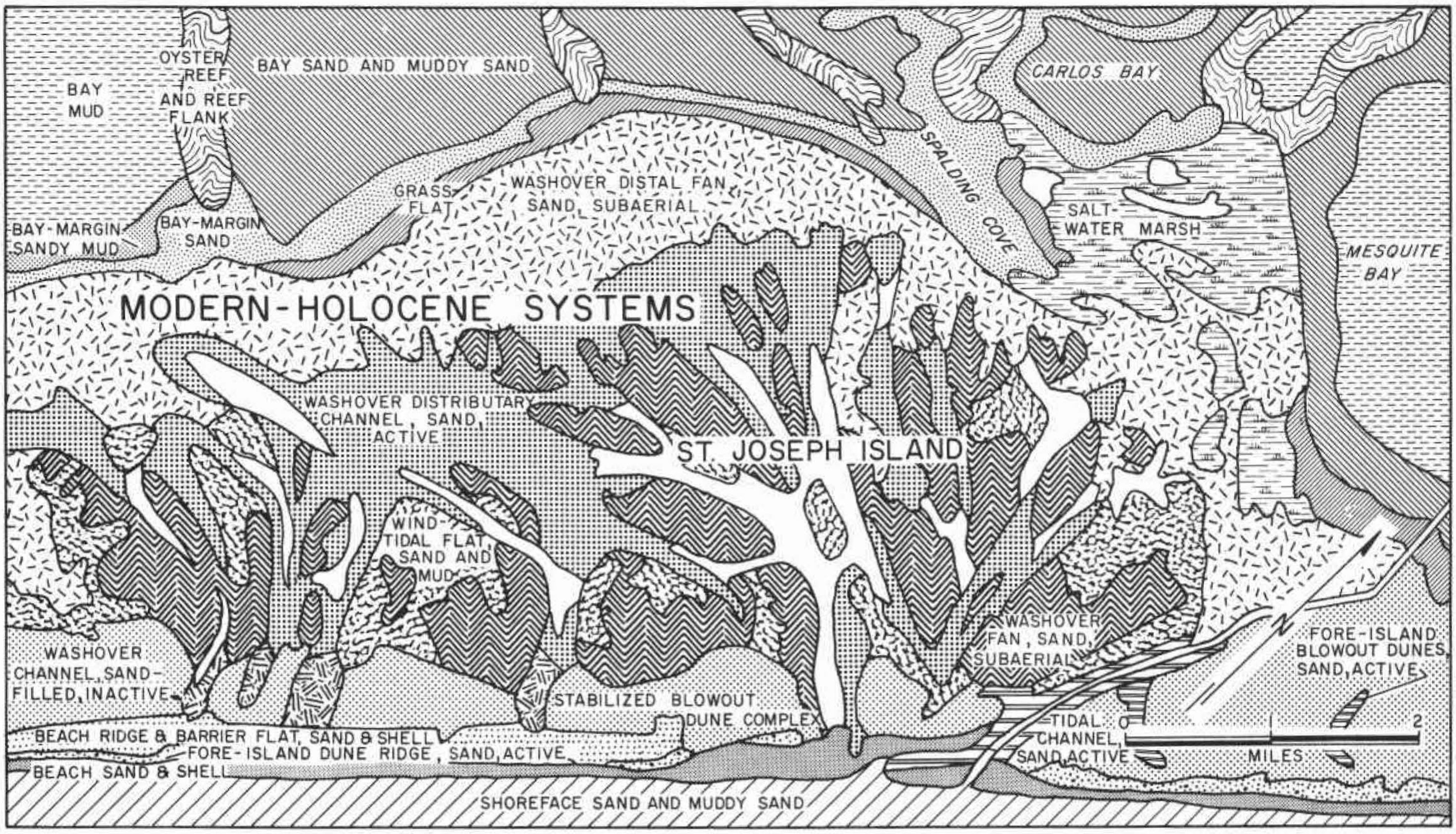


Figure 25. Modern washover fan, northeastern St. Joseph Island, Aransas County, Texas. Includes active and inactive subaerial sand facies, alternately submergent-emergent wind-tidal flat sands and muds, and elongate water-filled troughs. Represents a complex of several hurricane events and episodes of barrier island breaching.

Mud accumulates within the ponded channels. A fauna consisting of oysters, *Tagelus*, *Ensis*, and other molluscs, is characteristic of inactive channels. The shallow distal part of the distributary is mostly sand filled and grades bayward into the washover distal fan.

The subaerial, vegetated *washover fan* (7 square miles), which exhibits a few feet of relief, lies between major washover channels and washover distributaries. These sand bodies, termed eolian mounds by P. B. Andrews (1970), form a simple radiating pattern centered on the apex of the fan. These mounds 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 structure. Sand is stabilized by a dense growth of grasses and thorny shrubs.

The outer part of the washover fan, called the *washover distal fan* (about 8 square miles), is a level surface that is a maximum of 1 foot to 2 feet above mean sea level. Sediment is predominantly sand transported into the area by storm-surge flood. North winds produce wind tides that inundate large areas of the washover distal fan; at this time, a veneer of mud, derived from Aransas Bay, is deposited on the fan surface. Subsequent desiccation and eolian activity remove most of these mud veneers. This 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 produces 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. Another large, abandoned tidal delta, which has been modified partly by washovers, lies to the northeast of Cedar Bayou (Wilkinson, 1973). It forms a prominent bulge along the bay shore between Mesquite and San Antonio Bays (see *Environmental Geology Map*). This fan has not been active recently; the channel is filled on the seaward side of the barrier and is fronted by beach ridges and fore-island dunes.

Tidal passes and tidal deltas.—Natural breaks between barrier islands and peninsulas, through which there is tidal exchange between bay and Gulf waters, are called tidal 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 terminus of a tidal channel; these fan-shaped bodies 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 terminus of tidal channels. Since physical processes are more intense on the Gulf side of the barriers than on the bayside, much of the ebb sediment is immediately 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 the mouth of the pass; similar shoals are also a minor part of flood deltas. Subaqueous parts of tidal deltas, excluding extensive areas of marsh, occupy approximately 12 square miles of bay and Gulf bottom.

Major tidal passes on the Texas coast, such as Pass Cavallo (fig. 24) were initially situated over incompletely buried Pleistocene valleys. Pass Cavallo has migrated approximately 6.5 miles southwest of its original position. It no longer overlies the buried valley, the axis of which lies approximately 1.3 miles east of the Matagorda Ship Channel jetties. Acoustical profiles indicate that the depth of the Pleistocene valley was greater than 125 feet. These valleys are filled in their deepest parts by fluvial gravel and sand, succeeded upward by deltaic facies, estuarine deposits, and, near the surface, by tidal channel deposits. Deposits in the deeper parts of the *tidal channels* consist of a mixture of shell fragments and terrigenous sand. Most channels are unstable; they tend to migrate in the direction of longshore drift. As the channel migrates, it is successively filled by sand as spits accrete into the shifting channel.

The *flood deltas* consist of shell and sand near the mouth of the main tidal channel; sediment becomes finer grained on the distal part of the deltas toward the bay. When storms raise the water level in the bay, considerable sediment is deposited on the flood delta. With subsidence of the storm and associated high tides, parts of the flood delta may become emergent and be stabilized by marsh vegetation. *Ebb deltas* are characterized by shell and sand near the gulfward terminus of a tidal channel and become finer grained in the deeper waters of the Gulf; the distal ebb-tidal delta is predominantly sand and muddy sand. *Inlet-related shoals,* because they are affected by both tides and waves, consist of well-sorted, shell-bearing sand.

Other active or recently active tidal passes are Greens Bayou, situated on Matagorda Peninsula approximately 7.3 miles east of Matagorda Ship Channel, and Cedar Bayou. Cedar Bayou, an intermittent tidal pass, lies between Matagorda and St. Joseph Islands.

Marsh-Swamp System

The lower parts of coastal areas and river valleys, generally at elevations less than 5 feet above sea level, support a marsh-swamp system in the Port Lavaca area (fig. 4). Although there are four significant fluvial systems and two rather large bayhead deltas, swamps are areally restricted and are, therefore, a less important constituent of the coastal environment of the Port Lavaca area than in coastal areas to the east. Vegetation in marshes and swamps requires a perennially wet substrate with a permanently high water table. Marshes are composed primarily of grasses; swamps consist chiefly of trees. Marshes and swamps develop on a variety of landforms including: (1) flood-tidal deltas, (2) back sides of barrier islands and peninsulas, (3) mainland shorelines, (4) bayhead deltas, (5) abandoned tidal creeks and washover channels, (6) floodplains of major fluvial systems, and (7) abandoned courses and cutoffs of Modern and ancient stream systems.

Components of the marsh-swamp system in the Port Lavaca area include: (1) salt-water marsh, (2) fresh- to brackish-water marsh, (3) fresh-water marsh, and (4) swamp. In addition to being distinguished by 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 that controls 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. 26). Swamps are exclusively a fresh-water, tree-dominated environment.

Salt-water marsh.—Salt-water marshes, kept perennially wet by salt water, occupy 54 square miles of the Port Lavaca area. Chief occurrences are on the delta plains of bayhead deltas, along bay margins, on flood-tidal deltas, and along the back sides of barrier islands and peninsulas.

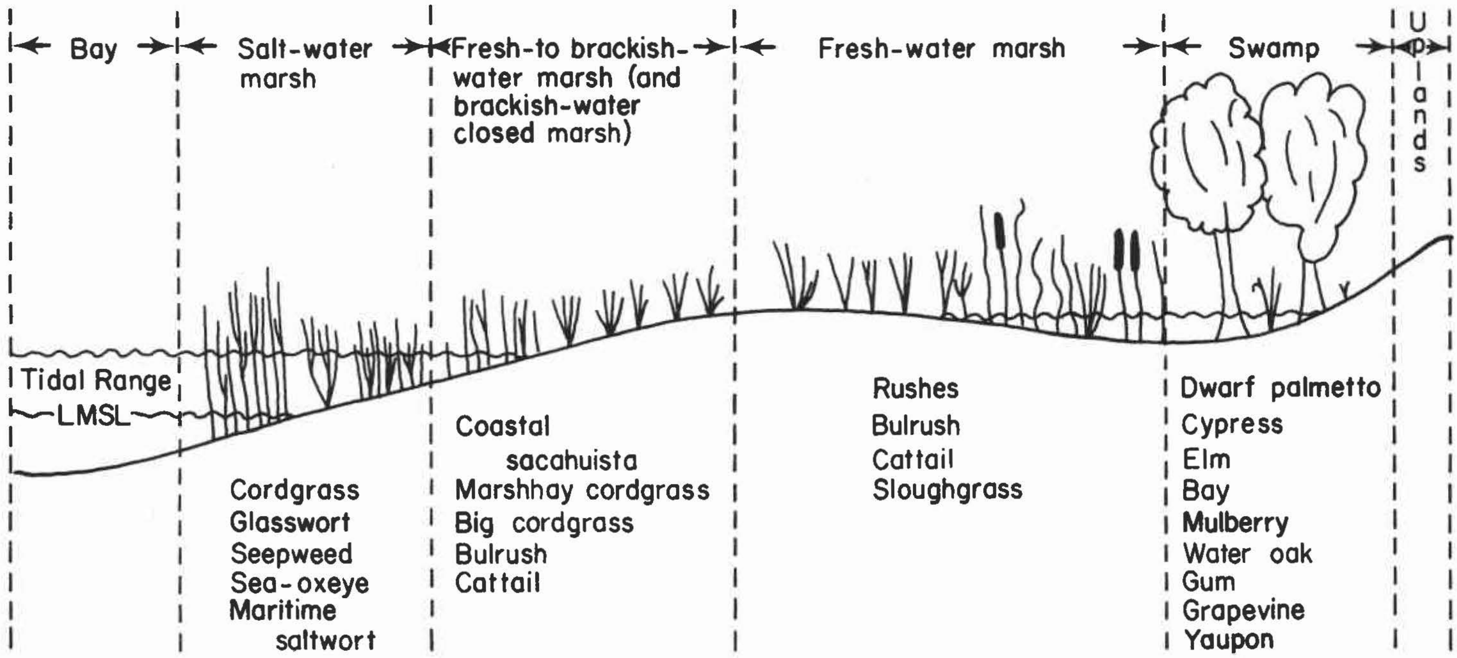


Figure 26. Schematic profile of Modern marsh-swamp system. Hypothetical cross section from bay to uplands illustrates relative lateral and vertical spatial relationships among salt-water, fresh- to brackish-water, and fresh-water marsh and swamps.

Salt marshes include low marsh and high marsh. The low salt-water marsh is characterized by pure stands of smooth cordgrass that grow at the margin of salt-water bodies in water a few inches deep (fig. 26). The high salt-water 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 is around normal marine salinity (35°/∘∘).

Climatological conditions affect salinity fluctuations experienced by high salt-water marsh. There is a decrease in marsh area from east to south along the Texas coast. This decrease is coincident with a decrease in rainfall and an increase in temperature (fig. 10). These climatic factors decrease the volume of fresh water contributed to bays and estuaries (resulting in an increase in salinity of bay water) and increase the rate of evaporation (resulting in an increase in salinity of pore water in some of the tidally influenced environments, such as salt marshes and wind-tidal flats).

Large areas of salt marsh occur on the Lavaca and Guadalupe deltas. These marshes are virtually at sea level along the bay margins, and elevations rise inland. Marshes are inundated by both astronomical and wind tides; wind tides inundate larger areas. From the bay margin inland, plant species are: (1) *Spartina alterniflora*, (2) *Batis maritima*, *Salicornia bigelovii*, *S. perennis*, *Distichlis spicata*, (3) *Spartina spartinae*, and (4) fresh-water marsh or levee vegetation, depending upon the specific location.

Bay-margin marshes are smaller than marshes on delta plains. They have the same species and display the same zonation, but they do not grade into fresh-water marsh. Many of the bay-margin marshes are situated on substrates of mixed shell and sand, including, for example, the area between the south shore of Powderhorn Lake and Magnolia Beach (see *Environmental Geology Map*).

Marshes on the back sides of barrier islands display an orderly plant succession from the bay line to the higher parts of the barrier. The succession is controlled by factors such as degree of inundation, salinity of the substrate, and height of the sediment surface above bay water level. From the bay line toward the higher marsh areas, the plant succession is: (1) *Spartina alterniflora*, (2) *Batis*, *Salicornia*, and *Distichlis*, (3) *Borrichia*, *Monanthochloe*, and *Suaeda*, and (4) sparse marsh vegetation in hypersaline areas (table 6). Similar species are found on the flood delta associated with Pass Cavallo. Here, the black mangrove (*Avicennia nitida*) has become rather prolific during the past few years.

Fresh- to brackish-water marsh.—Fresh- to brackish-water marshes, present at slightly higher elevations than salt marsh, are poorly developed in the Port Lavaca area. These marshlands cover approximately 2 square miles. They are present on the Carancahua delta, along some active and inactive tidal creeks associated with Powderhorn Lake and St. Charles Bay, and at the head of Keller Bay (see *Environmental Geology* and *Environments and Biologic Assemblages Maps*). 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 salt-water inundation depends primarily upon direction, intensity, and duration of the wind. Salinity in fresh- to brackish-water marshes varies with climatological conditions. During prolonged dry periods, both surface and soil water have salinity greater than 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 Port Lavaca area are most extensively developed on the Carancahua delta and along the Lavaca, Guadalupe, and San Antonio Rivers (fig. 22; *Environmental Geology Map*). Small areas of fresh-water marsh exist on the Pleistocene uplands chiefly in abandoned river courses and in the partially filled lakes and ponds in the northwestern map area (for example, Mustang and Flat Lakes). Fresh-water marshes cover a total of 13 square miles in the Port Lavaca area.

Swamp.—Swamps are relatively rare environments in the Port Lavaca area, constituting an area of slightly more than 1 square mile. Swamps are associated with lakes and ponds on the Guadalupe River floodplain. They are perennially inundated by fresh water and support a tree-dominated flora. Swamp vegetation (e.g., 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 some point-bar sands underlying parts of the swamp.

Bay-Estuary-Lagoon and Lake Systems

An extensive network of shallow-water bays, lagoons, and estuaries comprises a major natural system that characterizes much of the Texas Coastal Zone (fig. 4). The Port Lavaca area includes the inland-extending Carancahua, Keller, Lavaca, Guadalupe, Hynes, San Antonio, St. Charles, and Copano Bays and the coastwise lagoons named Matagorda, Espiritu Santo, Ayres, Barroom, Shoalwater, Mesquite, Carlos, and Aransas Bays. These shallow, submerged areas cover 570 square miles within the Port Lavaca area.

Also present in the Port Lavaca map area are 46 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 mainland shore of several bays, estuaries, and lagoons.

The Texas bays, estuaries, and lagoons 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 comprise the bay-estuary-lagoon system resulted when rising sea level following the last glacial period inundated and flooded older river valleys. The morphology of bay margins locally reflects relict erosional topography. Arcuate shorelines, such as exhibited by Carancahua Bay, are relict meander cuts of the old river valleys; these meander cuts have been modified in shape and enlarged through shoreline erosion. Further, where the bay shoreline impinges upon older Pleistocene sands, sand supply is locally sufficient to develop small sand beaches.

The salinity of the bay complex is variable and depends on the amount of fresh-water runoff into the bays. Following heavy rains, especially hurricane-aftermath storms, saline bay waters are greatly diluted by fresh water and are only slightly brackish. Conversely, during hot, comparatively dry summers, the inflowing Gulf water, evaporation within the bays, and the lack of runoff cause bay salinity to approach that of the open Gulf.

Maximum water depth of the bays of the Port Lavaca area occurs in the western part of Matagorda Bay where the bay is 14 feet deep (see *Environmental Geology Map*). Along the bay margin, water depths are generally less than 3 feet, and over large areas of the bays, average water depth is on the order of 6 feet.

Deepest areas are coextensive with the tidal channels, passes, and dredged channels.

Bay-Estuary-Lagoon Environments

The various environments composing the bay-estuary-lagoon system in the Port Lavaca area form two broad categories—bay-margin environments and bay-center environments. The former include both shallow-water and subaerial environments developed as part of the shoreline complex; the latter are exclusively subaqueous, though certain of the reefs may shoal and even break water. Bay waves and currents are critical factors controlling bay-margin environments (fig. 11). 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-margin environments.—The principal subaerial bay-margin environments include less than 7 square miles composed of: (1) bay-margin sand and shell berms, beaches, and active spits, (2) abandoned beach ridges and berms, and (3) wind-tidal flats. Beaches are very poorly developed along Carancahua, Matagorda, Keller, Lavaca, Hynes, Ayres, Mesquite, St. Charles, Aransas, and Copano Bays. These local narrow beaches derive their sand supply from the erosion of Pleistocene distributary or strandplain sand. Most of the bay shoreline is bounded either by an erosional escarpment cut into Pleistocene deposits (fig. 11) or by coastal marshes.

Locally, *shell beaches and berms* are well developed. Some of the berms are up to 10 feet above MSL. Shell derived from *Crassostrea virginica* (oyster) constitutes most of the material of these beaches and berms. The most extensive shell beaches and berms occur along the north shore of Matagorda Bay and from Powderhorn Lake to Magnolia Beach. In addition to beaches and berms along the present shoreline there are several relict beaches and berms between Old Town Lake and Indianola Island (see *Environmental Geology Map*). *Shell spits* occur along the north shore of Espiritu Santo Bay; these are represented by Blackberry, Dewberry, Long, and Grass Islands. Other active sand and shell spits and beaches occur along the southwest shore of Espiritu Santo and San Antonio Bays. Spits consist predominantly of shell derived from bay molluscs, such as *Crassostrea virginica*, *Phacoides*, *Chione*, *Aequipecten*, and *Cerithium* (Wilkinson, 1973). Shell spits are presently in an erosional state. Erosion is most pronounced during the winter when storm waves, generated by northers, move to the south and west.

Grass-covered *abandoned beach ridges, berms, and associated marsh and tidal mudflat deposits* occur along the north shore of Hynes Bay and to the west of the Guadalupe delta (fig. 22; *Environmental Geology Map*). Development is restricted to low-relief bay shorelines facing into prevailing southeast winds and subjected to onshore storm currents. Sediment of the beach ridge consists of caliche nodules, pebbles, sand, and shell fragments (Donaldson and others, 1970). These relict beaches and berms are the products of both normal and storm conditions; storm waves construct berms that may be a few feet above MSL. Intervening marsh and mudflat deposits are predominantly mud.

A flat, barren, relatively featureless surface, designated *wind-tidal flat*, occurs along the back side of the barrier islands between the vegetated barrier flat and beach ridge and the salt marshes along the bay shore. The wind-tidal flat occupies 21 square miles of the Port Lavaca map area. Inundation by salt water occurs a few times each winter during passage of a polar front; the flooding is directly related to the duration of the north wind. Since the area is flooded only a few days each year, most of the surface and near-surface salt water evaporates, leaving a thin salt crust on the flat surface. Blue-green algae flourish on these flats during and shortly after flooding; otherwise, the environment is largely barren. Some local salt-marsh vegetation exists, and *Uca*, the fiddler crab, commonly burrows the lower parts of the flats. Wind-tidal flat sediment is predominantly sand with interspersed mud layers.

Subaqueous bay-margin environments.—The submerged margin of Matagorda, San Antonio, and associated bays is characterized chiefly by about 73 square miles constituting a narrow band of shoal water, generally less than 2 to 3 feet deep and commonly only a few inches deep. Within this bay-margin zone, the substrate or bay bottom consists of sediment winnowed by waves and currents (fig. 11), including chiefly sand with shell and mud (fig. 25). Pleistocene mud and sand are locally exposed on shallow bay-margin bottoms.

Shallow bay margins are underlain by grassflats which are typified by marine grasses and a muddy sand and shell substrate, bay-margin sand and muddy sand that is virtually barren, bay and bay-margin sandy mud that is commonly burrowed, and local bay sand and muddy sand with oyster shell (see the west part of San Antonio Bay and east parts of Aransas and Copano Bays, *Environmental Geology Map*).

In *grassflat* areas, the submerged bay margin is characterized by growth of marine grasses. Principal grassflats are along the north shore of Matagorda Bay, Redfish and Salt Lakes, south shore of Keller Bay, south shore of Powderhorn Lake, and the north shore of Espiritu Santo Bay. Grassflats are also well developed along parts of the bayside of Matagorda Peninsula and Matagorda and St. Joseph Islands (fig. 25; *Environmental Geology Map*). The grassflats consist chiefly of *Diplanthera wrightii* (now known as *Halodule wrightii*). Following a large influx of fresh water, *Ruppia maritima* is common along some of the bay margins. Locally along the bay margin of Matagorda Peninsula and Matagorda and St. Joseph Islands, there are shoal sandflats (*bay-margin sand*) that support only a sparse marine grass cover. These sandflats extend from mean sea level, at the bay shores, to depths of 2 to 6 feet where they terminate abruptly. Sediment that accumulates on the sandflats is chiefly fine- to very fine-grained sand derived from tidal passes, tidal deltas, washovers, and bluffs adjacent to the flats.

Bay-center environments.—The central parts of the bay-estuary-lagoon system of the Port Lavaca area comprise two major classes of environments, exclusive of the environments associated with the tidal inlets and passes. Bay-center environments include those associated with oyster reef development and those devoid of reef development.

Prodelta mud, delivered to the bay-estuary-lagoon system by streams, has properties similar to bay-center muds. The chief differences are that bay-center muds, in general, contain less plant debris and display more biological reworking than prodelta mud. Other bay-center components are: (1) bay sand with mixed shell which is a veneer over Pleistocene deposits; (2) mottled bay mud with some mixed shell; (3) oyster reef; (4) oyster reef flank consisting of abundant shell debris with some terrigenous sand and mud; (5) bay sand and muddy sand with local occurrences of oyster shell; and (6) interreef mud with oyster shell.

A significant environment of San Antonio and related bays and parts of Matagorda and Lavaca Bays is the *reefs* built chiefly by the edible oyster *Crassostrea virginica* (fig. 27; *Environmental Geology Map*). Reefs range from clumps a few feet in diameter to complexes up to 6 miles long and occupy 32 square miles in the bays of the Port Lavaca map area. Small reefs are either elongate or L-shaped. Large reefs have complex, highly sinuous forms, particularly those in San Antonio Bay. The elongate reef axis is commonly 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. Oyster reefs favor fine, stable sands or stiff, compact muds for support; soft mud 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 salinities, but prefer 5‰ to 30‰. They can survive sudden changes of salinity for short periods by closing their valves and isolating themselves from unfavorable waters.

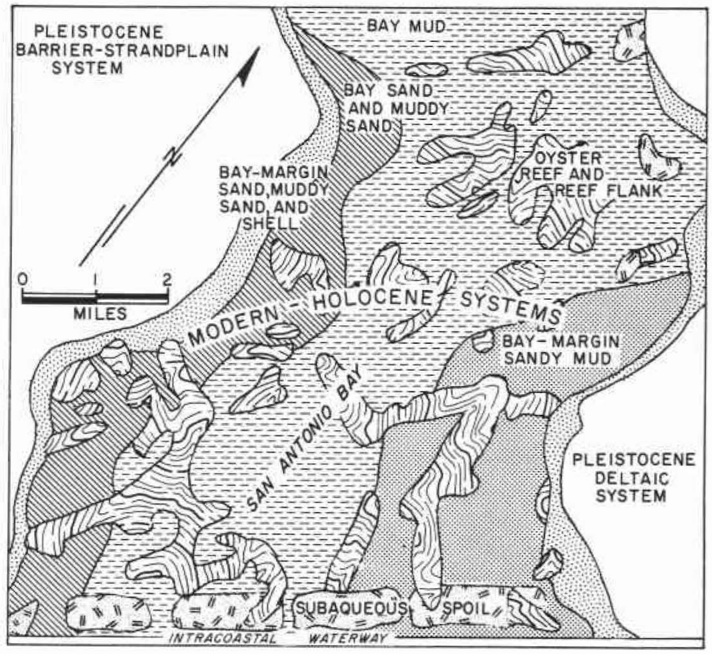


Figure 27. Modern bay-estuary facies, extensive oyster reef development, San Antonio Bay. Close proximity of subaqueous spoil with reef and reef flank environments along Intracoastal Waterway; spoil is the largest single source of bay sediment.

The *Environmental Geology Map*, as well as certain other maps of this Atlas, shows the location and distribution of reefs in bays of the Port Lavaca area. Mapped reefs include both dead and living oysters. Only the outer surface of the reef contains live oysters. Principal development is in San Antonio, Aransas, and Copano Bays, with local development in Lavaca and Matagorda Bays. Oyster reefs are not developed in those parts of the bay modified by tidal interchange and river discharge (fig. 11).

The *Environmental Geology Map* shows only exposed reefs; in addition, there are numerous relict reefs and areas of broken shell covered by varying amounts of bay-bottom sediments. Environmental factors controlling oyster reefs in the Texas Coastal Zone are summarized by Scott (1968), who cites several additional, significant references.

In areas of the bay where reefs are not developed, the substrate is of two basic types; these substrates, both chiefly mud, reflect two distinct bay environments. Immediately off the Carancahua, Lavaca, Garcitas, and Guadalupe deltas, the bay receives suspended load or prodelta mud transported by the rivers and creeks. Here the prodelta environment consists of 7 square miles of mud and sandy mud. These bay segments receive fresh-water inflow which is reflected in the molluscan fauna. For example, Carancahua and Lavaca Bays are characterized by the dominance of *Mulinia lateralis*. The centers of bays (fig. 28) which do not have reefs and which are least affected by the rivers are characterized by mud bottoms and a fauna dominated by *Nuculana concentrica*, *Pandora trilineata*, and brittle stars. This type of bay bottom comprises an area of about 268 square miles. Rate of sediment influx in these areas is slow. Principal areas of high benthonic activity include: (1) areas distal to flood-tidal deltas of Greens Bayou, Pass Cavallo, Carancahua Pass, and Cedar Bayou; (2) upper parts of Carancahua, Lavaca, and San Antonio Bays marginal to the prodelta environments; (3) Powderhorn Lake; (4) Espiritu Santo Bay; and (5) Ayres, Mesquite, and Carlos Bays.

Lake Environments

Small, enclosed, fresh- and salt-water bodies termed lakes or ponds occur throughout the Port Lavaca map area. There are three general lake types: (1) inland lakes and ponds associated with Pleistocene fluvial-deltaic sand; (2) floodbasin lakes, such as those associated with Lavaca, Guadalupe, and San Antonio Rivers; and (3) coastal lakes and ponds, some of which were separated from the bay proper by spit accretion. Inland lakes and ponds associated with Pleistocene deposits were discussed in the section on the Pleistocene fluvial-deltaic system. Lakes and ponds cover a total of 4.5 square miles in the Port Lavaca map area.

Floodbasin lakes.—Several fresh- to brackish-water lakes are present on the floodplains of the Lavaca, Guadalupe, and San Antonio Rivers, and Garcitas Creek. Most of the lakes are elongate 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, and are floored with muddy sand and sandy mud. Swan Lake, associated with the Lavaca River, is tidally connected to Lavaca Bay; salinity of the water in Swan Lake ranges from fresh immediately after a flood to saline during droughts. Green Lake is one of several prominent fresh-water bodies along the Guadalupe and San Antonio Rivers. Molluscs are common to abundant. Lake margins are characterized by fresh-water marsh and swamp; water hyacinth is seasonally abundant.

Coastal lakes and ponds.—Coastal lakes and ponds are an integral part of the coastal marsh complex (salt marsh and fresh to brackish marsh). These water bodies are widely distributed, occurring in the Carancahua Bay area, between Port O'Connor and Magnolia Beach, and along re-entrants of St. Charles and Copano Bays (see *Environmental Geology Map*). Water bodies adjacent to bay margins, for example Salt Lake and Redfish Lake (fig. 28; *Environmental Geology Map*), 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 climatic 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 (fig. 28) consist of unvegetated mudflats representing former bottoms of larger water bodies; locally, these coastal lakes have been completely filled by muddy lake-bottom sediments.

Artificial Units

A significant type of landform within the Port Lavaca area results directly from the activity of man. Artificial units shown on the *Environmental Geology Map* include made or reclaimed land and a variety of dredged spoil 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. The only made land in the Port Lavaca area covers an area of 0.3 square mile, formerly bay bottom along the east shore of Lavaca Bay. It is used as a holding pond for wastes produced at the Aluminum Company of America's industrial complex at Point Comfort. Though filling is requisite for certain physical uses, the practice permanently alters the original natural landform and environment.

Spoil.—The Port Lavaca area is covered by a total of about 30 square miles of spoil material dredged from transportation channels and canals (fig. 29). The natural environment is altered not only by the channel, but also by the discharge of disposed dredged sediment. Dredged spoil is further reworked and redistributed; 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

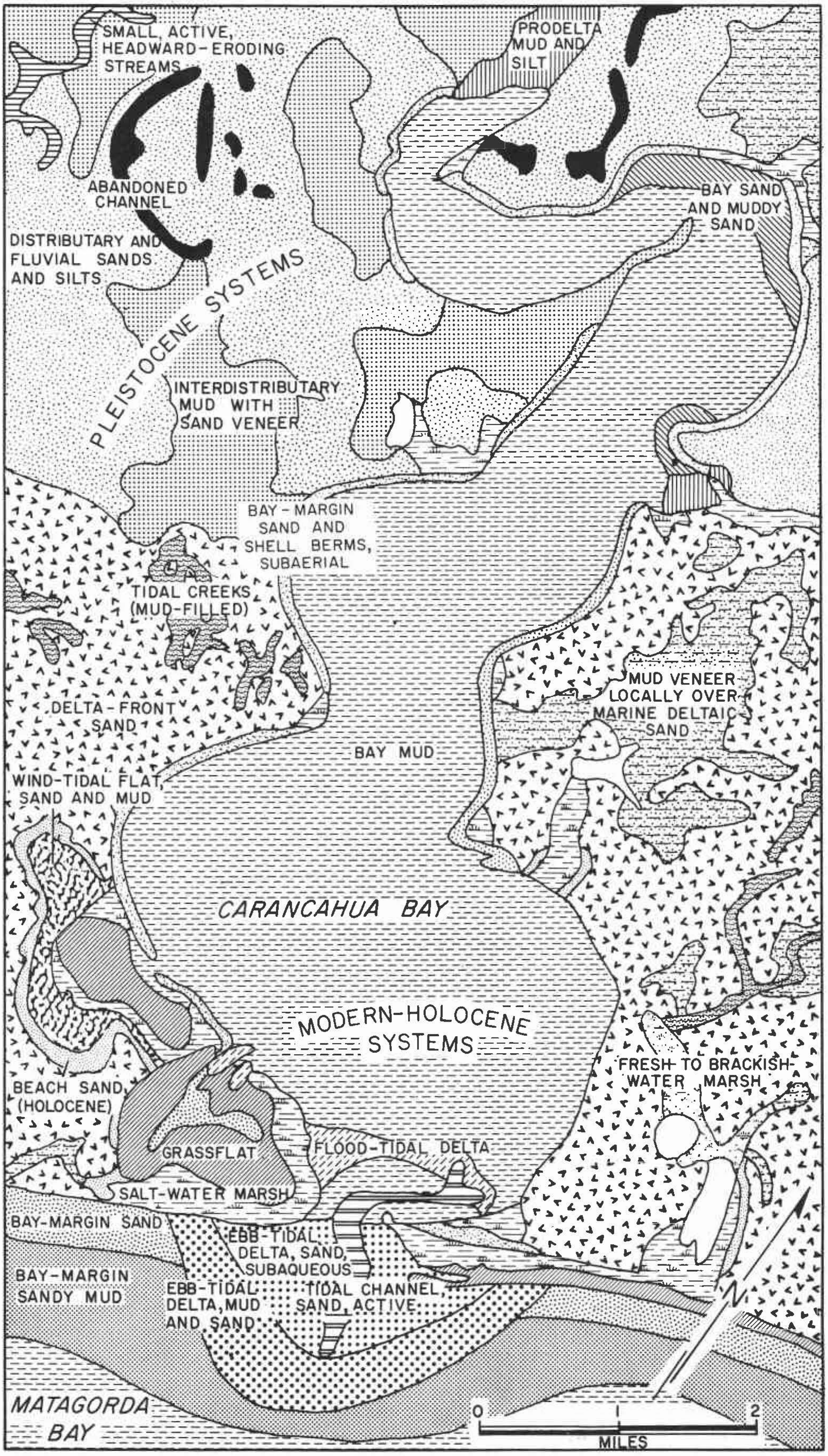


Figure 28. Modern bay-estuary facies, Carancahua Bay and northern Matagorda Bay. Sizable flood-tidal delta and larger ebb-tidal delta indicate significant tidal currents at the constricted mouth of Carancahua Bay despite low tide range.

spoil is, therefore, increased markedly. 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*, *subaerial reworked spoil*, and *subaqueous bay-bottom spoil.* Major spoil areas flank the land cuts and intrabay dredged channels of the Intracoastal Waterway (figs. 27 and 29; *Environmental Geology Map*) and associated subsidiary waterway systems.

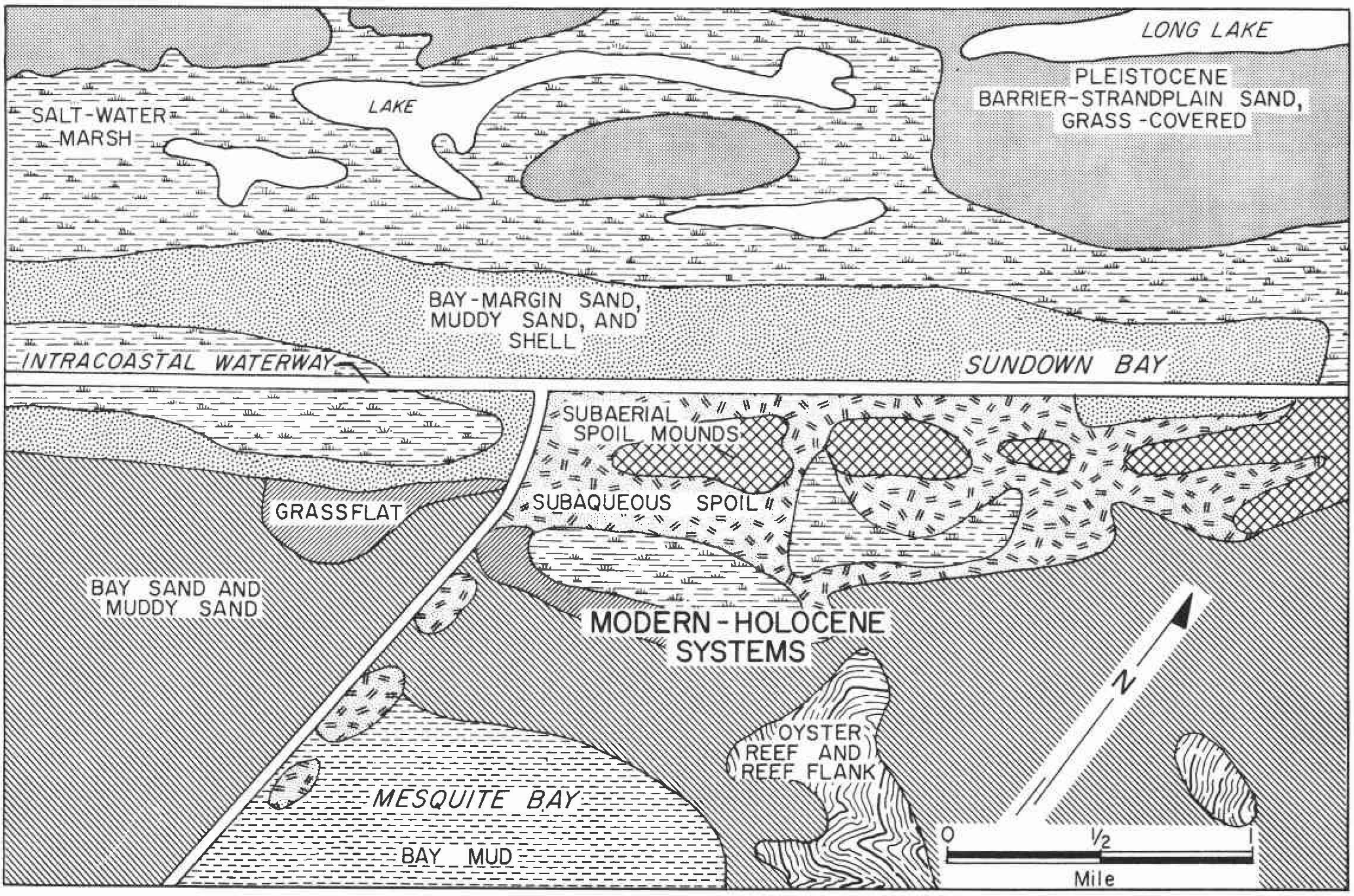


Figure 29. Subaerial and subaqueous spoil, Ayres-Mesquite Bay area, Aransas County, Texas. Dredged channels are cut through bays and shallow land areas on bay margins. Spoil is piled along the cut and locally covers highly productive salt marshes and other nearby bay-estuarine environments.

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 are 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 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 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 compose 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 Port Lavaca area can be compared directly with the distribution of potential 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. The many geologic, biologic, active-process, and man-made units of the *Environmental Geology Map* are organized into eight major groups in the Port Lavaca 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 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, use of materials as a base or foundation for paved or improved roads, and use of materials as 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 (e.g., 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 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

Table 4. Evaluation of the natural suitability of physical properties groups for various coastal activities and land uses, Port Lavaca 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			Fill Material		Foundation					Waste Disposal			Water Storage		
		(1) Earthen structures and fill material	(2) Base material	(3) Grade material	(4) Topsoil	(5) General, below topsoil	(6) Heavy	(7) Light	(8) Underground installations	(9) Buried cables and pipes	(10) Excavatability	(11) Septic systems	(12) Solid waste	(13) Unlined liquid-waste retention ponds	(14) Earthen dams and dikes	(15) Unlined reservoirs or ponds above ground-water level	(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-lake swales, abandoned channel-fill muds, overbank fluvial muds, mud-filled coastal lakes and tidal creeks, delta-plain and reworked delta-front muds	–	–	–	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	Modern barrier island sands (beach, fore-island dunes, beach ridge and barrier flat, stabilized blowout dune complex, washover sands), fluvial point-bar sands, lake-margin beach ridges, and Pleistocene barrier-strandplain sands	+	+	+	0	+	+	+	+	+	+	0	–	–	–	–	+
Group III Dominantly clayey sand and silt, moderate permeability and drainage, moderate 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 and crevasse splay, bay-margin sand and mud, Pleistocene fluvial, distributary, and delta-front sands, and Pleistocene 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 abandoned coastal lakes and tidal creeks, 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, inland marsh, marsh-filled barrier-strandplain swales, abandoned channel and course, and marsh-filled lakes	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
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 sides of Modern barrier island, properties on the Modern barrier-strandplain similar to Group II, and properties on the bay margin similar to Group V	Wind-tidal flat, salt marsh, and washover distributary channel and distal-fan facies	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Group VII Made land and spoil, properties highly variable, mixed mud, silt, and sand, reworked spoil commonly sandy and moderately sorted with properties similar to those of Group III	Subaerial spoil heaps or mounds, subaerial reworked spoil, subaqueous spoil, made land	HIGHLY VARIABLE: USE WITH CAUTION															
Group XI Active dunes, sand, friable, very high permeability, low water-holding capacity, low compressibility and shrink-swell potential, high shear strength but unstable due to migration, low plasticity; subject to intense eolian processes	Modern barrier fore-island blowout dunes and back-island dunes	+	+	+	–	–	–	–	0	0	+	–	–	–	–	–	0

frequent tidal inundation, made land and spoil, and unstable sand subject to eolian processes and migration of active dunes. 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 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 Port Lavaca map area are too limited and too local in distribution to ascribe precise quantitative parameters to the various units throughout the area. Data presented on the *Physical Properties Map* of this Atlas should not be substituted for specific site testing and evaluation but can be used to rate large tracts of land for a particular suitability.

In addition to the major physical land types shown, principal zones of active or potentially active surface 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, as well as from mud-filled lakes, tidal creeks, barrier-strandplain-lake-associated swales, and mud-veneered deltaic sand. Principal soils developed on these fine-grained substrates include clay soil types of the Lake Charles, Trinity, Victoria, and Edna 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. The very low permeabilities, however, 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 suitability of these lands for heavy construction, road building, and foundation construction unless artificial stabilization and special engineering are undertaken. Group I lands are a major land type which includes more than 884 square miles or 33 percent of the Port Lavaca map area. They occur inland of Pleistocene and Modern-Holocene barrier-strandplain systems and are distributed rather evenly over the map area.

Group II Lands

Materials of this group are dominantly fine- to medium-grained clean sands. In the Port Lavaca area, these sands form a major part of the Modern barrier islands, including the beach, foredunes, and vegetated barrier flats. They compose parts of an ancient (Pleistocene) barrier-strandplain system that extends from south of Lamar Peninsula northeastward to Port O'Connor. Other occurrences of Group II materials are restricted to active and abandoned point bars along Blanco, Melon, and Garcitas Creeks, Guadalupe River, and lake-margin beach ridges and berms on the south sides of Ninemile Flat and Willow, Flat, North St. Nicholas, and Sharps Lakes, as well as along margins of salt marsh and wind-tidal flats of coastal lakes and inlets. Principal soils developed on these sand deposits in the Port Lavaca map area are the Galveston, Mustang, Rahal, Port Alto, Roemer, and Veston series.

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 189 square miles, or 7 percent of the Port Lavaca map area, are included in Group II lands. This is the principal land type of the coastal barrier islands and Pleistocene barrier-strandplain system.

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

SPECIAL-USE ENVIRONMENTAL MAP UNITS	Aransas°	Bee°	Calhoun°	Goliad°	Jackson°	Matagorda°	Refugio°	Victoria°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Port Lavaca map area (excluding offshore area)	Percentage of Port Lavaca 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-lake swales, abandoned channel-fill muds, overbank fluvial muds, mud-filled coastal-inland lakes and tidal creeks, delta-plain and reworked delta-front muds	41.2	0	182.1	36.2	157.9	0	250.7	216.0	–	884.1	32.6
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, fore-island dunes, beach ridge and barrier flat, stabilized blowout dune complex, washover sands), fluvial point-bar sands, lake-margin beach ridges, and Pleistocene barrier-strandplain sands	68.8	0	105.9	0.2	1.0	8.4	3.7	0.8	–	188.8	7.0
GROUP III Dominantly clayey sand and silt, moderate permeability and drainage, moderate 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 and crevasse splay, bay-margin sand and mud, Pleistocene fluvial, distributary, and delta-front sands and Pleistocene strandplain sheet sands	30.2	3.5	173.9	63.5	115.5	0.3	282.1	220.7	–	889.7	32.8
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-covered levees, marsh-filled abandoned coastal lakes and tidal creeks	1.2	0	8.7	0	3.4	1.8	1.6	0.5	–	17.2	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, inland marsh, marsh-filled barrier-strandplain swales, abandoned channel and course, and marsh-filled inland lakes	3.6	0	11.4	1.0	1.0	4.8	1.3	2.5	–	25.6	0.9
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 sides of Modern barrier island, properties on the Modern barrier-strandplain similar to Group II, and properties on the bay margin similar to Group V Geologic units include wind-tidal flat, salt marsh, and washover distributary channel and distal-fan facies	32.3	0	43.0	0	5.0	0	4.5	2.0	–	86.8	3.2
GROUP VII Made land and spoil, properties highly variable, mixed mud, silt, and sand, reworked spoil commonly sandy and moderately sorted with properties similar to Group III Geologic units include subaerial spoil heaps or mounds, subaerial reworked spoil, subaqueous spoil, made land	4.3	0	20.3	0	0.5	4.8	0	0	0.7	29.9	1.1
GROUP XI Active dunes, sand, friable, very high permeability, low water-holding capacity, low compressibility and shrink-swell potential, high shear strength but unstable due to migration Geologic units include Modern barrier fore-island blowout dunes and back-island dunes	0.3	0	0.5	0	0	0	0	0	–	0.8	0.03
Pit or quarry, commonly shelly beach and delta-front sands■	0	0	6	0	0	0	0	0	–	6	–
Sludge pit or miscellaneous waste disposal site, may be abandoned■	0	0	5	0	0	0	0	1	–	6	–
Sewage disposal site, liquid effluent, normally treated■	0	0	1	0	1	0	0	0	–	2	–
Solid-waste disposal site, sanitary landfill, and open dumps■	0	0	4	0	1	0	3	1	–	9	–
Active or potentially active fault, based on lineament or grain displayed on aerial photographs▲	58.0	2.0	196.0	16.0	192.0	.3	332.0	206.0	–	1002.3	–

GROUPS VIII, IX, and X not present in this area

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

†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.

Group III Lands

Materials of Group III are dominantly clayey sands and silts. In the Port Lavaca area, these occur mainly as narrow, elongate belts situated in the coastal uplands flanking the San Antonio, Guadalupe, Lavaca, and Navidad Rivers. The narrow belts, aligned normal to the coast, represent ancient (Pleistocene) deltaic distributary channel silts and sands and younger (Modern-Holocene) meanderbelt sands and silts. Group III lands also extend parallel to the coast just inland of the Pleistocene barrier-strandplain system. These represent sheet sands derived from the Pleistocene strandplain and marine delta, delta front, and reworked delta sands. Principal soils developed on these lands include the clay loam and fine sandy loam soils of the Lake Charles and Edna series, particularly on the older (Pleistocene) fluvial and deltaic distributary and strandplain sheet sands. Soils of the Goliad, Bienville, and Milam series characteristically are developed on the fluvial deposits of Modern-Holocene age.

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 33 percent of the total area of the Port Lavaca map (excluding offshore), covering approximately 890 square miles. With the exception of the Pleistocene barrier-strandplain sands and the coastal barrier islands, Group III lands are rather evenly distributed throughout the mapped area.

Group IV Lands

Lands in this physical group include fresh- to brackish-water coastal marshlands that are most common around Mission and Green Lakes and along Lavaca River and several small tidal creeks. Their suitability 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 uses, but these activities destroy the marshland permanently. Fresh to brackish wetlands cover approximately 17 square miles in the Port Lavaca map area, representing less than 1 percent of the total area.

Group V Lands

Lands included in this group embrace 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 developed just inland from the wetlands of Group IV, in abandoned channels, river courses, and inland lakes; most extensive development of Group V lands occurs in marsh-filled swales in Pleistocene barrier-strandplain and associated sheet sands. 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 depressed relief, and are characterized by a water table that intersects the ground surface. 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. Fresh-water marshes and swamps occupy about 25 square miles of land area on the Port Lavaca map, making up almost 1 percent of the total mapped area.

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 back sides of St. Joseph Island, Matagorda Island, and Matagorda Peninsula; along the margins of several small bays, including Copano, St. Charles, Sundown, Hynes, Chocolate, Keller, Cox, and Carancahua Bays, and Powderhorn Lake; and along the distal margin of the Guadalupe and Lavaca deltas. Physical properties of 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. Tidal flats, formed by both astronomical and wind-generated tides, are well developed in the Port Lavaca map area along the back sides of coastal barriers and the low-lying areas of the bay shore. Most of the local tidal flats are barren sandflats that support little or no vegetation. Lack of stabilization precludes most types of physical uses. Salt marshes and wind-tidal flats cover about 87 square miles of the lowest coastal lands of the area, representing more than 3 percent of the total mapped 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 dredged spoil banks is along the artificially constructed Intracoastal Waterway, Ferry Channel, Victoria Channel, Port Lavaca Channel, and Matagorda Ship Channel. The principal area of made land is the small island and holding pond in Lavaca Bay near Point Comfort. Physical properties of spoil and made land are highly variable, dictated in part by the kind of 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 for physical purposes should be approached with caution and with adequate site testing. These lands occupy 30 square miles, or about 1 percent of the map area.

Group XI Lands

Lands classed in this group include areas of sand dunes having unstable, migrating surfaces influenced by onshore winds. These lands occur along the Gulf side of Matagorda Island (fore-island blowout dunes) and scattered over St. Joseph Island (fore-island blowout and back-island dunes). 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 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 only 0.03 percent of the Port Lavaca map area, totaling less than 1 square mile.

Land-Surface Subsidence and Surface Faulting

Problems of land-surface subsidence and surface faulting affect, in varying degrees, substantial parts of the Texas Coastal Zone. Detailed discussions and analyses of subsidence and surface faulting, including reference to many previous studies, are included in Brown and others (1974). Both subsidence and surface faulting are most pronounced in the Houston area (Fisher and others, 1972; Brown and others, 1974) where large volumes of ground water are withdrawn. Extensive ground-water withdrawal, with the consequence of land subsidence (fig. 30) and the activation of surface faulting, is not a major problem in the Port Lavaca map area.

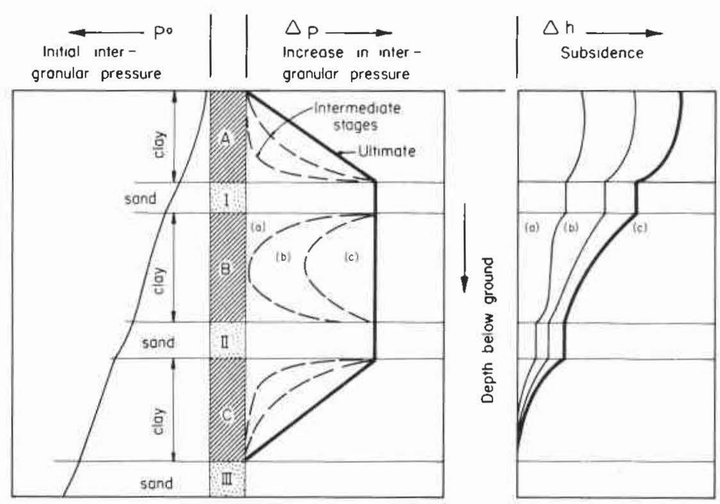


Figure 30. Effects of ground-water withdrawal on intergranular pressure, with consequent volume reductions and surface subsidence. After Turner, Collie, and Braden, Inc., 1966.

Releveling of previously existing level lines by the National Geodetic Survey indicated land-surface subsidence of 0.2 to 1.0 foot in the Jackson County area from 1943 to 1972. Brown and others (1974) estimated that approximately 250 square miles within the Port Lavaca map area are affected by subsidence ranging from 0.2 to 1.0 foot. Extensive pumpage of ground water for irrigation of cultivated lands is a major cause of land-surface subsidence in Jackson County (Baker, 1965). Baker states that there is a correlation between subsidence of the land surface and decline in water level as shown by releveling of benchmarks by the U. S. Coast and Geodetic Survey between 1918 and 1951 and measurements of water-level declines between 1944 and 1964.

Although subsidence is caused predominantly by ground-water withdrawal, local subsidence may result from other activities. At Goose Creek oil field, for example, production of oil prior to 1924 resulted in withdrawal of large volumes of water and sand along with the oil, which led to local subsidence in excess of 3 feet (Pratt and Johnson, 1926). Frasch or solution mining of sulfur from caprocks of certain salt domes has also resulted in localized land-surface subsidence. Deere (1961) documents subsidence of almost 5 feet in a span of only 31 months over a sulfur production zone. Several tens of feet of subsidence occurred locally over Gulf (Big Hill) dome in its early phase of sulfur production from 1919 to 1932 (Sheets, 1947). In addition, proposed production of potential geothermal resources in the Coastal Zone may also result in fluid withdrawals on a scale that may cause eventual subsidence of the land surface (Kreitler, in press). Near Lolita in the Port Lavaca map area, oil production since 1940 exceeds 50 million barrels. Land-surface subsidence of 0.8 to 0.9 foot between 1943 and 1972 has occurred in this same area. Though data are insufficient to separate the effects of oil withdrawal from ground-water withdrawal, it appears that oil production may have contributed to land-surface subsidence in this area.

Approximately 1,002 miles of linear surface anomalies occur within the Port Lavaca map area. These lineations are undoubtedly of structural origin and probably represent faults and joints or fractures that may become faults. No active surface faults are known in the Port Lavaca map area. The most severe area of known active surface faulting in the Texas Coastal Zone is in the Houston area, and active faulting occurs to a lesser degree in the Corpus Christi area (Brown and others, 1974).

Kreitler (in press) demonstrates a close relationship between the trends of linear surface anomalies and active and inactive surface faults in the Houston area. In addition, the trends of these surface lineations and surface faults are shown to be related to subsurface faults. Several lineations in the Port Lavaca map area are coincident with the surface traces of faults extrapolated from the subsurface (Kreitler, in press). The strong parallelism and close coincidence of surface faults, lineations, and subsurface faults indicate that most surface faults are closely related either to the numerous salt domes in the upper Coastal Zone or to the numerous, long coastwise faults extending upward from several thousands of feet below the surface. These associations point to the long geologic existence of the faults and to the fact that they are products of natural geologic processes.

Although Coastal Zone faults are a product of natural geologic processes and existed long before man, there is clear indication that certain of man's activities (fluid withdrawal) cause increased frequency and activity of surface fault movement (Brown and others, 1974). Most of the known currently active faults are located in areas of heavy withdrawal of ground water, oil, and gas—the areas of greatest surface subsidence. Of course, these areas also experience greatest land use; hence, the presence of active surface faults and their effects are more likely to be recognized than in areas of less intensive land use.

The *Physical Properties Map* of this Atlas shows the location and distribution of many lineations in the Port Lavaca map area. If extensive ground-water development occurs, active surface faults can be expected. The location of these faults will probably be within the zone defined by the lineations. Surface faults, either active or inactive, need cause no real hazard provided that 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 designed and engineered to accommodate potential movement and displacement.

Waste Disposal

A significant activity in the heavily populated and industrial area of the upper 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 the surface. Ultimately, recycling of waste materials will reduce the waste load, but because of the present level of technology and the cost of 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 lands in the Port Lavaca map area include placement of solid wastes in dumps or landfills (fig. 31), retention of liquid industrial wastes in surface lagoons, and disposal of human wastes through septic fields.

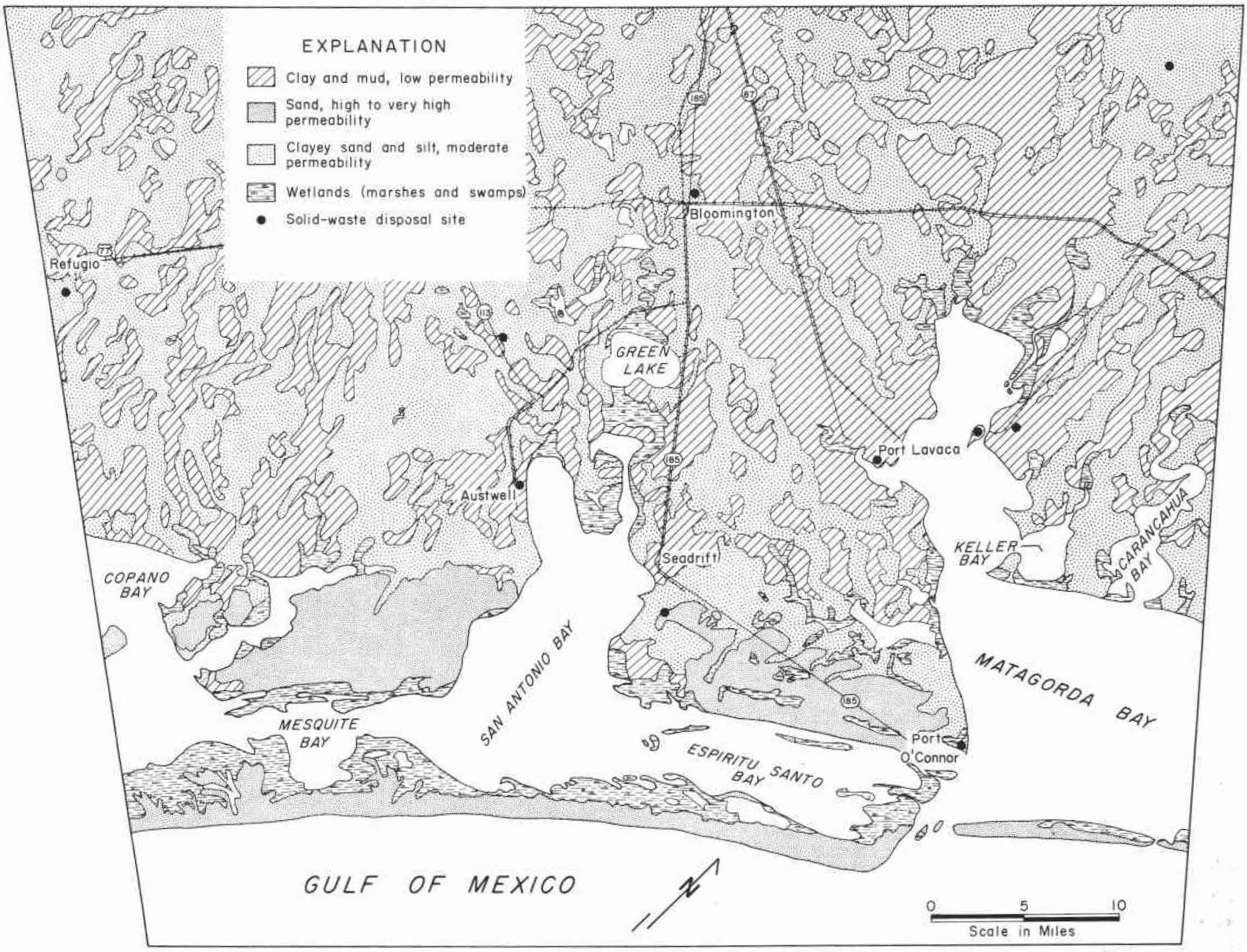


Figure 31. Distribution of solid-waste disposal sites in various substrate units in the Port Lavaca map area. Location of disposal sites courtesy of Texas Health Department.

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 eight basic land types discussed previously may be grouped into four main solid-waste suitability groups (fig. 31); suitability for liquid-waste disposal can also be evaluated within these four main groups.

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 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 have highly variable physical properties and must be utilized only after thorough testing and evaluating. 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 excavating 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 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. Group II sand bodies, in particular, 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 this group 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 their 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 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 Port Lavaca 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.

Within the mapped portion of the Port Lavaca Atlas, 10 solid-waste disposal sites, including sanitary landfills and open dumps, were in operation in 1968. Nine of these sites are plotted on the *Physical Properties Map* of this Atlas; locations of most of the sites are from a 1968 survey by the Texas State Health Department. The tenth site, located on made land just off Point Comfort, is not indicated on the *Physical Properties Map*. This is an industrial liquid- and solid-waste disposal site operated by the Aluminum Company of America. Of these solid-waste disposal sites, four are within host materials that are physically secure, according to the evaluation of physical properties units. One site is located in land constituting a very poor host, principally highly permeable sands of the Pleistocene barrier-strandplain about 3 miles south of Seadrift. The remaining five sites are located in lands classed as marginal for solid-waste disposal; several of these sites may be secure while others are possibly 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. Sites currently in use should be evaluated. Adequate sites exist for sewage disposal and for miscellaneous waste disposal facilities such as sludge pits.

Within the Port Lavaca map area, approximately 33 percent of the total mapped area provides adequate and secure hosts for waste disposal. About 33 percent of the area is classed as marginal from a physical standpoint, and the remaining 15 percent constitutes poor disposal potential because of a high water table, high soil and substrate permeability, or susceptibility to hurricane-surge flooding. Geographic distribution of secure hosts is good for most major population centers of the Port Lavaca map area (fig. 31).

It should be emphasized that a considerable part of the secure and favorable lands are also those of higher economic value in that they are the principal agricultural lands. 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 of disposal capability 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 where physical uses are involved. When additional, specific information is desired, a number of 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 potential faults to identify areas where surveillance may be necessary. A comparison of bayshore erosion or deposition displayed on the *Active Processes Map* with physical substrate types shown on the *Physical Properties Map* 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 also in conjunction with the *Physical Properties Map* for terrain analysis that is 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 Port Lavaca 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, the Pleistocene meanderbelt sands support extensive areas of oak and brush on prairie grasslands. Pleistocene distributary channel sands and interdistributary muds originally supported 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 meant 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 30 environments and assemblages is noted on table 7.

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

SUBAQUEOUS, PRINCIPALLY BENTHONIC ASSEMBLAGES

SHELF (INNER) AND LOWER SHOREFACE:
Atrina, Dinocardium, Dosinia, Spisula, Tellina (clams); *Architectonica, Oliva, Phalium, Terebra* (snails); *Luidia* (starfish); *Mellita* (sand dollar)

UPPER SHOREFACE:
Anadara, Dinocardium, Donax, Noetia, Nuculana (clams); *Oliva, Polinices, Olivella, Terebra* (snails); *Luidia, Astropecten* (starfish)

INLET AND TIDAL DELTA:
Inlet includes *Mulinia, Anadara, Crassinella, Lucina, Tellidora, Anomia, Donax* (clams); *Ostrea* (oyster); *Turbonilla, Anachis, Polinices* (snails); *Dentalium* (scaphopod); *Luidia* (starfish), *Ophiolepis* (brittle star), *Mellita* (sand dollar); *Astrangia* (coral); bryozoans; tidal delta region includes marsh plants (see Salt-Water Marsh); *Amygdalum, Anomalocardia, Laevicardium, Pseudocyrena* (clams); *Bittium, Caecum, Cerithidea, Cerithium, Vermicularia* (snails); *Uca* (fiddler crab)

BAY MARGIN:
Sparse marine grasses; *Mulinia, Ensis, Nuculana, Mercenaria, Phacoides, Trachycardium, Tagelus, Aequipecten* (clams); *Nassarius, Retusa, Vermicularia* (snails); *Thyone* (echinoderm)

GRASSFLATS:
Diplanthera (Halodule) wrightii, Ruppia maritima, Thalassia testudinum, Syringodium filiforme (marine grasses); *Laevicardium, Anodontia, Anomalocardia* (clams); *Bittium, Cerithium, Melampus, Cerithidea, Crepidula, Littorina* (snails)

OPEN BAY WITH TIDAL INFLUENCE:
Mulinia, Nuculana, Pandora, Anadara (clams); *Crassostrea, Ostrea* (oysters); *Nassarius, Retusa* (snails)

OPEN BAY WITH REEFS:
Similar to Open Bay, with *Crassostrea* and *Ostrea* (oysters), and other reef-associated organisms; *Macoma* (clam) abundant in Lavaca Bay (see Reef)

ENCLOSED BAY:
Macoma, Mulinia, Rangia, Nuculana (clams); *Retusa* (snail); *Amphiodia* (brittle star)

ENCLOSED BAY WITH REEFS:
Similar to enclosed bay, with *Crassostrea* and *Ostrea* (oysters), and other reef-associated organisms (see Reef)

REEF:
Clumps of *Crassostrea* and *Ostrea* (oysters); organisms associated with reefs include *Brachidontes, Anomia, Diplothyra* (clams); *Crepidula, Anachis, Mitrella, Thais* (snails); *Balanus* (barnacle); clionid sponges; bryozoans; *Crangon, Menippe* (crustaceans)

REEF FLANK AND MARGIN:
Broken shell and debris of reef organisms; *Callinectes* (blue crab)

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

SPOIL:
Variable assemblages

FRESH- TO BRACKISH-WATER BODIES:
Marsh plants (see Marsh); *Rangia, Macoma* (clams) in areas with minor tidal influence; *Littorina, Neritina* (snails); *Uca* (fiddler crab), *Cambarus* (crustacean)

*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.

SUBAERIAL, PRINCIPALLY FLORAL ASSEMBLAGES

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

VEGETATED BARRIER FLAT, FOREDUNE RIDGE, BEACH RIDGE, AND VEGETATED FLAT:
Andropogon scoparius littoralis (seacoast bluestem), *Spartina patens* (marshhay cordgrass), *Sesuvium portulacastrum* (sea purslane), *Cenchrus incertus* (sandbur), *Croton punctatus* (beach tea), *Ipomoea* spp. (morningglory), *Panicum* spp., *Helianthus* spp. (sunflower), *Uniola paniculata* (sea-oats); *Ocypode* (ghost crab); coyote, kangaroo rat, other small rodents, snakes, fowl

SANDFLATS:
Salicornia spp. (glasswort), *Distichlis spicata* (saltgrass); blue-green algae; *Uca* (fiddler crab); waterfowl

SALT-WATER MARSH:
Spartina alterniflora (cordgrass), *Batis maritima* (saltwort), *Salicornia* spp. (glasswort), *Suaeda* spp. (seepweed), *Distichlis spicata* (saltgrass), *Borrichia frutescens* (sea-oxeye), *Monanthochloe littoralis* (shoregrass); waterfowl, raccoon, small mammals

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

INLAND FRESH-WATER MARSH:
Juncus spp. (rush), *Scirpus* spp. (bulrush), *Typha* spp. (cattail), *Spartina pectinata* (sloughgrass); nutria, muskrat, otter, alligator, snakes, waterfowl

PRAIRIE GRASSLANDS:
Andropogon spp. (bluestem), *Sorghastrum* spp. (Indiangrass), *Prosopis glandulosa* (mesquite), *Celtis* spp. (hackberry), *Acacia farnesiana* (huisache), chaparral, cactus; *Quercus* spp. (oak) and brush on areas of Pleistocene meanderbelt sand; prairie chicken, quail, some waterfowl, rabbits, rodents

SWAMP:
Sabal minor (dwarf palmetto), *Taxodium distichum* (baldcypress), *Salix* spp. (willow), *Ulmus* spp. (elm), *Persea borbonia* (redbay), *Morus* spp. (mulberry), *Liquidambar styraciflua* (sweetgum), *Quercus nigra* (water oak), *Nyssa biflora* (blackgum), *Vitis* spp. (grape), *Ilex vomitoria* (yaupon); raccoon, opossum, mink, squirrel, fowl, snakes

FREQUENTLY FLOODED FLUVIAL AREAS:
Phragmites communis (common reed), *Juncus* spp. (rush), *Scirpus* spp. (bulrush), *Typha* spp. (cattail), *Salix* spp. (willow); mammals and fowl similar to Swamp

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

FLUVIAL GRASSLAND:
Andropogon spp. (bluestem), *Spartina spartinae* (coastal sacahuista), *Prosopis glandulosa* (mesquite), *Acacia greggii* (catclaw), *Acacia farnesiana* (huisache); opossum, skunk, fox, squirrel, rabbit, armadillo, quail and other fowl, snakes

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

BERMS ALONG BAY-LAGOON MARGIN:
Salt-tolerant grasses (such as *Spartina* spp. (cordgrass), see Salt-Water Marsh); snakes, fowl

BARREN LAND:
No significant vegetation or wildlife

MADE LAND:
Variable assemblages

Subaqueous Environments and Biologic Assemblages

A total of 15 natural environments and biologic assemblages is delineated for the Port Lavaca map area (tables 6 and 7). 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 include: (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 Guadalupe River, Lavaca River, Garcitas, Copano, Placedo, and Willow Creeks as well as other smaller drainage systems, where turbidity is relatively high and salinity markedly reduced; (4) open- and enclosed-bay environments, where reef growth is prominent; and (5) 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.

Studies of benthonic macro-invertebrate assemblages that include all or part of the subaqueous environments in the Port Lavaca map area were the main sources of information consulted for compilation of table 6. These include Ladd and others (1957), Parker (1959, 1960), Bernard and others (1970), J. Andrews (1971), and studies in progress by McGowen and Byrne, Bureau of Economic Geology.

Subaerial Environments and Biologic Assemblages

A total of 15 subaerial environments and associated biologic assemblages is delineated on the Port Lavaca map (tables 6 and 7). These are defined chiefly on the basis of vegetation, though most are coextensive with distinct faunal assemblages, including mammals, reptiles, and birds. Various soil, floral, and faunal studies within the Port Lavaca map area were consulted for the compilation of table 6, including Carter (1911), Carter and others (1927), Blair (1950), Gould (1962), and Mallouf and others (1973).

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 of 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 of the lower parts of major river valleys (fig. 26). 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 streams in the Port Lavaca map area. Sinuous, abandoned channels, inland lakes, and some active channels on the coastal upland support a local water-tolerant flora.

The coastal uplands, underlain chiefly by Pleistocene sediments, support an extensive prairie grassland, but much of the grassland has been converted into agricultural lands, particularly north of the Guadalupe River and in the Tivoli-Austwell area of Refugio County. Oak mottes and groves are prominently developed on the older barrier-strandplain sands of Blackjack and Lamar Peninsulas.

The vegetation of the coastal barriers comprises a distinct complex. Inland from the beach, which is 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*. Behind the fore-island dunes is a broad area of ridges and swales. Ridges are covered with grasses (among them Indiangrass and seacoast bluestem), shrubs, and cacti. Swales commonly contain fresh-water marshes. Beyond the ridge-and-swale zone, the back-island area is low and relatively featureless; it is adjacent to the wind-tidal flat. Grass dominates this area; one of the common grasses is coastal sacahuista. Wind-tidal flats are largely barren mud and sand surfaces that are periodically covered with blue-green algal mats and scattered marsh plants. Salt-water marsh forms bayward of the tidal flats and vegetated back-island areas.

Table 7. Areal extent of individual units shown on Environments and Biologic Assemblages Map, Port Lavaca map area, Texas.† (Table pertains only to that part of each county occurring within the Port Lavaca 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°	Bee°	Calhoun°	Goliad°	Jackson°	Matagorda°	Refugio°	Victoria°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Port Lavaca map area (excluding offshore area)	Percentage of Port Lavaca 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‰), mottled mud, diverse infauna and benthonic assemblage, depth >30 feet	–	–	–	–	–	–	–	–	–	–	–
Lower shoreface, open marine, normal salinity (35‰), moderate wave action, sand, silt, and mud, infauna, mud shrimp, molluscs, depth 15 to 30 feet	–	–	–	–	–	–	–	–	35.7	–	–
Upper shoreface, strong wave action, surf zone, shifting sands, normal salinity (35‰), molluscs, sand dollars and starfish, crustaceans, depth low tide to 15 feet	–	–	–	–	–	–	–	–	20.8	–	–
Inlet and tidal delta, sand, mud, and shell, diverse epifauna, molluscs, echinoderms, coral and bryozoans, clionid sponges, depth <40 feet	0.3	–	19.6	–	0	3.7	0	0	20.8	23.6	0.9
Bay margin, shoal water bordering bay, sand to mud, sparse marine grass, variable salinity and temperature, molluscs, depth to 3 feet	13.2	–	46.0	–	0.4	2.0	1.7	0	–	63.3	2.3
Grassflats, shallow bay margin with dense grasses, salinity 25 to 35‰, moderately diverse mollusc assemblage, depth <5 feet	1.8	–	9.5	–	0	0.5	0	0	–	11.8	0.4
Open bay, lower end of bay with tidal influence, salinity 20 to 35‰, mottled mud, high species diversity, infauna, molluscs, depth 6 to 10 feet	0	–	74.0	–	0	61.2	0	0	–	135.2	5.0
Open bay with reefs, similar to open bay with scattered clumps of oyster reef, depth 3 to 10 feet	36.0	–	61.0	–	0	0	0	0	–	97.0	3.6
Enclosed bay, away from tidal or river influence, mottled mud, similar to open bay but reduced species diversity, clams, depth 3 to 8 feet	5.5	–	28.5	–	4.8	0	0	0	–	38.8	1.4
Enclosed bay with reef, similar to enclosed bay, with scattered clumps of oyster reefs, depth 3 to 8 feet	13.5	–	63.0	–	0	0	4.2	0	–	80.7	3.0
Reef, dense oysters, distinct mounds or ridges, commonly aligned normal to circulation, firm substrate, salinity 10 to 30‰, depth 8 feet or less, associated molluscs, coral, bryozoans	3.0	–	6.0	–	0	0.5	0.3	0	–	9.8	0.4
Reef flank and margin, level bottom between reefs, few clumps of oysters, sand, mud, and broken shell, salinity 10 to 30‰, depth 3 to 6 feet	6.9	–	14.5	–	0	0.5	0.3	0	–	22.2	0.8
River-influenced bay, low salinity (<10‰), near fresh-water discharge, laminated mud, mottled mud, low species diversity with molluscs, crustaceans, depth 3 to 7 feet	3.5	–	47.0	–	0	0	0.3	0.5	–	51.3	1.9
Subaqueous and subaerial spoil, artificial, sand and silt, poorly sorted, assemblage depends on age of spoil, depth and elevation variable	4.3	0	20.0	0	0.5	4.8	0	0	0.7	29.6	1.1
Fresh- to brackish-water bodies, landlocked ponds and lakes, variable substrates, inland bodies fresh, coastal bodies temporarily brackish or saline	5.6	0	26.7	1.2	4.5	1.3	4.0	7.0	–	50.3	1.9

SUBAERIAL ENVIRONMENTS AND ASSEMBLAGES (Principally floral assemblages)											
Beach, low tide to 5 feet above sea level, swash zone, high energy, sand, shell debris, infauna, back-beach sea-oats and halophytes, dunes, ghost crab	0.5	–	6.0	–	0	2.5	0	0	–	9.0	0.3
Vegetated barrier flat, foredune ridge, beach ridge, and vegetated flat, relief 5 to 15 feet, salt-tolerant grasses, mesquite and live-oak trees, ghost crab, small rodents, snakes, fowl	9.7	–	37.2	–	0	5.6	0	0	–	52.5	1.9
Sandflats, a few inches above mean sea level, undulatory sand surface with blue-green algal mats, thin halite film, marsh plants rare	16.6	–	11.2	–	0	1.3	0	0	–	29.1	1.1
Salt-water marsh, frequently inundated by tides, sand, muddy sand to mud, cordgrass, grasswort, seepweed, sea-oxeye, mammals, fowl	13.0	–	29.0	–	5.0	0.5	4.5	2.0	–	54.0	2.0
Brackish- to fresh-water marsh, sand, muddy sand, and mud, grades into salt marsh, coastal sacahuista, marshhay cordgrass, big cordgrass, bulrush, cattail, rush, mammals, snakes, fowl	1.2	0	2.0	0	0.5	0	0.8	0	–	4.5	0.2
Inland fresh-water marsh, sand and mud, rush, bulrush, cattail, sloughgrass, mammals, fowl	3.5	0	17.5	0.5	3.3	0	1.3	2.5	–	28.6	1.1
Prairie grasslands, flat to gently rolling upland, prairie grasses, mud and sand substrate, much of area cultivated, bluestem, Indiangrass, sparse mesquite, hackberry, huisache, chaparral, cactus, fowl, small mammals	108.2	2.7	363.6	76.0	223.0	0.3	429.8	329.0	–	1532.6	56.6
Swamp, drainage poor, sediment and water by overbanking fluvial systems, dwarf palmetto, cypress, elm, bay, mulberry, water oak, gum, grape, yaupon, raccoon, opossum, some mink and squirrel, fowl, snakes	0.1	0	0.6	0.5	0.6	0	0.3	0.5	–	2.6	0.1
Frequently flooded fluvial areas, water-tolerant plants, mud to sand, fresh-water reeds, rushes, and trees, mammals, fowl	0.5	0	29.6	12.9	16.7	0	52.9	33.7	–	146.3	5.4
Fluvial woodland, water-tolerant hardwoods, pecan, hickory, live oak, water oak, blackjack oak, elm, hackberry, sweetgum, red haw, ash, carpetgrass, Bermudagrass, greenbriar, yaupon, grape, mammals, fowl, snakes	1.2	0.5	8.0	7.0	19.3	0	18.1	42.8	–	96.9	3.6
Fluvial grassland, grass and brush, bluestem, sacahuista, mesquite, catclaw, huisache, mammals, fowl, snakes	0	0.3	1.7	4.0	12.0	0	9.0	27.0	–	54.0	2.0
Oak mottes and groves, live oak and dwarfed live oak, permeable and well-drained, salt spray may kill leaves on windward side, trees grow rapidly leeward producing sculptured oak mottes; rodents, snakes	14.0	0	2.3	0	3.0	0	1.6	5.0	–	25.9	1.0
Berms along bay-lagoon margin, storm deposits, sand, shell, local salt- and brackish-water marsh in swales and ponds, salt-tolerant grasses, snakes, fowl	0.3	–	5.0	–	0.3	0.3	0	0	–	5.9	0.2
Barren land, small bayside beaches, sandflats	8.8	0	11.8	0	0.1	0	25.6	0	–	46.3	1.7
Made land, filled, graded, sand, mud, and shell, locally some vegetation	0	0	0.3	0	0	0	0	0	–	0.3	.01

†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.

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 especially in the upper Coastal Zone, but also in other areas of the coast, including the Corpus Christi and Brownsville-Harlingen regions. Second, it is an area endowed with extensive mineral resources—notably oil, gas, and chemical raw materials (sulfur, salt, and brine)—supporting major petroleum-refining and petrochemical centers. 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.

Many of the factors that have led to diverse land and water use in the Texas Coastal Zone have also led to current and potential 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 routes, a landfill area for real-estate developments, and as part of a waste disposal system. 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 with the shore zone largely privately owned and the estuaries and offshore areas publicly owned. Because the legal boundary is also a high-energy geological boundary, actions taken by one proprietor have an immediate and significant effect on others.

Since the number of people in the Port Lavaca map area is not as large as elsewhere along the Texas coast, problems of conflicting land use are not intensified by large population concentrations. With population growth, however, such land use conflicts may become more of a problem.

Current land use in the Port Lavaca map area is classed in 18 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*. Base materials available for the entire area are generally about a decade old (fig. 3A). Where more recent, detailed base materials existed, they were used to bring land use as up-to-date as possible; information should be updated at least every decade, or as often as new coastwide aerial photography becomes available.

Major classes of current or potential land use in the Port Lavaca area include agricultural lands, timber or wooded lands, marshes or grassed wetlands, urban lands, government lands (State and Federal), formally designated wildlife refuges, general recreational lands, made and reclaimed lands, dredged spoil and barren lands, 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 Port Lavaca map area of 183 oil and gas fields, 24 educational sites, 6 pits and quarries, 7 sludge pits, 2 sewage treatment and disposal sites, 10 solid-waste disposal sites (9 shown on map), and 15 airfields. Major pipeline, transportation-navigation, and irrigation-drainage networks are indicated.

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

Agricultural Lands

Approximately 63 percent of the Port Lavaca map area is used for agriculture. Of total agricultural lands, approximately 27 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 rice and cotton. A relatively small amount of hay and grain is produced to support beef production and dairying, the main uses 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 136 square miles, or 5 percent of the Port Lavaca map area, are wooded and are largely associated with the various river and stream systems, especially where drainage is developed on sandy soils and substrates. The major wooded land unit occurs along the smaller streams of the coastal uplands and along the floodplains and lower terraces of the San Antonio, Guadalupe, Lavaca, and Navidad Rivers and Garcitas Creek. Principal vegetation includes water-

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

SPECIAL-USE ENVIRONMENTAL MAP UNITS	Aransas°	Bee°	Calhoun°	Goliad°	Jackson°	Matagorda°	Refugio°	Victoria°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Port Lavaca map area (excluding offshore area)	Percentage of Port Lavaca 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	5.0	0	151.0	0.3	103.0	0	72.5	135.0	–	466.8	17.2
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 marine deltaic sand and mud, grass- and scrub-covered Pleistocene fluvial-deltaic sand and mud	74.4	2.0	236.0	92.5	142.8	5.0	434.0	242.7	–	1229.4	45.4
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	3.5	1.5	13.3	7.4	26.7	0	24.5	56.5	–	133.4	4.9
Swamp-timber, continually wet floodplains and levees of Modern fluvial systems, water table near or slightly above surface, poor drainage, palmetto, black willow, and associated hardwoods, abundant wildlife, informal wildlife preserve	0	0	0	0.3	0	1.0	0.5	1.0	–	2.8	0.1
Saline and brackish-water marsh, locally inundated by tides, water table may be locally above surface, developed on back side of barrier islands, distal fringes of Pleistocene deltas, Modern delta plain and bayfill areas, common cordgrass, saltgrass, sacahuista, cattail, bulrush, and other marsh plants, some cattle on drier fringes, abundant wildlife, numerous tidal creeks	8.0	0	28.4	0	4.5	0	5.5	3.5	–	49.9	1.8
Fresh-water marsh, continually wet floodplains, abandoned channels and inland parts of Modern deltas, swales, and drainage courses on Pleistocene barrier-strandplain, and depressions on Pleistocene delta-front and delta areas, vegetated with rush, cattail, and sloughgrass, wildlife locally abundant	0.2	0	30.0	0.3	4.5	0	2.5	1.5	–	39.0	1.4
Residential-urban, commercial and residential development, includes towns and small rural villages and settlements, may include some minor industrial areas	0.2	0	4.0	0	2.0	.01	3.0	1.5	–	10.71	0.4
Industrial, municipal works, chemical and metal-refining plants, and petroleum facilities	0.1	0	0.5	0.1	0.5	0	0.3	0.8	–	2.3	0.08
Undifferentiated urban land, undeveloped tracts, greenbelts, cemeteries	0	0	0.3	0	0.3	0	0.1	0	–	0.7	0.03
Park and recreational facility, formally defined state and most county and municipal facilities such as ball parks, athletic fields, golf courses, includes some private facilities	0.5	0	1.5	0	0	0	0	0	–	2.0	0.07
Government land, excluding recreational and educational, includes Department of Defense property (Matagorda Island airbase and bombing-gunnery range), major tracts only	0	0	45.5	0	0	0	0	0	–	45.5	1.7
Wildlife refuge, formally defined federal protection area, restricted access	68.5	0	2.5	0	0	0	0.5	0	–	71.5	2.6
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	0.5	0	0.5	0	0	2.7	0	0	–	3.7	0.1
Made land, filled, graded, developed over shallow bay areas	0	0	0.3	0	0	0	0	0	–	0.3	0.01
Spoil, subaerial land resulting from dredging, some waterfowl, locally used for fishing sites, relatively barren areas within bays and coastal marshes	1.5	0	7.0	0	0.5	0.3	0	0	–	9.3	0.3
Barren land, commonly sand, mostly on back side of barrier island and marginal to Pleistocene barrier-strandplain, commonly associated with marsh, some waterfowl	18.0	0	14.5	0	0	1.8	0.5	0	–	34.8	1.3
Oil or gas field	22.9[17]■	0	85.3[46]■	1.2[5]■	54.6[33]■	0.3[1]■	96.6[21]■	70.4[60]■	–	331.3[183]■	12.2
Educational site, public school■	0	0	6	1	3	0	6	8	–	24	–
Pit or quarry, commonly shelly beach and delta-front sand■	0	0	6	0	0	0	0	0	–	6	–
Sludge pit or miscellaneous waste disposal site, may be abandoned■	0	0	6	0	0	0	0	1	–	7	–
Sewage disposal site, liquid effluent, normally treated■	0	0	1	0	1	0	0	0	–	2	–
Solid-waste disposal site, sanitary landfill, and open dumps■	0	0	4	0	1	0	3	1	–	9	–
Pipeline, major lines only, incomplete	–	–	–	–	–	–	–	–	–	–	–
Airfield, paved, graded, or sod■	0	0	10	0	1	0	3	1	–	15	–
Artificial reservoir, flood control, municipal water supply, industrial and agricultural purposes, or recreation	1.0	0	4.8	0	0.5	0	0	4.0	–	10.3	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.

tolerant hardwood, pecan, hickory, live oak, water oak, blackjack oak, elm, hackberry, sweet gum, red haw, and ash. Swamp vegetation develops in areas with a permanently high water table, primarily along lowlands of the Guadalupe River. Swamps include cypress, palmetto, elm, black willow, mulberry, water oak, and gum. Oak mottes are developed extensively on the Pleistocene barrier-strandplain sands on Blackjack and Lamar Peninsulas.

Current use of wooded lands in the Port Lavaca area for commercial timbering is very slight. Locally, small areas have been cleared for range and cultivation. At present, the principal use for the timber and woodlands of the area is as a wildlife habitat.

Marshes and Grassed Wetlands

Marshlands are extensive along coastal and river lowlands in the Port Lavaca area, representing about 89 square miles or more than 3 percent of the mapped area. Salt- or brackish-water marshes comprise about 56 percent of these wetlands; principal distribution is in the lowermost parts of the Guadalupe and Lavaca Rivers and Garcitas Creek, along the mainland bay shores, and along the back sides of the coastal barrier islands. Fresh-water marshes comprise about 44 percent of the marshlands in the area and develop locally along inland parts of most waterways and in elongate depressions and swales on the older coastal barrier-strandplain and sheet sands between Seadrift and Port O'Connor.

Oil and gas wells are located in some of the marshlands. Principal current use is for a wildlife habitat; marshes are present in the Aransas National Wildlife Refuge in Aransas, Refugio, and Calhoun Counties. The coastal marshes are areas of high organic productivity, second only to sugar cane fields in 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

Small population centers are numerous in the mapped area included in the Port Lavaca Atlas. Just under 16 square miles, or less than 1 percent of the map area, are classed as urban-industrial. The larger centers include Port Lavaca, Edna, Refugio, and Bloomington, and smaller urban areas include Lamar, Austwell, Tivoli, Placedo, Seadrift, Port O'Connor, Inez, Vanderbilt, Lolita, and Point Comfort. 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) industrial areas, including municipal works, petroleum facilities, chemical and metal-refining 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 69 percent is residential-urban land, over 14 percent is classed as industrial land, 12 percent is devoted to parks and recreational land, and about 5 percent is undifferentiated urban land. Principal industrial land is concentrated at petrochemical complexes north of Long Mott and south of Dernal and at the Aluminum Company of America's metal-refining operation at Point Comfort. Large tank farms exist at several places throughout the mapped area.

Other Land Use Categories

Other types of current land use comprise more than 18 percent of the total mapped area. The 183 oil and gas fields shown on the Port Lavaca map cover an area exceeding 330 square miles, more than 12 percent of the total mapped area. Much of this land, however, is used simultaneously for other purposes. More than 45 square miles exist as government land, including the Federal government's Matagorda Island Air Force Base and Bombing and Gunnery Range (presently inactive—ultimate disposition of land is undecided). Only major tracts of government land are included in this category.

Approximately 72 square miles of land within the Port Lavaca map area are formally designated wildlife refuges with restricted access—the Aransas National Wildlife Refuge on Blackjack Peninsula in Aransas, Calhoun, and Refugio Counties. General recreational lands include the public beaches along the Gulf side of the coastal barrier islands, totaling 3.7 square miles or only 0.1 percent of the area. Only 0.3 square mile of made land occur in the Port Lavaca map area. The Aluminum Company of America maintains a solid- and liquid-waste disposal site on made land reclaimed from spoil dredged for the deep-water port at Point Comfort. Barren sandflats along the back side of the barrier islands and on the north shore of San Antonio Bay have little direct use, but comprise 34 square miles of land area. Subaerial spoil from dredging, situated mainly along the land cuts of the Intracoastal Waterway, Ferry Channel, Victoria Channel, Port Lavaca Channel, and the Matagorda Ship Channel, also has limited use. Surface reservoirs constructed for flood control, irrigation, municipal and industrial water supplies, and recreation occupy about 10 square miles.

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 neither conflict with nor 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 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 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 for lime. The abundance of these chemical and petroleum raw materials and their occurrence in a zone with ocean access make this area one of the major petrochemical and petroleum-refining centers of the world. Most of the major refining and chemical companies have plants in the upper Coastal Zone, including the Galveston-Houston and Beaumont-Port Arthur industrial areas.

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 in the Port Lavaca area. Also shown are existing pits and quarries, petrochemical plants, and metal-refining facilities. The energy-distribution network is outlined by all major pipeline transmission facilities, major power or utility transmission lines, and existing power-generation stations. Statistical data for each map unit are shown in table 9.

Oil and Natural Gas

As of January 1, 1974, 148 oil and gas fields were producing within the mapped area. Major active and inactive fields are indicated on the *Mineral and Energy Resources Map*. Of the 148 active fields, 70 produce both oil and gas, 34 are oil fields, and 44 produce only gas. Most of the producing reservoirs are traps associated with down-to-basin gravity faults along two major flexure fault zones trending nearly parallel to the present shoreline; the chief producing unit is the Frio Formation (fig. 32). Of these 148 fields, 26 are developed below the waters of Matagorda, Lavaca, Keller, Carancahua, Espiritu Santo, San Antonio, Aransas, St. Charles, and Copano Bays; the remainder are on land. Oil and gas platforms, not shown on the map, are especially common in Lavaca and Matagorda Bays. No significant production exists within the mapped offshore area, though some production comes from Federal blocks farther offshore.

Cumulative production of crude oil in the Port Lavaca map area was approximately 1.3 billion barrels through 1973. Crude oil production in 1973 was over 60 million barrels from 104 fields and more than 680 pay zones. Three fields in the area—Tom O'Connor and Greta in Refugio County and West Ranch in Jackson County—have each produced a total of more than 100 million barrels of oil as of January 1, 1974.

Gas is produced from a total of 114 fields in the mapped area, and annual production currently exceeds 170 billion cubic feet. Nine fields—Fagan, Greta, Heyser, Huff, Lake Pasture, Magnolia Beach-Keller Bay, McFaddin, Tom O'Connor, and West Ranch—each produced over 5 billion cubic feet of gas in 1973.

The production of oil, natural gas, and natural gas liquids figures very prominently in the total economy of the Port Lavaca area. In addition to the direct value of these minerals, oil and gas production supports major industries within the map area and elsewhere along the Coastal Zone by providing readily available fuels and raw materials. Approximately 300 square miles of land and water within the map area are included in the 148 active fields; the major nonagricultural land use in the Port Lavaca map area is directly or indirectly related to oil and gas production.

Table 9. Areal extent and number of individual units shown on Mineral and Energy Resources Map, Port Lavaca map area, Texas.† (Table pertains only to that part of each county occurring within the Port Lavaca 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°	Bee°	Calhoun°	Goliad°	Jackson°	Matagorda°	Refugio°	Victoria°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Port Lavaca map area (excluding offshore area)	Percentage of Port Lavaca 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, subaerial and subaqueous spoil; see *Physical Properties Map* for specific description	122.2	3.5	324.6	60.7	110.6	15.3	279.6	213.0	0.7	1129.5	41.7
Mud, includes all subaerial muddy deposits, floodbasin mud, interdistributary mud, delta-plain mud, marsh and swamp facies, filled lakes; see *Physical Properties Map* for specific description	59.7	0	221.2	40.2	173.7	0	264.3	229.5	–	988.6	36.5
Oyster reef, areas of prominent oyster colonies, includes both live and dead oysters; buried reef not included	3.0	–	6.0	–	0	0.5	0.3	0	–	9.8	0.4
Pit or quarry, commonly shelly beach and delta-front sands■	0	0	6	0	0	0	0	0	–	6	–
Oyster shell, dredged from bay bottom to 30 feet below bay bottom, shipped by barge, source of lime for cement, locally used in construction; in San Antonio Bay, production is from areas between living reefs; in Matagorda Bay, production is from buried, relict shell ("mud shell") where significant living reefs are absent■	0	–	2	–	0	0	0	0	–	2	–
Oil or gas field	22.9[17]■	0	85.3[46]■	1.2[5]■	54.6[33]■	0.3[1]■	96.6[21]■	70.4[60]■	–	331.3[183]■	12.2
Aluminum plant■	0	0	1	0	0	0	0	0	–	1	–
Petrochemical plant■	0	0	1	0	0	0	0	1	–	2	–
Power-generation plant■	0	0	1	0	0	0	0	0	–	1	–
Utility line or cable, major power transmission line, incomplete	–	–	–	–	–	–	–	–	–	–	–
Pipeline, major lines only, incomplete	–	–	–	–	–	–	–	–	–	–	–

†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.

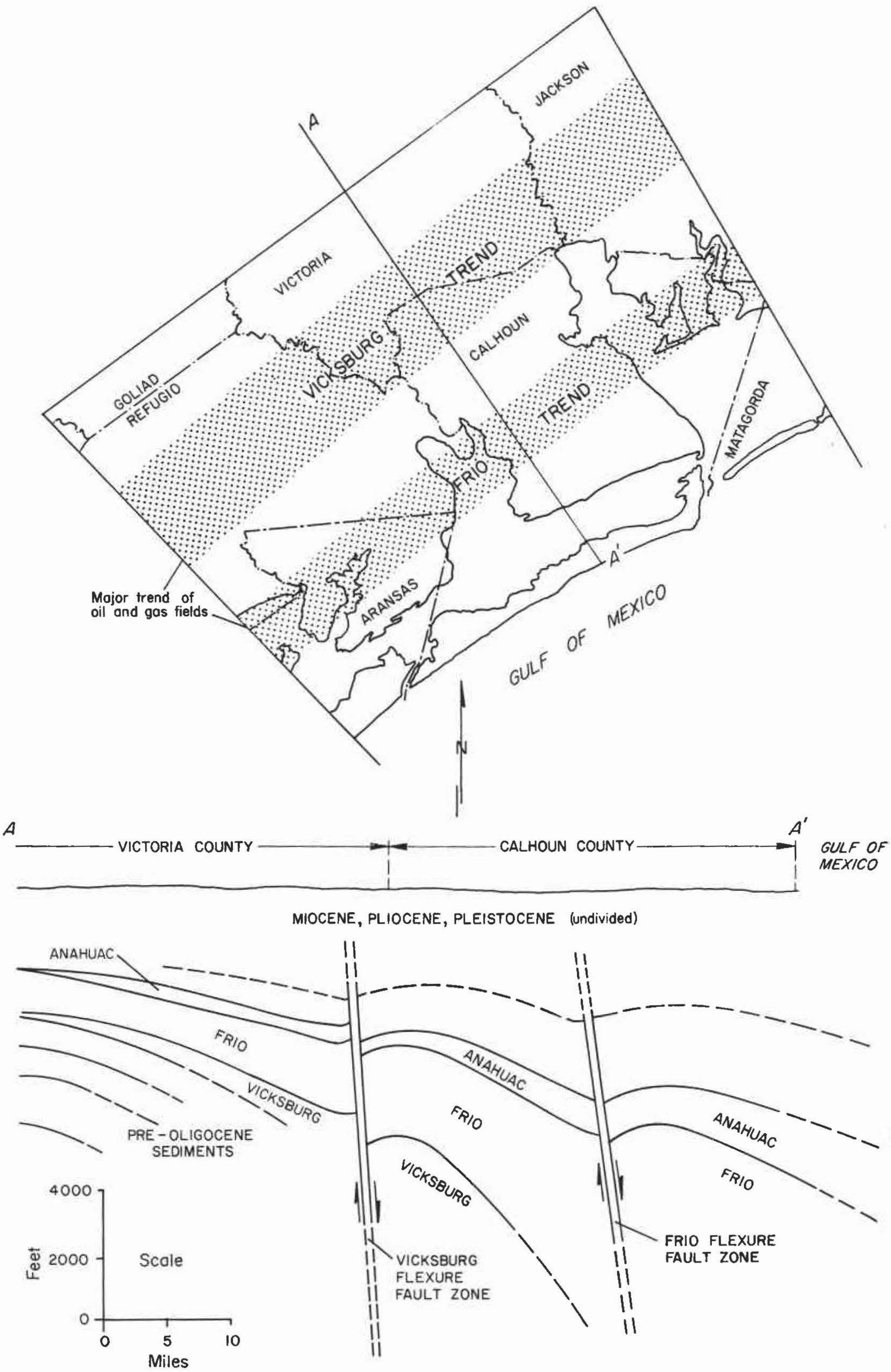


Figure 32. Trends of oil and gas fields, Port Lavaca map area. Trends of productive fields parallel major flexure fault zones and related structures. Flexure fault zones represent down-to-basin faults formed contemporaneously with deposition of sediments. Frio Formation is the major oil-producing unit in the mapped area. Modified from Stoneham, 1953.

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, with physical properties suitable for use as aggregate and road base and chemical properties suitable for lime, cement, and other chemical uses, has been a locally available substitute for these resources. 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 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 occur either 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, and shell was first used in the manufacture of cement in 1916 and of lime in 1929. It 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 calcined 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, mostly from Galveston and Trinity Bays, exceeds 325 million cubic yards. At present, shell is being dredged only in Matagorda Bay from buried, relict shell deposits. San Antonio Bay shell production, shown on the *Mineral and Energy Resources Map*, is presently halted.

About half 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. Current production of cement from shell in Texas accounts for approximately half the shell produced in the Port Lavaca map area.

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.

The *Mineral and Energy Resources Map*, along with certain other maps of this Atlas, shows the distribution of oyster reefs within the Port Lavaca map area. The reefs delineated are those that are exposed on the bay bottom or that form bathymetric highs; they cover a total of nearly 10 square miles. The largest reefs are located in San Antonio, Lavaca, Matagorda, and Espiritu Santo Bays. Smaller reefs occur in parts of Copano, Aransas, Ayres, and Carlos Bays. A few reefs have developed in the bays near the mouths of small rivers.

No adequate studies of shell reserves in the Texas Coastal Zone have been published. Estimates of reserves in Galveston and Trinity Bays, northeast of the Port Lavaca map area, range from 40 to 90 million cubic yards. Several factors preclude a reasonable estimate of reserves: (1) inadequate field investigation (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 (e.g., gravel and crushed stone). This scarcity exists along with the high consumption of these materials in the heavily populated and industrialized areas of the Coastal Zone; therefore, a large volume of these materials must be imported from inland sources. A partial substitute for aggregate exists in local shell deposits, and local supplies of fine-grained fill sand are plentiful, but gravel and crushed stone must be imported.

Most of the gravel supply of the Coastal Zone 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 and the nearest inland deposits) are rapidly becoming depleted; future supplies must come from sources farther inland. Although the unit value for bulk constructional materials is 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 essential to the heavy construction of the industrial and urban parts of the area, and their availability at the lowest possible cost is desirable.

Shell is the only constructional raw material produced on a significant scale within the Port Lavaca map area. Pits south of Magnolia Beach testify to local attempts to produce shell aggregate and fill sand but these operations are now abandoned. A possible substitute for natural aggregate can be 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 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.

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). The closest market for such upgraded sands would be the Houston area, but there is little potential for any sand deposits in the Port Lavaca area being used to supply these upper Coastal Zone markets. Modern beach and dune sands near this 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 occur in the Port Lavaca map area and might be useful in the manufacture of certain clay products, including brick and tile. Though reserves of common clay in the area are very large, no production is known.

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

Cement and lime.—No cement is currently manufactured in the Port Lavaca map area. Approximately half the shell dredged there is used to manufacture cement at plants not within the mapped area. Lime is produced from shell by burning this natural calcium carbonate to calcium oxide. The major consumer of lime in the Port Lavaca area is the aluminum refinery at Point Comfort. Central Texas limestone is also imported to the Coastal Zone to meet the demand for natural calcium carbonate.

Other Major Industries

Bauxite ore is imported to the Aluminum Company of America's Point Comfort plant to produce aluminum metal. Other products of the plant include chlorine, caustic soda, aluminum fluoride, cryolite, and carbon briquettes.

Two major petrochemical complexes occur within the Port Lavaca map area. Union Carbide Corporation operates a plant north of Seadrift in Calhoun County at which a variety of products are manufactured, including acetylene, miscellaneous synthetic organic chemicals, thermoplastic resins, and liquified refinery gases. Four miles northwest of Bloomington, a plant which produces polyethylene, nitric acid, adiponitrile, and other synthetic organic products is operated by E. I. Du Pont de Nemours and Co., Inc.

Summary

The Port Lavaca 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 shell, to those present in almost limitless supply, such as common clay and fill sand. Petroleum and natural gas constitute the vast bulk of the area's mineral wealth. Reserves of oil and natural gas remain significant, though in recent years discovered additions to reserves have not kept pace with production. The decline and ultimate depletion of these basic raw materials will call for a fundamental readjustment of the 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 characterization of bay and Gulf shorelines in their present state—erosional, depositional, or stabilized. The *Active Processes Map* also delineates areas of oyster reef deposition, wind-tidal flooding, eolian sand transport and deposition, 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. 12). In the mapped portion of the Port Lavaca area, a total of 496 square miles of lowlands was flooded by storm surges of Hurricane *Carla* in 1961; this is approximately 18 percent of the entire mapped area. Hurricane *Beulah* (1967), a hurricane of less intensity in the upper coast than *Carla*, resulted in the flooding of approximately 249 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 to detailed topographic maps. 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 San Antonio Bay could conceivably flood more than 850 square miles of the map area if the hurricane-tidal surge reached 25 feet above mean sea level.

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 impact on the Coastal Zone is given elsewhere in the text of this Atlas. Coastal hazards, including hurricane flooding and shoreline erosion, have been described in a report by 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. 11), which are commonly altered by a variety of shoreline activities involving construction. On the *Active Processes Map*, approximately 444 linear miles of bay and Gulf shorelines of the Port Lavaca map area are characterized by a specific, dominant active process.

Shoreline changes indicated on the *Active Processes Map* of the Port Lavaca 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 others, in preparation; Morton and Pieper, in preparation) and bay and Gulf shorelines in the Matagorda Bay region (McGowen and Brewton, 1975) 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* in the Port Lavaca Atlas reflects the state of knowledge concerning 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 more detailed, comprehensive historical shoreline monitoring programs that are currently being completed. With such programs (Morton and others, in preparation; Morton and Pieper, in preparation; McGowen and Brewton, 1975), refinement of available knowledge of bay and Gulf shoreline conditions is now and will be possible. For example, observational data suggested that the west shoreline of Pass Cavallo was predominantly accretionary; however, historical monitoring data based on several vintages of aerial photography and topographic maps extending back to 1856, as well as extensive field observations and measurements (1971-1972), indicate that this shoreline segment has been dominantly erosional over the past 119 years. Similar refinement of our knowledge of shoreline conditions in the Port Lavaca map area can be made at several other places in Lavaca, Matagorda,

Table 10. Areal extent, length, and number of individual units shown on Active Processes Map, Port Lavaca map area, Texas.† (Table pertains only to that part of each county occurring within the Port Lavaca 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°	Bee°	Calhoun°	Goliad°	Jackson°	Matagorda°	Refugio°	Victoria°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Port Lavaca map area (excluding offshore area)	Percentage of Port Lavaca 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	–	–	–	–	–	–	–	–	9.3	–	–
Area of moderate erosion or scour to slight deposition, natural tidal channels shift laterally by cut and fill	0	–	5.1	–	0	0.5	0	0	0.5	5.6	0.2
Areas of rapid deposition, predominantly tidal delta accretion and aggradation or prodelta progradation	0	–	18.6	–	0.5	2.0	0	0.5	19.3	21.6	0.8
Site of active or potential hurricane washover channel■	1	–	0	–	–	2	–	–	–	3	–
Shoreline, erosional, eolian processes active along Gulf side of barriers▲	36.8	–	92.4	–	16.4	22.0	15.6	0.8	–	184.0	–
Shoreline, depositional, accretionary, eolian processes active along Gulf side of barriers▲	24.8	–	146.8	–	12.0	3.2	0.4	0.8	–	188.0	–
Shoreline in depositional-erosional equilibrium, eolian processes active along Gulf side of barriers▲	32.8	–	103.6	–	2.0	0	3.2	0	–	141.6	–
Shoreline stabilized by seawall, dredging, or other man-made means▲	0	–	0	–	0	1.6	0	0	–	1.6	–
Area of slow to moderate deposition within bays, predominantly suspension in deeper bay, accretion in some marginal areas	77.0	–	315.7	–	4.6	63.0	6.6	0	–	466.9	17.2
Area of active reworking and redistribution of subaqueous spoil by waves and currents	2.8	–	12.8	–	0	4.8	0	0	0.7	20.4	0.8
Oyster reef deposition, predominantly vertical growth with some lateral growth, mapped reefs not necessarily all live communities	3.0	–	6.0	–	0	0.5	0.3	0	–	9.8	0.5
Area of wind-tidal flooding, commonly generated by persistent north (winter) or southeast (summer) winds, alternating submergence and emergence, local areas of wind-driven sand transport during exposure, algal mat development during submergence	19.9	–	17.1	–	0	1.5	0.8	0	–	39.3	1.5
Eolian sand dunes, barrier-island blowout dunes and small back-island dunes on St. Joseph Island, areas of active eolian sand transport and deposition	0.3	0	0.5	0	0	0	0	0	–	0.8	0.03
Inland lake, area of wave erosion and deposition, beach ridge accretion along southern margin and erosion and recession along north and northeast shore, resulting from waves generated by north (winter) and southeast (summer) winds, processes may be presently inactive, ephemeral, some areas artificially drained▲	0	0	0	0	0	0	6.8*/4.4+	0	–	6.8*/4.4+	–
Area inundated by marine water, Hurricane *Carla* storm-surge tide	83.6	0	328.2	0	43.6	8.3	20.4	11.7	–	495.8	18.3
Hurricane *Carla* recording tide gage, high watermark elevation, datum mean sea level■	0	–	1	–	0	0	0	0	–	1	–
Hurricane *Carla* recording site, still high watermark elevation, datum mean sea level■	1	–	12	–	0	1	0	0	–	14	–
Hurricane *Carla* storm-surge and river-flooding debris or drift-line elevation, datum mean sea level■	4	–	6	–	4	0	0	0	–	14	–
Area inundated by marine water, Hurricane *Beulah* storm-surge tide	62.0	0	132.1	0	28.1	6.5	16.8	3.7	–	249.2	9.2
Area inundated by river flooding and rainfall runoff, Hurricane *Beulah* rainfall and aftermath storms, local ponding in depressions	4.1	1.0	11.5	15.0	13.3	0	72.4	86.1	–	203.4	7.5
Hurricane *Beulah* recording tide or river gage, high watermark elevation, datum mean sea level■	1	–	7	–	1	1	2	0	–	12	–
Hurricane *Beulah* recording site, still high watermark elevation, datum mean sea level■	3	–	6	–	0	0	2	0	–	11	–
Hurricane *Beulah* storm-surge and river-flooding debris or drift-line elevation, datum mean sea level■	5	–	4	1	3	0	6	2	–	21	–

†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.
*Inland lake erosional shoreline.
+Inland lake depositional shoreline.

Keller, and Carancahua Bays where sufficient historical monitoring data now exist. However, updated information on bay shoreline conditions in San Antonio, Espiritu Santo, Hynes, Guadalupe, Ayres, Mesquite, Carlos, Aransas, St. Charles, and Copano Bays will necessarily await future detailed monitoring programs. Initiation and completion of historical shoreline monitoring 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 Port Lavaca map area, less than 2 linear miles of shoreline have been stabilized artificially, principally by dredging Matagorda Ship Channel through Matagorda Peninsula. The shoreline of made land west of Point Comfort is artificially maintained by spoil emplacement; spoil reworking, however, results in accreting shorelines. Approximately 71 linear miles, or about 16 percent of the total shoreline of the map area, are mapped as naturally stabilized or essentially in depositional-erosional equilibrium (based on earlier observational data). The principal natural agent of shoreline stabilization is extensive vegetation in salt marshes, especially where this vegetation is developed on compact clay substrates. Much of the shoreline on the back sides of Matagorda and St. Joseph Islands is stabilized in this manner. Shorelines on small, protected inlets are generally stable, including such areas as Copano, St. Charles, Sundown, Chocolate, Keller, and Carancahua Bays, and Mission, Green, and Powderhorn Lakes. In addition, these shorelines are bordered by salt marshes. A large stretch of the Gulf shoreline extending southwest from the area of Matagorda Island Air Force Base to near Aransas Pass (not on the map) is mapped as an in-equilibrium shoreline despite the relatively high energy of the open coast. Along this shoreline, sand is pushed onshore from the inner part of the shelf and, until recent times, was carried to the southwest by longshore drift from river sources (Colorado and Brazos Rivers) farther north along the coast. Recent jetty construction on the coast and continued damming of rivers upstream from the coast have decreased sediment supply available for longshore transport. Though the Matagorda Island and St. Joseph Island Gulf shorelines have been in equilibrium, currently the deficit sediment supply has made this shoreline erosional (Brown and others, 1974).

About 42 percent, or 188 linear miles, of the total shoreline of the mapped area is undergoing some degree of accretion or net gain in land (based on observational data). These are invariably shorelines receiving a surplus volume of sediment. Active accretion of the offshore barrier shorelines is most pronounced in the vicinity of tidal passes, such as the islands west of Pass Cavallo. The shoreline of the emergent portion of the flood-tidal delta associated with Pass Cavallo is undergoing active deposition and accretion. The mainland shorelines of Barroom, Espiritu Santo, Shoalwater, Ayres, Mesquite, and Carlos Bays are accretionary. There is a ready source of sediment available from reworking of dredge spoil of the Intracoastal Waterway, as well as a source of sand from shorelines cutting into Pleistocene barrier-strandplain sands. Extensive areas of subaerial spoil are accreting in Matagorda Bay along the Port Lavaca and Matagorda Ship Channels. The shorelines of the Guadalupe and Lavaca deltas, of course, receive an adequate sediment supply and are prograding. Other areas characterized by depositional shorelines include Garcitas Cove, parts of St. Charles and Carancahua Bays, and the west shore of Green Lake; these areas occur either at the mouths of drainage systems carrying sediment into the bays or very near local sources of sand from older distributary channel deposits.

A total of 184 linear miles of shoreline, or 41 percent of the total bay and Gulf shoreline in the Port Lavaca map area, is indicated as undergoing some degree of net land loss. The principal areas of shoreline erosion are Copano, St. Charles, Hynes, Carancahua, and Matagorda Bays, and parts of Mesquite, San Antonio, and Lavaca Bays. Also, the west shoreline of Pass Cavallo, though shown on the *Active Processes Map* as accretionary, has actually been erosional for over the last 100 years. Both the bay and Gulf shorelines of Matagorda Peninsula are eroding; recently, erosional processes have dominated the Gulf shorelines of Matagorda Island as well. Waves generated by seasonal northers and prevailing south and southeast onshore winds strike the exposed bay and Gulf shorelines. The main cause of shoreline erosion in the Port Lavaca area is the opposite of that of shoreline accretion—a less than adequate supply of sediment along a relatively high-energy coast.

Five inland lakes in Refugio County have shorelines that are growing by beach ridge accretion along the south shores due to the seasonal northers. The north shores of these inland lakes are actively eroding, however, due to wave activity generated by the more frequent south and southeast summer winds.

In short, 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. 11). The interaction of these natural processes can be altered on a local or regional 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 Port Lavaca map area are the flood and ebb deltas of Pass Cavallo, the tidal pass through Matagorda Peninsula (Greens Bayou), the mouth of Carancahua Bay, the accreting west shore of Green Lake, and the prodeltas of Lavaca River, Garcitas Creek, and Guadalupe River (fig. 11). 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 (generally 1.5 to 2.0 feet in daily range along the Matagorda Island area coast), 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 sediments to the Gulf side 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; Grass Island, Pelican Island, and other associated land areas at Pass Cavallo are examples of emergent flood deltas.

A constricted bay mouth and a readily available sediment supply from Pleistocene distributary channel and marine deltaic sands have combined to form a tidal delta at the mouth of Carancahua Bay. Sediment is carried to the narrow pass across the shallow bay where tidal currents actively distribute the sediment as flood- and ebb-tidal deltas. With the exception of high sedimentation rates near small bayhead deltas of Lavaca River, Garcitas Creek, and Guadalupe River, the remaining bay areas 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 is the tidal channels, where a confinement of tidal currents scours the deeper parts of the channel; the other 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 10 square miles of bottom in the bay-estuary-lagoon system. Principal reef development is in San Antonio, Lavaca, Espiritu Santo, and Matagorda Bays.

Just under 40 square miles of land within the Port Lavaca area (less than 2 percent) are subject to alternating periods of submergence and emergence due to wind-generated tides affecting low-lying areas along bay shores. The back-island areas of the coastal barriers, particularly St. Joseph Island, are most extensively subjected to wind-tidal flooding.

Eolian processes dominate slightly more than 1 square mile on Matagorda and St. Joseph Islands. Here wind activity is sufficient to move sand grains and create blowout dunes, back-island dunes, and other actively migrating sand dunes.

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 areas 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 Port Lavaca area are treated here only in a qualitative manner. Unfortunately, much of the observation and monitoring necessary for quantitative assessment of active processes and their effects 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, scale, statistical, and numerical models have been developed (e.g., Simmons and Rhodes, 1966; Davis, 1971), but few of these have been sufficiently tested against observed processes in the field. Similarly, the total array of natural variables within the bay-estuary-lagoon system is poorly understood and, therefore, has not yet been included in theoretical modeling. 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 in part from the *Current Land Use Map* and illustrate man's impact on the Port Lavaca area. One aspect of man's activity here is urban and industrial construction; indicated are urban and residential areas, industrial 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, Ferry Channel, Victoria Channel, Port Lavaca Channel, and Matagorda Ship Channel. Made or reclaimed land occurs near Point Comfort where Aluminum Company of America opened a deep-water port. The made land is now the site of a holding pond for disposal of solid and liquid wastes. Also adopted from the *Current Land Use Map* are other 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 Texas Railroad Commission (1971) and Transcontinental Gas Pipe Line Corporation (1970), were used in the compilation of the pipeline networks of the area. Constructed platforms within the bays used in oil and gas production are not indicated on the map, but these man-made features are common in portions of Lavaca and Matagorda Bays.

A significant type of coastal or shoreline construction is the building of piers, jetties, and groins. Principal concentrations of constructed piers and jetties are along the west shore of Carancahua Bay, at Port O'Connor near the Intracoastal Waterway, along the west shore of Lamar Peninsula, and along the peninsula west of Lamar Peninsula. Most of the jetties and piers along the margins of the various bays are privately operated for fishing and recreation.

Water Systems

The surface water systems of the Port Lavaca map area include 647 square miles of natural and artificial water bodies excluding the Gulf. The natural water systems include about 58 square miles of fresh-water bodies (streams, natural lakes and ponds, and sloughs of abandoned channels) and about 579 square miles of marine bodies excluding the Gulf (tidal inlets, bays, lagoons, tide-influenced estuaries, and wind-tidal flats). The principal fresh-water streams of the area are the San Antonio and Guadalupe Rivers and upper reaches of the Lavaca and Navidad Rivers, along with several secondary streams such as Melon Creek, Copano Creek, Chocolate Bayou, Placedo Creek, Willow Creek, and Garcitas Creek. Although tide levels are low, a few streams have some tidal influence in their lower parts; examples are the lower Lavaca River, Guadalupe River, Garcitas Creek, and several other small streams.

A number of natural lakes and ponds covering 46 square miles are concentrated in the marshlands on the mainland sides of Sundown and Shoalwater Bays, along the valleys of San Antonio, Guadalupe, and Lavaca Rivers, and Garcitas Creek, and in swales between beach ridges and on the vegetated barrier flats of the Modern-Holocene barrier islands. The natural lakes formed in low-lying areas are now landlocked due to migrating river courses, bayhead extension of river deltas, and isolation of these areas on the coastal barriers by various active processes. In Refugio County, several heart-shaped lakes or ponds are occasionally filled with water.

Table 11. Areal extent, length, and number of individual environmental units shown on Man-Made Features and Water Systems Map, Port Lavaca map area, Texas.† (Table pertains only to that part of each county occurring within the Port Lavaca 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°	Bee°	Calhoun°	Goliad°	Jackson°	Matagorda°	Refugio°	Victoria°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Port Lavaca map area (excluding offshore area)	Percentage of Port Lavaca map area covered by map unit (excluding offshore area)
MAN-MADE FEATURES											
Urban and residential area, towns and minor villages	0.2	0	4.0	0	2.0	.01	3.0	1.5	–	10.71	0.4
Undifferentiated urban land, undeveloped tracts, greenbelts, cemeteries	0	0	0.3	0	0.3	0	0.1	0	–	0.7	0.03
Industrial area, isolated industrial developments	0.1	0	0.5	0.1	0.5	0	0.3	0.8	–	2.3	0.08
Made land, filled, graded, developed over shallow bay areas	0	0	0.3	0	0	0	0	0	–	0.3	0.01
Subaerial spoil, includes spoil heaps or mounds and reworked spoil, small wash areas common	1.5	0	7.0	0	0.5	0.3	0	0	–	9.3	0.3
Subaqueous spoil, in part reworked by waves and currents	2.8	–	13.0	–	0	4.5	0	0	0.7	20.3	0.8
Jetty or pier, individual structure or area of numerous structures	–	–	–	–	–	–	–	–	–	–	–
Pipeline, major lines only, incomplete	–	–	–	–	–	–	–	–	–	–	–
Airfield, paved, graded, or sod■	0	0	10	0	1	0	3	1	–	15	–
Sewage disposal site, commonly liquid effluent treatment plant site■	0	0	1	0	1	0	0	0	–	2	–
Solid-waste disposal site, sanitary landfills and open sites■	0	0	4	0	1	0	3	1	–	9	–
Sludge pit or miscellaneous waste disposal site, may be abandoned■	0	0	5	0	0	0	0	1	–	6	–
WATER SYSTEMS											
Open ocean	–	–	–	–	–	–	–	–	–	–	–
Tidal inlet and pass, natural pass, commonly dredged or otherwise modified for navigation purposes	0.3	–	8.9	–	0	0	0	0	1.3	9.2	0.3
Lagoon, bay, and estuary, variable salinity depending upon rainfall and runoff	85.5	–	369.2*	–	5.2	68.4	6.8	0.5	–	535.6	19.8
Transportation canal and channel, including intracoastal system and other ship channels▲	39.6[2.8]+	0	116.8[2.8]+	0	0	21.6	0	7.2	2.0	182.4	–
Wind-tidal flats, intermittently flooded by bay and lagoon waters	19.3	–	14.0	–	0	0	0.5	0.3	–	34.1	1.3
Tidally affected stream, influenced by low astronomical or wind tide▲	6.4	0	15.2[1.2]+	0	25.6[5.6]+	0	18.0[9.2]+	8.0[6.0]+	–	62.2	–
River or stream, natural drainage	–	–	–	–	–	–	–	–	–	–	–
Slough or abandoned course and cutoff, water-filled	3.6	0	4.0	0.2	1.0	0	0.8	2.0	–	11.6	0.4
Lake or pond, natural with minimum modification, perennial	2.0	0	28.1+	1.2	3.6	0	4.0	3.0	–	41.9	1.6
Lake or pond, natural, some areas artificially drained, ephemeral	0	0	0	0	0	0	4.3	0	–	4.3	0.2
Drainage or irrigation ditch and canal, major systems only, supplies or drains many small systems▲	5.6	0	111.2	0.8	140.0	0	94.0	115.6	–	467.2	–
Artificial reservoir, flood control, municipal water supply, industrial purposes, or recreation, some quarries and pits	1.0	0	4.8	0	0.5	0	0	4.0	–	10.3	0.4
Principal river▲	0	0	[16.8]+	[6.8]+	51.2[20.0]+	0	[36.8]+	86.0[60.4]+	–	127.2	–
Bay-lagoon-estuary shoreline▲	88.8	–	260.0*	–	30.4	14.8	19.2	1.6	–	414.8	–
Open Gulf shoreline▲	5.6	–	36.0	–	0	12.0	0	0	–	26.8	–

†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.
*Some bays may be classified as lake or pond occasionally, depending on variations in salinity.
+Miles of principal rivers, tidally affected streams, canals, and channels along county line; common with adjacent county.

These ephemeral, artificially drained lakes are subject to river flooding and rainfall runoff, but are not affected by occasional salt-water flooding at high tides or by storm surge, as are most of the landlocked coastal water bodies. Most of these water bodies are circular to elliptical; exceptions are the heart-shaped ephemeral lakes in Refugio County and the irregular to very elongate natural ponds formed on the coastal barrier islands. All of these natural lakes and ponds are very shallow.

Elongate sloughs formed from abandoned loops and channels of older streams are a third type of natural fresh-water body in the Port Lavaca area. Slough development, covering nearly 12 square miles, is most extensive along the Guadalupe, lower Lavaca, and Navidad Rivers.

The major marine bodies in the mapped area are Matagorda, San Antonio, and Aransas Bays, with associated Lavaca, Espiritu Santo, and Copano Bays, and several smaller, partly enclosed bays such as St. Charles, Carlos, Mesquite, Ayres, Hynes, Guadalupe, Sundown, Shoalwater, Barroom, Pats, Keller, Carancahua, Cox, and Chocolate Bays, Garcitas Cove, and Mission Lake. Salinity of bay waters ranges from less than 10‰ in the upper river-influenced portions to nearly 35‰ in the open-bay and tidal-channel areas. 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: major transportation channels, and drainage and irrigation canals. Approximately 182 linear miles of transportation canals, including the Intracoastal Waterway, Ferry Channel, Matagorda Ship Channel, Port Lavaca Channel, and Victoria Channel, as well as numerous subdivisions of these systems, are present in the Port Lavaca map area. These are constructed as land cuts and dredged channels within the bays, estuaries, and tidal passes. More than 467 linear miles of major drainage and irrigation canals form extensive networks in the agricultural coastal uplands and locally in the low coastal marshes. Canals in the marshlands are used exclusively for drainage, so that portions of the marshes can be utilized as rangeland. The canal systems in the coastal uplands have been developed largely for drainage and irrigation as part of extensive crop cultivation. Most have been privately constructed; others are maintained by local government units.

A large number of surface reservoirs (more than 10 square miles) have been constructed throughout the area and are used for municipal, industrial, and irrigation water supplies.

RAINFALL, STREAM DISCHARGE, AND SURFACE SALINITY MAP

The *Rainfall, Stream Discharge, and Surface Salinity Map* of this Atlas summarizes salient climatic features for the Port Lavaca 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 seven stations within or adjacent to the mapped area: Refugio, Austwell Wildlife Refuge, Port O'Connor, Port Lavaca No. 2, Point Comfort, Victoria Airport, and Edna 3 SW (the last two stations are not in 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 five stations, all of which are located just outside the map area: Station 8-1640 on the Lavaca River, Station 8-1645 on the Navidad River, Station 8-1765 on the Guadalupe River, Station 8-1770 on Coleto Creek, and Station 8-1885 on the San Antonio River.

Measurements of surface salinity were compiled from 75 stations in Copano, St. Charles, Aransas, Mesquite, Sundown, Ayres, San Antonio, Hynes, Espiritu Santo, Barroom, Matagorda, Carancahua, Keller, and Lavaca Bays, Cedar Bayou, Pass Cavallo, and other water bodies just inland from the bay shore. These data were obtained from yearly reports of the Texas Parks and Wildlife Department (Martinez, 1965, 1966, 1967) and are shown for the same time period covered by discharge and rainfall data; measurements from 21 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 $1^{\circ}/_{\circ\circ}$ to about $22^{\circ}/_{\circ\circ}$. Lowest salinities are recorded during these periods in the upper part of San Antonio Bay where stream discharge is greatest; highest salinities occur in areas of the tidal inlets where interchange of bay and Gulf waters takes place (fig. 11).

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 $24^{\circ}/_{\circ\circ}$ in the upper parts of San Antonio Bay to more than $38^{\circ}/_{\circ\circ}$ in the tidal inlets—Pass Cavallo and Cedar Bayou. The highest salinity during this period was recorded in restricted Cedar Bayou.

Calculated average surface salinities for the 1965-67 period ranged from less than $6^{\circ}/_{\circ\circ}$ in the upper part of San Antonio Bay to more than $28^{\circ}/_{\circ\circ}$ in the vicinity of Pass Cavallo. 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. 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 135 feet in the inland portions of the Port Lavaca map area. Topographic control, used for this map at a scale of 1:250,000 and on the *Environmental Geology Map* at 1:125,000, was compiled from U. S. Geological Survey detailed 7.5-minute topographic maps at 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 zero or mean sea level to more than 30 feet. Deepest areas are within 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 areas and amounts of land 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, the 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 land area and bay-Gulf area for each contour interval (topography and bathymetry). Such information readily inventories the amount of land at a particular elevation. For example, if a flood crest is predicted at 25 feet, the amount of land subject to flooding is known 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, Port Lavaca map area, Texas.† (Table pertains only to that part of each county occurring within the Port Lavaca 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°	Bee°	Calhoun°	Goliad°	Jackson°	Matagorda°	Refugio°	Victoria°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Port Lavaca map area (excluding offshore area)	Percentage of Port Lavaca map area covered by map unit (excluding offshore area)
	130-135	0	0	0	2.3	0	0	0	0	–	2.3	.08
	125-130	0	0	0	7.5	0	0	0	0	–	7.5	0.3
	120-125	0	0	0	7.0	0	0	0	0	–	7.0	0.3
	115-120	0	0	0	11.0	0	0	0	0.3	–	11.3	0.4
	110-115	0	0	0	10.5	0	0	0	2.3	–	12.8	0.5
	105-110	0	0	0	11.0	0	0	0	6.0	–	17.0	0.6
	100-105	0	0	0	15.0	0	0	0	5.0	–	20.0	0.7
	95-100	0	0	0	15.0	0	0	1.3	12.3	–	28.6	1.1
	90-95	0	0.3	0	10.3	0	0	8.8	16.5	–	35.9	1.3
	85-90	0	0.8	0	6.3	0	0	16.3	16.5	–	39.9	1.5
	80-85	0	1.5	0	1.5	0	0	16.3	18.8	–	38.1	1.4
	75-80	0	0.3	0	1.5	1.8	0	20.0	23.0	–	46.6	1.7
	70-75	0	0.3	0	1.5	5.5	0	25.8	23.8	–	56.9	2.1
ABOVE SEA LEVEL (feet)	65-70	0	0.3	0	0.5	12.8	0	38.3	31.3	–	83.2	3.1
	60-65	0	0	0	0	16.5	0	35.0	35.5	–	87.0	3.2
	55-60	0	0	0.3	0	17.5	0	31.3	47.2	–	96.3	3.6
	50-55	0	0	4.8	0	16.8	0	39.8	33.5	–	94.9	3.5
	45-50	0	0	7.3	0	21.5	0	40.3	32.5	–	101.6	3.8
	40-45	0	0	10.0	0	23.3	0	40.5	29.7	–	103.5	3.8
	35-40	0	0	18.5	0	34.5	0	43.0	25.3	–	121.3	4.5
	30-35	1.0	0	20.5	0	27.8	0	43.0	18.0	–	110.3	4.1
	25-30	3.0	0	29.3	0	34.8	0	29.5	19.0	–	115.6	4.3
	20-25	7.5	0	37.7	0	17.0	0	29.3	9.3	–	100.8	3.7
	15-20	18.3	0	45.0	0	17.8	0	28.3	15.3	–	124.7	4.6
	10-15	49.8	0	110.8	0	10.3	0.5	28.8	11.3	–	211.5	7.8
	5-10	47.0	0	133.0	0	6.3	2.0	14.3	7.0	–	209.6	7.7
	0-5	52.5	0	119.3	0	20.0	6.5	14.0	2.8	–	215.1	7.9
SEA LEVEL												
	0-6	72.5	0	267.0	0	5.3	5.7	3.5	0.8	7.0	354.8	13.1
	6-12	15.8	0	109.3	0	0	51.0	3.3	0	14.0	179.4	6.6
BELOW SEA LEVEL (feet)	12-18	0	0	16.5	0	0	16.5	0	0	12.3	33.0	1.2
	18-24	0	0	0	0	0	1.5	0	0	18.8	1.5	.06
	24-30	0	0	0.3	0	0	0	0	0	24.3	0.3	.01
	30-	–	–	–	–	–	–	–	–	–	–	–

†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.

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 capabilities 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, processes, and other characteristics of land and water resource units that limit or restrict their use for specific purposes or activities. Examples are: (1) flooding by hurricane surges or by overbanking rivers; (2) shrink-swell soil conditions; (3) corrosion of pipes and conduits; (4) transmission of pollutants through highly permeable substrates; (5) gravity failure and extreme rainfall runoff on steep slopes; (6) ponding of water over impermeable substrates following prolonged rainfall; (7) erosion and transportation of sediment by wind and water; (8) flooding of broad tidal flats by wind tides; (9) restricting growth of stabilizing vegetation; (10) erosion of shorelines by waves and currents; (11) faulting or potential faulting; and (12) land-surface subsidence caused by intense use of ground water.

Evaluation of land and water resource units depends upon the human activities that result in the use of these units. A wide variety of land and water use activities occurs within the Coastal Zone (table 13); other activities will develop as population grows and urban and industrial expansion continues in the Zone.

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 because of its tendency to transmit wastes into aquifer systems, but the same permeable sand provides an excellent foundation for coastal structures. On the other hand, 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 is 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 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 land and water 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.

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 Port Lavaca area (fig. 33) 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; capabilities of each natural resource unit on the map, therefore, can be judged for each specific use,

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).

LAND AND WATER RESOURCE UNITS			LIQUID-WASTE DISPOSAL: Surface disposal of untreated liquid wastes	LIQUID-WASTE DISPOSAL: Shallow subsurface disposal of untreated liquid wastes	Maintenance of feed lots	SOLID-WASTE DISPOSAL: Disposal of solid-waste materials	SHORELINE CONSTRUCTION: Construction of jetties, groins, and piers	SHORELINE CONSTRUCTION: Construction of storm barriers and/or seawalls	COASTAL AND INLAND CONSTRUCTION: Light construction	COASTAL AND INLAND CONSTRUCTION: Construction of highways (excluding causeways)	COASTAL AND INLAND CONSTRUCTION: Heavy construction	COASTAL AND INLAND CONSTRUCTION: Flooding as a result of dam construction	COASTAL, INLAND, AND OFFSHORE CONSTRUCTION: Construction of production platforms and other oil well development activities	COASTAL, INLAND, AND OFFSHORE CONSTRUCTION: Placement of pipelines and/or subsurface cables	COASTAL, INLAND, AND OFFSHORE CONSTRUCTION: 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

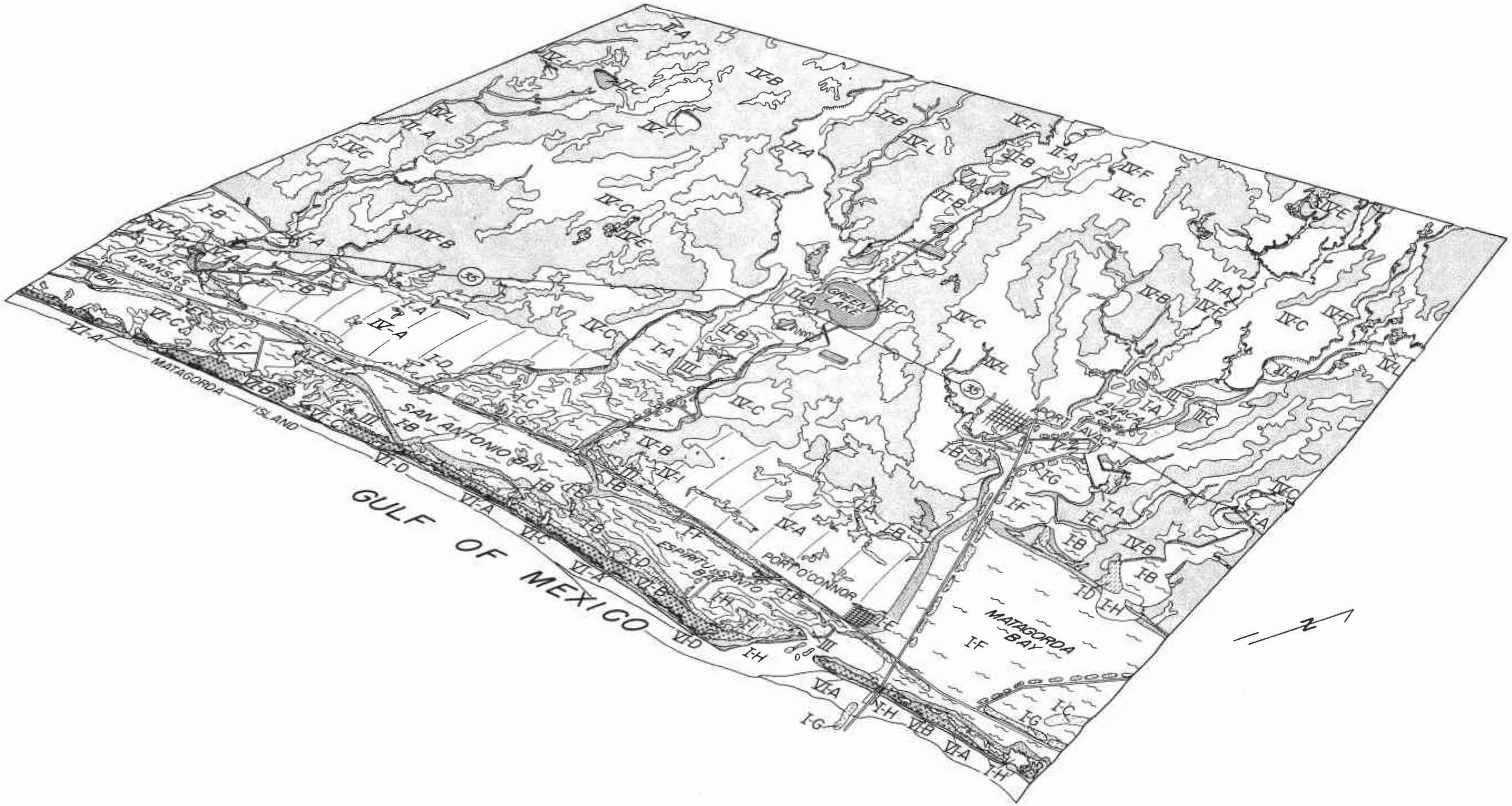
Not applicable (shaded)

X Undesirable—significant problems likely

‡ Significant problems unlikely on vegetated barrier flat. Construction and recreation activities on fore-island dunes are undesirable.

Significant problems unlikely (blank)

0 Possible problems



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
- G. Subaqueous spoil
- H. Tidal inlet and tidal delta
- I. Wind-tidal flats

II. Major river systems
- A. Meanderbelt and levee sands
- B. Overbank and deltaic 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 (not illustrated)
- E. Highly forested upland areas
- F. Steep lands
- G. Stabilized (vegetated) dunes and sandflats (absent)
- H. Unstabilized (unvegetated) dunes (absent)
- I. Fresh-water lakes, ponds, sloughs, playas
- J. Mainland beaches (not illustrated)
- 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. Vegetated beach ridge and barrier flat
- C. Washover areas
- D. Active dunes
- E. Tidal flats (absent)
- F. Swales (absent)

Figure 33. Schematic map of land and water resource capability units, Port Lavaca map area.

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 Port Lavaca 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.

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, daily 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 and destroys a natural barrier to 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 OCCURRENCE. SHORELINE USES SHOULD BE IN ACCORDANCE WITH THE NATURAL STATE.

WASTE DISPOSAL

A significant activity in the populated and industrial area of the upper part 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 sediments. Dredging or excavation of fill material renders the fill more permeable than the original sediments and commonly creates unsuitable hosts 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 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 Port Lavaca 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 in the terminal parts of these rivers in the Coastal Zone. 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 Port Lavaca 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 resource use in harmony with equally requisite environmental quality. Natural resource inventory and evaluation, 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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