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

W. L. Fisher, Director

ENVIRONMENTAL GEOLOGIC ATLAS OF THE TEXAS COASTAL ZONE – Kingsville 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, Discharge, and Surface Salinity
Topography and Bathymetry

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

Cartography by J. W. Macon, D. F. Scranton
and Barbara Hartmann

L. F. Brown, Jr., Project Coordinator

Preface by
Peter T. Flawn

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Cover photo: Beach and fore-island dunes on Padre Island south of Yarborough Pass. Dune vegetation is *Uniola paniculata* (sea oats) and croton. The beach is composed of a mixture of terrigenous sand and a high percentage of whole and fragmented shell. View is northeast. Photograph by J.H. McGowen, 1972.

CONTENTS

PREFACE vii

INTRODUCTION 1
- Role of environmental geology in the Coastal Zone . . . 1
- The coastal Environmental Atlas project 2
  - Environmental Geology Map 2
  - Special-Use Environmental Maps 6
- Sources of supplemental data 6
- Acknowledgments 12

KINGSVILLE AREA 12
- General setting 12
- Resource activities 14

GEOLOGY AND GEOLOGIC HISTORY 15
- Pleistocene history 17
- Holocene history 20
- Modern history 21
  - Estuarine erosion and deposition 21
  - Headward-eroding streams 22
  - Eolian deflation and dune development 22
  - Barrier island and lagoon development 23
  - Lagoon deposition 23
  - Wind-tidal flats 24
- Historical summary 24
- Human impact on coastal geology 25
- Conclusions 26

CLIMATE AND DYNAMIC COASTAL PROCESSES 27
- Climatic character of the Kingsville area 27
- Coastal wind regimes 29
  - Persistent southeasterly winds 31
  - Northerly winds 33
- Tidal currents 34
- River discharge 34
- Effects of hurricane impact 34

HOW TO USE THE ATLAS 35
- General map interpretation 35
  - Map orientation 35
  - Map scales 37
  - Topography and bathymetry 37
  - Other general map information 37
- Map legend 38
- Environmental resource subject guide 38
- Generating additional data 45

ENVIRONMENTAL GEOLOGY MAP 45
- Pleistocene systems 46
  - Fluvial-deltaic system 46
    - Meanderbelt sands and floodplain muds 50
    - Distributary and fluvial sands and silts 50
    - Interdistributary muds 51
    - Marine deltaic mud and sand 52
  - Barrier-strandplain system 52
    - Ingleside barrier 53
- Modern-Holocene systems 53
  - Fluvial system 53
  - Barrier and offshore systems 55
    - Barrier system 55
      - Beach 55
      - Fore-island dune ridge 56
      - Fore-island blowout dunes 57
      - Stabilized blowout dunes 58
      - Barrier flat 58
      - Back-island dune fields 58
      - Washover channels and fans 58
      - Wind-deflation troughs and storm runnels 59
      - Sandflats and coppice sand dune fields 59
      - Sparsely vegetated barrier flat 60
      - Back-island sandflats 60
    - Offshore system 60
  - Marsh system 60
  - Bay-estuary-lagoon system 61
    - Bay-estuary-lagoon environments 62
      - Subaerial bay-lagoon margin environments 62
      - Subaqueous bay- or lagoon-margin environments 67
      - Bay-lagoon-center environments . . . 70
  - Eolian system 72
    - Principal elements of the eolian system . . . 73
      - Parra Lake eolian sand lobe 73
      - Sarita eolian sand lobe 74
      - San Pedro Ranch eolian sand lobe . . 77
      - Norias eolian sand lobe 79
      - Riviera loess sheet 79
      - Rudolph sand and loess plains 80
      - Candelaria Lake-Santa Rosa Ranch deflation complex 80
    - Eolian environments 81
      - Active dune complex 81
      - Active dune blowout areas 82
      - Sand sheet with strong relict grain . . 82
      - Sand and loess sheet with no relict grain 82
      - Moderately stabilized dunes 83
      - Well-stabilized dune sands 83
      - Sand and loess sheet deflation area . 83
      - Active clay-sand accretionary dunes . 84
      - Inactive clay-sand dune complexes . . 84
      - Loess sheets 85
  - Artificial units 85
      - Made land 85
      - Spoil 85
      - Other map symbols 85

SPECIAL-USE ENVIRONMENTAL MAPS 86
Physical Properties Map 86
Group I lands 91
Group II lands 91
Group III lands 92
Group IV lands 92
Group V lands 92
Group VI lands 93
Group VII lands 93
Group VIII lands 93
Group IX lands 93
Group X lands 94
Group XI lands 94
Group XII lands 94
Potential for land-surface subsidence and surface faulting 94
Land-surface subsidence 94
Surface faulting 95
Waste disposal 97
Comparative uses of Physical Properties Map . . . 99
Environments and Biologic Assemblages Map 99
Subaqueous environments and biologic assemblages 102
Subaerial environments and biologic assemblages 102
Current Land Use Map 102
Agricultural lands 105
Wooded lands 107
Fresh-water marsh 107
Urban and industrial lands 107
Parks and recreational facilities 107
Transitional and barren lands 107
Other land use categories 108
Utility of Current Land Use Map 108
Mineral and Energy Resources Map 108
Oil and natural gas 109
Constructional raw materials 110
Industrial sands 110
Common clay 110
Serpulid reefs 111
Summary 111
Active Processes Map 111
Hurricane flooding 111
Shoreline processes 113
Wind-dominated processes 114
Other active processes 115
Man-Made Features and Water Systems Map 116
Man-made features 116
Water systems 116
Rainfall, Stream Discharge, and Surface Salinity Map . 119
Topography and Bathymetry Map 120
RESOURCE CAPABILITY: UTILITY IN LAND AND WATER MANAGEMENT 120
COASTAL PROBLEMS: OBSERVATIONS AND RECOMMENDATIONS 125
Channelization 125
Devegetation 126
Shoreline construction 126
Waste disposal 126
Filling and land reclamation 126
Artificial passes 127
Natural catastrophes 127
Hurricanes 127
Shoreline erosion 127
Inland flooding 128
Surface faults and land subsidence 128
CONCLUSIONS 128
REFERENCES 129

FIGURES

1. Index of the Environmental Geologic Atlas of the Texas Coastal Zone 3
2. Sources and flow of data for the Environmental Geologic Atlas of the Texas Coastal Zone 4
3. Source and dateline for principal data used in mapping the Kingsville area 5
4. Natural systems defined by environmental mapping in the Kingsville area 16
5. Sea-level changes related to glacial and interglacial stages 17
6. Late Pleistocene-Holocene valleys 20
7. Regional climatic data, Texas Coastal Zone 28
8. Relationship between wind regimes and long-shore current circulation, Texas Coastal Zone 29
9. Circulation, waves, sediment transport, and other physical processes, bay-estuary-lagoon and offshore systems, Kingsville area 30
10. Schematic model of hurricane effects on the Texas Coastal Zone 36
11. Pleistocene fluvial-deltaic system, coastal uplands northwest of Baffin Bay, Kingsville area 50
12. Distributary sand and silt, interdistributary mud, and associated delta-front sand, mud, and silt, Pleistocene delta system, north side of Baffin Bay, Kingsville area 51
13. Pleistocene (Ingleside-Encinal) barrier-strandplain system, modified by eolian deflation north of Baffin Bay, Kingsville area 52
14. Modern headward-eroding stream system (San Fernando Creek) near Kingsville, Texas 54
15. Modern barrier island system, Padre Island, near Land-Cut Area, Kingsville area 56
16. Barrier island facies along the northern part of Little Shell Beach, Padre Island, Kingsville area 57
17. Modern bay-estuary facies within Baffin Bay 64

18. Wind-tidal flats and adjacent subtidal lagoonal facies, Laguna Madre, Kingsville area 65
19. Relict eolian blowout (rincons) preserved on broad wind-tidal flats, Kingsville area 66
20. Eolian accretionary deposits associated with wind-tidal flats, Kingsville area 67
21. Principal elements within the South Texas eolian system, Kingsville and Brownsville-Harlingen areas 74
22. Active banner dune field, eolian system, Kingsville area 76
23. Facies mosaic within the South Texas eolian system, Kingsville area 77
24. Termination of eolian dune train along a fault or fracture zone, Kingsville area 78
25. Inactive dune fields stabilized by live oaks and brush, South Texas eolian system, Kingsville area 79
26. Interdune area where wind has apparently deflated sand and loess sheet to the top of shallow water table 81
27. Piezometric decline in the Goliad aquifer, Kingsville area 96
28. Possible effect of ground water on the occurrence and distribution of banner dunes 97
29. Profiles of plant communities within environments extending from bay, lagoon, or Gulf to coastal uplands or Padre Island 100
30. Schematic map of land and water resource units, Kingsville map area 124

TABLES

1. Index of map units, Kingsville map area, Texas 39
2. Environmental subject index, Kingsville map area, Texas 42
3. Areal extent of environmental geologic units, Kingsville map area, Texas 47
4. Eolian environments and deposits, Kingsville map area, Texas 72
5. Environments, principal elements, and map units within the South Texas eolian system, Kingsville and Brownsville-Harlingen map areas 75
6. Evaluation of the natural suitability of physical properties groups for various coastal activities and land uses, Kingsville map area, Texas 87
7. Areal extent, length, and number of individual environmental units shown on Physical Properties Map, Kingsville map area, Texas 89
8. Common macro-biologic assemblages within Texas coastal environments, Kingsville map area, Texas 101
9. Areal extent of individual units shown on Environments and Biologic Assemblages Map, Kingsville map area, Texas 103
10. Areal extent and number of individual units shown on Current Land Use Map, Kingsville map area, Texas 106
11. Areal extent and number of individual units shown on Mineral and Energy Resources Map, Kingsville map area, Texas 109
12. Areal extent, length, and number of individual units shown on Active Processes Map, Kingsville map area, Texas 112
13. Areal extent, length, and number of individual environmental units shown on Man-Made Features and Water Systems Map, Kingsville map area, Texas 117
14. Areal extent of each 5-foot topographic contour interval and each 6-foot bathymetric contour interval shown on Topography and Bathymetry Map, Kingsville map area, Texas 121
15. Coastal Zone land and water resource units—use and capability 122

MAPS

Environmental Geology Map . . . . In pocket

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

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.

PETER T. FLAWN
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Director, Division of Natural Resources
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ENVIRONMENTAL GEOLOGIC ATLAS OF THE TEXAS COASTAL ZONE—

KINGSVILLE AREA

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

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.

[1] Chairman, Department of Geological Sciences, The University of Texas at El Paso.

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.

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.

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

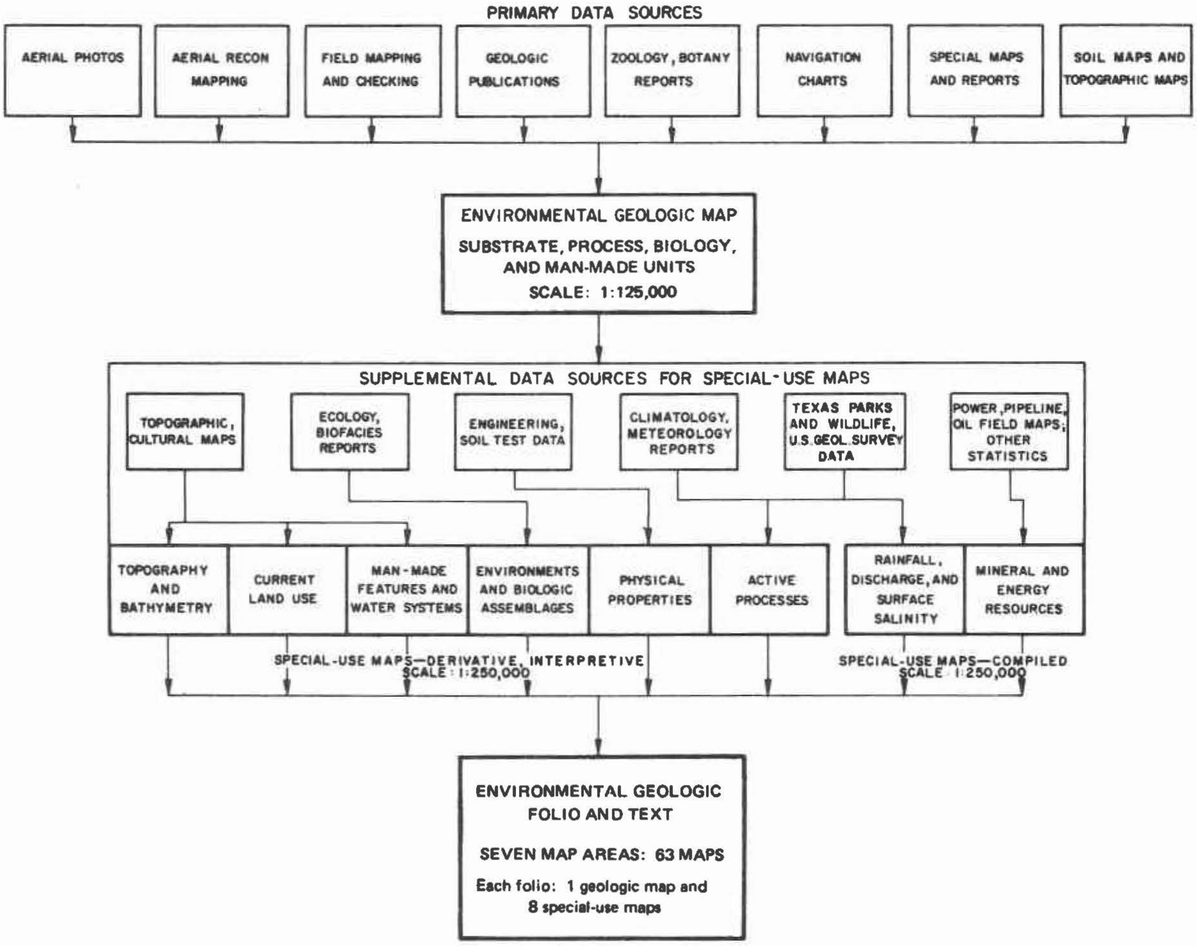
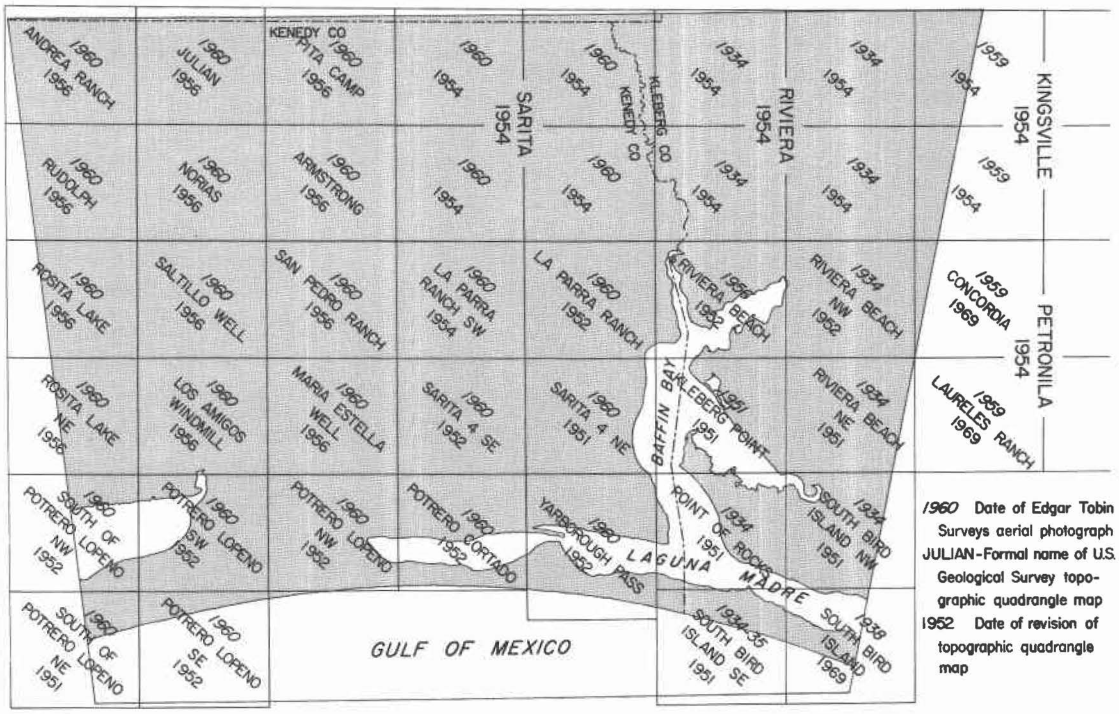


Figure 2. Sources and flow of data for the Environmental Geologic Atlas of the Texas Coastal Zone.

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, 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 and serpulid 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, eolian, 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



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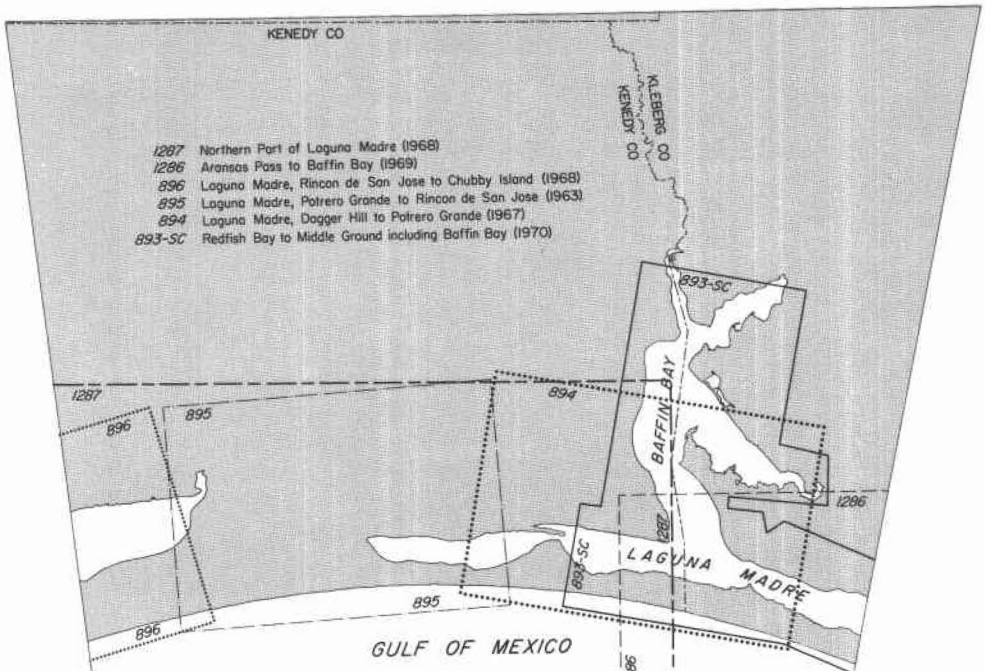

B

Figure 3. Source and dateline for principal data used in mapping the Kingsville area. (A) U. S. Geological Survey topographic maps and Edgar Tobin Aerial Survey's 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.

revision. Edgar Tobin Aerial Surveys photomosaics provide uniform coverage of the entire Coastal Zone.

Remapping in future decades with updated aerial photography and other multispectral remote sensing devices carried by aircraft and satellites will provide a valuable historical reference to rates and degree of both natural and man-made changes in the Coastal Zone. The Atlas is, therefore, an open-ended document which can be updated to maintain a current record of the change and modification of the region. It is also anticipated that the Atlas will serve to stimulate interest in and provide the environmental baseline for many more specialized and localized studies addressed to specific pollution, land use, ecologic, economic, and resource problems.

Special-Use Environmental Maps

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

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

SOURCES OF SUPPLEMENTAL DATA

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

Aerial photographic mosaics—

Edgar Tobin Aerial Surveys, Aerial photographic mosaics: San Antonio, Texas, Edgar Tobin Aerial Surveys.

Barrier island, processes, environments, and sediments—

Andrews, P. B., 1970, Facies and genesis of a hurricane-washover fan, St. Joseph Island, central Texas coast: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 67, 147 p.

Fisk, H. N., 1959, Padre Island and the Laguna Madre flats, coastal south Texas: La. State Univ., April 1959, 2d Coastal Geography Conf., p. 103-151.

Hayes, M. O., 1964, Grain size modes in Padre Island sands, *in* Depositional environments, south-central Texas coast: Gulf Coast Assoc. Geol. Socs., Field Trip Guidebook (A. J. Scott, leader).

Hunter, R. E., 1972, Traverse across central Padre Island, *in* Modern depositional environments and processes, northern and central Padre Island, Texas: Gulf Coast Assoc. Geol. Socs., Padre Island Natl. Seashore Field Guide, pt. I, p. 24-25.

_______, Hill, G. W., and Dickinson, K. A., 1972, Traverse across northern Padre Island, *in* Modern depositional environments and processes, northern and central Padre Island, Texas: Gulf Coast Assoc. Geol. Socs., Padre Island Natl. Seashore Field Guide, pt. I, p. 4-17.

McGowen, J. H., Garner, L. E., and Wilkinson, B. H., 1977, The Gulf shoreline of Texas: Processes, characteristics, and factors in use: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 77-3, 27 p.

Shepard, F. P., 1960, Gulf Coast barriers, *in* Shepard, F. P., Phleger, F. B., and van Andel, T. H., eds., Recent sediments, northwest Gulf of Mexico: Am. Assoc. Petroleum Geologists, p. 197-220.

Base map. See *topography.*

Bathymetry, bay-estuary-lagoon bottom sediment and spoil, intracoastal canals, offshore platforms—

U. S. Army Corps of Engineers, Galveston District, District Engineer, 1966, Maps of Gulf intracoastal waterway, Sabine River to the Rio Grande: U. S. Army Corps Engineers, Galveston Dist., 59 maps.

U. S. Coast and Geodetic Survey, Nautical charts: Rockville, Md., U. S. Dept. Commerce, Environmental Sci. Services Adm., Coast and Geod. Survey.

Bay-estuary-lagoon bottom sediment, general nature and distribution—

Alaniz, R. T., and Goodwin, R. H., 1974, Recent sediments of a hypersaline estuarine bay: Gulf Coast Assoc. Geol. Socs. Trans., v. XXIV, p. 308-313.

Dalrymple, D. W., 1964, Recent sedimentary facies of Baffin Bay, Texas: Rice Univ., Ph.D. dissert., 192 p.

Fisk, H. N., 1959, Padre Island and the Laguna Madre flats, coastal south Texas: La. State Univ., 2d Coastal Geography Conf., April 1959, p. 103-151.

Ladd, H. S., Hedgpeth, J. W., and Post, Rita, 1957, Environments and facies of existing bays on the central Texas coast, *in* Ladd, H. S., ed., V. 2, Paleoecology, Treatise on marine ecology and paleoecology: Geol. Soc. America Mem. 67, p. 599-639.

Lohse, E. A., 1958, Geochronology of mud flats through varve analysis, *in* Sedimentology of South Texas: Corpus Christi Geol. Soc. Guidebook, p. 47.

Rusnak, G. A., 1960, Sediments of Laguna Madre, Texas, *in* Shepard, F. P., Phleger, F. B., and van Andel, T. H., eds., Recent sediments, northwest Gulf of Mexico: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 153-196.

Shepard, F. P., and Rusnak, G. A., 1957, Texas bay sediments: Univ. Texas, Marine Sci. Inst. Pub., v. 4, p. 5-13.

Bay-estuary-lagoon salinity, background information—

Breuer, J. P., 1957, An ecological survey of Baffin and Alazan Bays, Texas: Univ. Texas, Marine Sci. Inst. Pub., v. 4, no. 2, p. 134-155.

Hahl, D. C., and Ratzlaff, K. W., 1970, Chemical and physical characteristics of water in estuaries of Texas, September 1967-September 1968: Texas Water Devel. Board Rept. 117, 91 p.

Martinez, Rudy, 1965, Coastal hydrographic and meteorological study: Texas Parks and Wildlife Dept., Coastal Fisheries Proj. Rept., p. 169-210.

_______ 1966, Coastal hydrographic and meteorological study: Texas Parks and Wildlife Dept., Coastal Fisheries Proj. Rept., p. 105-146.

_______ 1967, Coastal hydrographic and meteorological study: Texas Parks and Wildlife Dept., Coastal Fisheries Proj. Rept., p. 77-112.

Water Resources Division, Unpublished records, chemical and physical characteristics of Texas coastal waters; basic data, October 1968 through September 1969: Austin, Texas, U. S. Geol. Survey, Water Resources Div.

Bay-estuary-lagoon salinity values. See *salinity.*

Bay-estuary-lagoon spoil. See *bathymetry.*

Bay-estuary-lagoon system, general circulation and salinity—

Behrens, E. W., 1966, Surface salinities for Baffin Bay and Laguna Madre, Texas, April 1964-March 1966: Univ. Texas, Marine Sci. Inst. Pub., v. 11, p. 168-173.

Breuer, J. P., 1957, An ecological survey of Baffin and Alazan Bays, Texas: Univ. Texas, Marine Sci. Inst. Pub., v. 4, no. 2, p. 134-155.

Collier, A. W., and Hedgpeth, J. W., 1950, An introduction to the hydrography of tidal waters of Texas: Univ. Texas, Marine Sci. Inst. Pub., v. 1, p. 120-194.

Gunter, G., 1945, Some characteristics of ocean waters and the Laguna Madre: Texas Game and Fish, v. 3, no. 11, p. 7, 19, 21-22.

Hedgpeth, J. W., 1947, The Laguna Madre of Texas: 12th North Am. Wildlife Conf., Trans., p. 364-380.

Ladd, H. S., Hedgpeth, J. W., and Post, Rita, 1957, Environments and facies of existing bays on the central Texas coast, *in* Ladd, H. S., ed., V. 2, Paleoecology, Treatise on marine ecology and paleoecology: Geol. Soc. America Mem. 67, p. 599-639.

Simmons, E. G., 1957, An ecological survey of the upper Laguna Madre of Texas: Univ. Texas, Marine Sci. Inst. Pub., v. 4, no. 2, p. 156-200.

Biologic assemblages, subaerial—

Andrews, J., Burchfield, P. M., Callaway, B., Endres, J. M., Hill, G. W., Otteni, Lee, Thomas, W. D., and Travis, R. F., 1972, Natural history of Padre Island: Part II (Shell collecting, snakes, history, birds, crustaceans, plants, mammals, and fish): Gulf Coast Assoc. Geol. Socs., Padre Island Natl. Seashore Field Guide, p. 28-61.

Franki, G. E., Garcia, R. N., Hajek, B. F., Arriaga, D., and Roberts, J. C., 1965, Soil survey of Nueces County, Texas: U. S. Dept. Agriculture, Soil Conserv. Service, ser. 1960, no. 26, 65 p., 79 aerial photographic maps.

Gould, F. W., 1962, Texas plants—A checklist and ecological summary: Agr. and Mech. Coll. of Texas, Texas Agr. Expt. St., MP-585, 112 p.

Johnston, M. C., 1955, Vegetation of the eolian plain and associated features of southern Texas: Univ. Texas [Austin], Ph.D. dissert., 167 p.

Biological assemblages, subaqueous—

Andrews, J., Burchfield, P. M., Callaway, B., Endres, J. M., Hill, G. W., Otteni, Lee, Thomas, W. D., and Travis, R. F., 1972, Natural history of Padre Island: Part II (Shell collecting, snakes, history, birds, crustaceans, plants, mammals, and fish): Gulf Coast Assoc. Geol. Socs., Padre Island Natl. Seashore Field Guide, p. 28-61.

Breuer, J. P., 1957, An ecological survey of Baffin and Alazan Bays, Texas: Univ. Texas, Marine Sci. Inst. Pub., v. 4, no. 2, p. 134-155.

Ladd, H. S., 1951, Brackish-water and marine assemblages of the Texas coast, with special reference to mollusks: Univ. Texas, Marine Sci. Inst. Pub., v. 2, no. 1, p. 125-164.

McMahan, C. A., project leader, 1965-1967, Ecology of principal waterfowl foods of Laguna Madre: Texas Parks and Wildlife

Dept., Federal Aid in Wildlife Restoration Act, Texas, Job Progress Rept. No. 17.

Parker, R. H., 1959, Macro-invertebrate assemblages of central Texas coastal bays and Laguna Madre: Am Assoc. Petroleum Geologists Bull., v. 43, p. 2100-2166.

_______ 1960, Ecology and distributional patterns of marine macro-invertebrates, northern Gulf of Mexico, *in* Shepard, F. P., Phleger, F. B., and van Andel, T. H., eds., Recent sediments, northwest Gulf of Mexico: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 302-337.

Siler, W. L., and Scott, A. J., 1964, Biotic assemblages, south Texas coast, *in* Depositional environments, south-central Texas coast: Gulf Coast Assoc. Geol. Socs., Annual Field Trip Guidebook, p. 137-157. Prepared by Corpus Christi Geol. Soc. and Univ. Texas.

Simmons, E. G., 1957, Ecological survey of the upper Laguna Madre of Texas: Univ. Texas, Marine Sci. Inst. Pub., v. 4, no. 2, p. 156-200.

Buried river valleys—

Behrens, E. W., 1963, Buried Pleistocene river valleys in Aransas and Baffin Bays, Texas: Univ. Texas, Marine Sci. Inst. Pub., v. 9, p. 7-18.

Fisk, H. N., 1959, Padre Island and the Laguna Madre flats, coastal south Texas: La. State Univ., 2d Coastal Geography Conf., April 1959, p. 103-151.

Census, cultural—

Bureau of Business Research, 1967-1972, Texas Business Review: Univ. Texas, Austin, Bur. Business Research.

Bureau of Census, 1962, 1967, and 1972, City and county data book: U. S. Dept. Commerce, Bur. Census.

The Dallas Morning News, 1972, Texas almanac and state industrial guide: Dallas, Texas, A. H. Belo Corp.

Climatic data, evapotranspiration, rainfall, temperatures, wind—

Carr, J. T., Jr., 1967, The climate and physiography of Texas: Texas Water Devel. Board Rept. 53, 27 p.

Environmental Science Services Administration, 1965, Climatological data, Texas, annual summary, 1965: U. S. Dept. Commerce, Weather Bur., v. 70, no. 13, p. 449 [1966].

_______ 1966, Climatological data, Texas, annual summary, 1966: U. S. Dept. Commerce, Weather Bur., v. 71, p. 407-408 [1967].

_______ 1967, Climatological data, Texas, annual summary, 1967: U. S. Dept. Commerce, Weather Bur., v. 72, no. 13, p. 419-420 [1968].

Kohler, M. A., Nordenson, T. J., and Baker, D. R., 1959, Evaporation maps for the United States: U. S. Dept. Commerce, Weather Bur. Tech. Paper No. 37, 13 p.

Orton, Robert, 1964, The climate of Texas and the adjacent Gulf waters: U. S. Dept. Commerce, Weather Bur. Rept. 16, 195 p.

_______ 1969a, Map of Texas showing normal precipitation deficiency in inches: Austin, Texas, U. S. Dept. Commerce, Environmental Sci. Services Adm., Weather Bur.

_______ 1969b, Climates of the states—Texas: U. S. Dept. Commerce, Environmental Data Service, Climatography of the United States No. 60-41 (revised), 46 p.

Coastline construction, seawall, jetty, pier. See *topography* and *bathymetry*.

Culture. See *topography.*

Current land use. See *land use.*

Ditches and canals. See *water systems.*

Drainage. See *topography.*

Drainage systems. See *water systems.*

Engineering information. See *soil data.*

Eolian processes and deposits, Texas Coastal Zone—

Beck, M. W., and Henderson, B. H., 1928, Soil survey of Cameron County, Texas: U. S. Bur. Chemistry and Soils, ser. 1923, no. 17, p. 537-575.

Coffey, George N., 1909, Clay dunes: Jour. Geology, v. 17, p. 754-755.

_______ 1912, Reconnaissance soil survey of south Texas: U. S. Bur. Soils Field Operations for 1909, p. 1029-1129.

Fisk, H. N., 1959, Padre Island and the Laguna Madre flats, coastal south Texas: La. State Univ., 2d Coastal Geography Conf., April 6-9, 1959, p. 103-151.

Huffman, G. G., and Price, W. A., 1949, Clay dune formation near Corpus Christi, Texas: Jour. Sed. Petrology, v. 19, no. 3, p. 118-127.

Price, W. A., 1933, Role of diastrophism in topography of Corpus Christi area, south Texas: Am. Assoc. Petroleum Geologists Bull., v. 17, no. 8, p. 907-962.

_______ 1958, Sedimentology and Quaternary geomorphology of south Texas: Gulf Coast Assoc. Geol. Socs. Trans., v. 8, p. 41-75.

_______ 1963, Physiochemical and environmental factors in clay dune genesis: Jour. Sed. Petrology, v. 33, p. 766-778.

_______, and Kornicker, L. S., 1961, Marine and lagoonal deposits in clay dunes, Gulf Coast, Texas: Jour. Sed. Petrology, v. 31, no. 2, p. 245-255.

U. S. Eolian Map, 1952, Pleistocene eolian deposits of the United States, Alaska, and parts of Canada: Natl. Research Council, Comm. for Study of Eolian Deposits, Div. of Geology and Geography Map 4 sections, 1:2,500,000.

Evapotranspiration. See *climatic data.*

Gas fields. See *oil and gas fields.*

Geology of the Texas Gulf coast, background information—

Barton, D. C., 1930a, Deltaic coastal plain of southeastern Texas: Geol. Soc. America Bull., v. 41, p. 359-382.

_______ 1930b, Surface geology of coastal southeast Texas: Am. Assoc. Petroleum Geologists Bull., v. 14, p. 1301-1320.

Bernard, H. A., and LeBlanc, R. J., 1965, Resume of the Quaternary geology of the northwestern Gulf of Mexico province, *in* Wright, H. E., Jr., and Frey, D. G., eds., The Quaternary of the United States: Princeton, N. J., Princeton Univ. Press, p. 137-185.

Curray, J. R., 1960, Sediments and history of Holocene transgression, continental shelf, northwest Gulf of Mexico, *in* Shepard, F. P., Phleger, F. B., and van Andel, T. H., eds., Recent sediments, northwest Gulf of Mexico: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 221-266.

Deussen, A., 1924, Geology of the coastal plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, 139 p.

Doering, J., 1956, Review of Quaternary surface formations of Gulf Coast region: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 1816-1862.

Fisher, W. L., McGowen, J. H., Brown, L. F., Jr., and Groat, C. G., 1972, Environmental geologic atlas of the Texas Coastal Zone—Galveston-Houston area: Univ. Texas, Austin, Bur. Econ. Geology, 91 p., 9 maps.

Frazier, D. E., 1974, Depositional-episodes: Their relationship to the Quaternary stratigraphic framework in the northwestern portion of the Gulf Basin: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 74-1, 28 p.

Galtsoff, P. S., ed., 1965, Gulf of Mexico: its origin, waters, and marine life: U. S. Dept. Interior, Fish and Wildlife Service Fishery Bull. 89, 604 p.

Hunter, R. E., Watson, R. L., Hill, G. W., and Dickinson, K. A., 1972, Geology of Padre Island, Part I: Modern depositional environments and processes, northern and central Padre Island, Texas: Gulf Coast Assoc. Geol. Socs., Padre Island Natl. Seashore Field Guide, pt. I, p. 1-27.

LeBlanc, R. J., and Hodgson, W. D., 1959, Origin and development of the Texas shoreline: Gulf Coast Assoc. Geol. Socs. Trans., v. 9, p. 197-220.

Lohse, E. A., 1952, Shallow marine sediments of the Rio Grande delta: Univ. Texas [Austin], Ph.D. dissert., 113 p.

McGowen, J. H., and Garner, L. E., 1972, Relation between Texas barrier islands and late Pleistocene depositional history (abst.): Am. Assoc. Petroleum Geologists Bull., v. 56, no. 3, p. 638-639.

Murray, G. E., 1947, Cenozoic deposits of the Gulf Coastal Plain: Am. Assoc. Petroleum Geologists Bull., v. 31, p. 1825-2850.

_______ 1961, Geology of the Atlantic and Gulf coastal province of North America: New York, Harper and Brothers, 692 p.

Nelson, H. F., and Bray, E. E., 1970, Stratigraphy and history of the Holocene sediments in the Sabine-High Island area, Gulf of Mexico, *in* Morgan, J. P., and Shaver, R. H., eds., Deltaic sedimentation, modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. No. 15, p. 48-77.

Price, W. A., 1933, Role of diastrophism in topography of the Corpus Christi area, south Texas: Am. Assoc. Petroleum Geologists Bull., v. 17, no. 8, p. 907-962.

_______ 1947, Geomorphology of depositional surfaces: Am. Assoc. Petroleum Geologists Bull., v. 31, p. 1784-1800.

_______ 1954, Shorelines and coasts of the Gulf of Mexico, *in* Gulf of Mexico, its origin, waters, and marine life: U. S. Dept. Interior, Fish and Wildlife Service Fishery Bull. 89, p. 39-65.

_______ 1958, Sedimentology and Quaternary geomorphology of south Texas: Gulf Coast Assoc. Geol. Socs. Trans., v. 8, p. 41-75.

_______, and Gunter, Gordon, 1943, Certain recent geological and biological changes in south Texas, with consideration of probable causes: Texas Acad. Sci. Proc. and Trans., v. 26, p. 138-156.

Scott, A. J., Hayes, M. O., Andrews, P. B., Siler, W. L., and Behrens, E. W., 1964, Depositional environments, south-central Texas coast: Gulf Coast Assoc. Geol. Socs., Field Trip Guidebook, 170 p.

Shepard, F. P., Phleger, F. B., and van Andel, T. H., eds., 1960, Recent sediments, northwest Gulf of Mexico: Tulsa, Okla., Am. Assoc. Petroleum Geologists, 394 p.

Weeks, A. W., 1945, Quaternary deposits of Texas coastal plain between Brazos River and Rio Grande: Am. Assoc. Petroleum Geologists Bull., v. 29, no. 12, p. 1693-1720.

Wilkinson, B. H., 1973, Matagorda Island—The evolution of a Gulf Coast barrier complex: Univ. Texas, Austin, Ph.D. dissert., 178 p. [1974].

_______, McGowen, J. H., and Lewis, C. R., 1975, Ingleside strandplain sand of central Texas coast: Am. Assoc. Petroleum Geologists Bull., v. 59, no. 2, p. 347-352.

Glaciation sea-level changes—

Curray, J. R., 1960, Sediments and history of Holocene transgression, continental shelf, northwest Gulf of Mexico, *in* Shepard, F. P., Phleger, F. B., and van Andel, T. H., eds., Recent sediments, northwest Gulf of Mexico: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 221-266.

Frazier, D. E., 1974, Depositional-episodes: Their relationship to the Quaternary stratigraphic framework in the northwestern portion of the Gulf Basin: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 74-1, 28 p.

Lundelius, E. L., Jr., 1972, Fossil vertebrates from the Late Pleistocene Ingleside fauna, San Patricio County, Texas: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 77, 74 p.

Nelson, H. F., and Bray, E. E., 1970, Stratigraphy and history of the Holocene sediments in the Sabine-High Island area, Gulf of Mexico, *in* Morgan, J. P., and Shaver, R. H., eds., Deltaic sedimentation, modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. No. 15, p. 48-77.

Shepard, F. P., 1960, Rise of sea level along northwest Gulf of Mexico, *in* Shepard, F. P., Phleger, F. B., and van Andel, T. H., eds., Recent sediments, northwest Gulf of Mexico: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 338-344.

Government land. See *land use information.*

Ground water, aquifers—

Shafer, G. H., and Baker, E. T., Jr., 1973, Ground-water resources of Kleberg, Kenedy, and southern Jim Wells Counties, Texas: Texas Water Devel. Board Rept. 173, 162 p.

Woodman, J. T., 1975, Availability of ground water, Coastal Bend region, Texas: Univ. Texas, Austin, Master's thesis, 119 p.

Hazards, natural impact on Coastal Zone—

Brown, L. F., Jr., Morton, R. A., McGowen, J. H., Kreitler, C. W., and Fisher, W. L., 1974, Natural hazards of the Texas Coastal Zone: Univ. Texas, Austin, Bur. Econ. Geology, 13 p., 7 maps.

Highway information—

Texas Highway Department, General highway maps: Texas Highway Dept., in coop. with U. S. Dept. Commerce, Bur. Public Roads.

Hurricane Beulah, effects—

U. S. Army Corps of Engineers, 1968, Report on Hurricane Beulah 8-21 September 1967: U. S. Army Corps Engineers, Galveston Dist., 26 p., tables, plates.

Hurricane Carla, effects—

U. S. Army Corps of Engineers, 1962, Report on Hurricane Carla 9-12 September 1961: U. S. Army Corps Engineers, Galveston Dist., 29 maps, tables, plates.

Hurricanes, impact sites on Texas coast—

Carr, A. J., 1969, Hurricanes affecting the Texas Gulf Coast: Texas Water Devel. Board Rept. 49, 58 p.

Cry, G. W., 1965, Tropical cyclones of the north Atlantic Ocean, tracks and frequencies of hurricanes and tropical storms, 1871-1963: U. S. Dept. Commerce, Weather Bur. Tech. Paper No. 55, 148 p.

Hayes, M. O., 1967, Hurricanes as geological agents: Case studies of Hurricanes Carla, 1961, and Cindy, 1963: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 61, 56 p.

McGowen, J. H., Groat, C. G., Brown, L. F., Jr., Fisher, W. L., and Scott, A. J., 1970, Effects of Hurricane Celia—A focus on environmental geologic problems of the Texas Coastal Zone: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 70-3, 35 p.

Hurricanes, nature—

McGowen, J. H., 1974, Hurricanes, *in* Brown, L. F., Jr., and others, Natural hazards of the Texas Coastal Zone: Univ. Texas, Austin, Bur. Econ. Geology, 13 p., 7 maps.

Scott, A. J., Hoover, R. A., and McGowen, J. H., 1969, Effects of Hurricane Beulah, 1967, on coastal lagoons and barriers, *in* Castañares, A. A., and Phleger, F. B., eds., Lagunas Costeras, Un simposio: Mexico City, Universidad Nacional Autónoma de México, UNAM-UNESCO, Mem. Simp. Internatl. Lagunas Costeras, p. 221-236.

Industrial land. See *land use information.*

Impact sites. See *hurricanes.*

Intracoastal canals. See *water systems.*

Jetty. See *coastline construction.*

Lakes and ponds, natural. See *water systems.*

Land and water resources of the Coastal Zone, general background—

Brown, L. F., Jr., Fisher, W. L., Erxleben, A. W., and McGowen, J. H., 1971, Resource capability units—Their utility in land- and water-use management with examples from the Texas Coastal

Zone: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 71-1, 22 p.

Fisher, W. L., McGowen, J. H., Brown, L. F., Jr., and Groat, C. G., 1972, Environmental geologic atlas of the Texas Coastal Zone—Galveston-Houston area: Univ. Texas, Austin, Bur. Econ. Geology, 91 p., 9 maps.

Fruh, E. G., and others, 1972, The management of bay and estuarine systems: Austin, Texas, Office of the Governor, Coastal Resources Management Program, p. F1—F36.

Goodwin, J. T., and Moseley, J. C., eds., 1971, The coastal resources management program of Texas, appendices to the interim report: Austin, Texas, The Interagency Nat. Resources Council of Texas, Vols. I, II.

McGowen, J. H., Groat, C. G., Brown, L. F., Jr., Fisher, W. L., and Scott, A. J., 1970, Effects of Hurricane Celia—A focus on environmental geologic problems of the Texas Coastal Zone: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 70-3, 35 p.

St. Clair, A. E., Proctor, C. V., Jr., Fisher, W. L., Kreitler, C. W., and McGowen, J. H., 1975, Land and water resources—Houston-Galveston Area Council: Univ. Texas, Austin, Bur. Econ. Geology, Land Resources Lab. Series, 25 p.

Land use information—

Edgar Tobin Aerial Surveys, Aerial photographic mosaics: San Antonio, Texas, Edgar Tobin Aerial Surveys.

U. S. Geological Survey, Topographic maps of Texas: Denver, Colo., U. S. Geol. Survey.

Man-made features. See *specific listings.*

Mineral and energy resources. See *specific listings.*

Mineral industry—

Girard, R. M., 1970, Texas mineral producers: Univ. Texas, Austin, Bur. Econ. Geology, 62 p.

Jones, O. W., Netzeband, F. F., and Girard, R. M., 1969, The mineral industry of Texas, *in* Minerals yearbook 1969, v. III, Area reports: Domestic: U. S. Bur. Mines, p. 701-736 [1971]. *Reprinted as* Univ. Texas, Austin, Bur. Econ. Geology Mineral Resource Circ. No. 52, 36 p., 1970.

Netzeband, F. F., and Girard, R. M., 1968, The mineral industry of Texas, *in* Minerals yearbook 1968, v. III, Area reports: Domestic: U. S. Bur. Mines, p. 695-729 [1970]. *Reprinted as* Univ. Texas, Austin, Bur. Econ. Geology Mineral Resource Circ. No. 51, 35 p., 1969.

U. S. Bureau of Mines, 1968, Minerals yearbook 1968: U. S. Bur. Mines, v. 1-3, 2046 p. [1970].

Zaffarano, R. F., Girard, R. M., and Slatick, E. R., 1970, The mineral industry of Texas, *in* Minerals yearbook 1970, v. II, Area reports: Domestic: U. S. Bur. Mines, p. 681-712 [1972]. *Reprinted as* Univ. Texas, Austin, Bur. Econ. Geology Mineral Resource Circ. No. 53, 32 p., 1972 [1973].

Mosaics. See *aerial photographs.*

Offshore platforms. See *bathymetry and pipelines.*

Oil and gas fields, location—

Transcontinental Gas Pipe Line Corporation, 1970, Map of Texas Gulf coast and Texas continental shelf showing natural gas pipe lines: Houston, Texas, Transcontinental Gas Pipe Line Corporation, Gas Supply Dept., prepared by M. F. Stanley and R. W. Evans.

Oil and gas fields, production—

Railroad Commission of Texas, 1973a, Annual report of the Oil and Gas Division: Railroad Comm. of Texas, Oil and Gas Div., 100 p.

_______ 1973b, Inactive oil and gas fields, 1973: Railroad Comm. of Texas, Oil and Gas Div., 233 p.

_______ 1973c, Oil and gas annual production by active fields, 1973: Railroad Comm. of Texas, Oil and Gas Div., 193 p.

Oolites, origin—

Behrens, E. W., 1964, Oolite formation in Baffin Bay and Laguna Madre, Texas, *in* Depositional environments, south-central Texas coast: Gulf Coast Assoc. Geol. Socs., Field Trip Guidebook (A. J. Scott, leader), p. 83-100.

Dalrymple, D. W., 1964, Recent sedimentary facies of Baffin Bay, Texas: Rice Univ., Ph.D., dissert., 192 p.

Freeman, T., 1962, Quiet water oolites from Laguna Madre, Texas: Jour. Sed. Petrology, v. 32, p. 475-483.

Frishman, S. A., 1969, Geochemistry of oolites, Baffin Bay, Texas: Univ. Texas, Austin, Master's thesis, 82 p.

Physical properties data. See *soil data.*

Pier. See *coastline construction.*

Pipelines and offshore platforms, location—

Railroad Commission of Texas, 1971, Map of Gulf coast area showing pipelines that carry liquid hydro-carbons and products exclusive of dry gas: Railroad Comm. of Texas.

Transcontinental Gas Pipe Line Corporation, 1970, Map of Texas Gulf coast and Texas continental shelf showing natural gas pipe lines: Houston, Texas, Transcontinental Gas Pipe Line Corporation, Gas Supply Dept., prepared by M. F. Stanley and R. W. Evans.

Pipelines. See *topography.*

Pits. See *quarry sites.*

Power-generation plants and distribution systems—

Federal Power Commission, 1974, Principal electric facilities, south-central region: Fort Worth, Texas, Federal Power Comm., Bur. of Power, map.

U. S. Geological Survey, Topographic maps of Texas: Denver, Colo., U. S. Geol. Survey.

Quarry sites—

Edgar Tobin Aerial Surveys, Aerial photographic mosaics: San Antonio, Texas, Edgar Tobin Aerial Surveys.

U. S. Geological Survey, Topographic maps of Texas: Denver, Colo., U. S. Geol. Survey.

Rainfall. See *climatic data.*

Recreational land, general. See *land use information.*

Reefs, serpulid, nature and location—

Andrews, P. B., 1964, Serpulid reefs, Baffin Bay, southeast Texas, *in* Depositional environments, south-central Texas coast: Gulf Coast Assoc. Geol. Socs., Field Trip Guidebook (A. J. Scott, leader), p. 101-120.

Breuer, J. P., 1957, An ecological survey of Baffin and Alazan Bays, Texas: Univ. Texas, Marine Sci. Inst. Pub., v. 4, no. 2, p. 134-155.

Rusnak, G. A., 1960, Sediments of Laguna Madre, Texas, *in* Shepard, F. P., Phleger, F. B., and van Andel, T. H., eds., Recent sediments, northwest Gulf of Mexico: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 153-196.

Reservoirs, artificial. See *water systems.*

Residential-urban land. See *land use information.*

Salinity values, bay-estuarine-lagoon—

Breuer, J. P., 1957, An ecological survey of Baffin and Alazan Bays, Texas: Univ. Texas, Marine Sci. Inst. Pub., v. 4, no. 2, p. 134-155.

Hahl, D. C., and Ratzlaff, K. W., 1970, Chemical and physical characteristics of water in estuaries of Texas, September 1967-September 1968: Texas Water Devel. Board Rept. 117, 91 p.

Martinez, Rudy, 1965, Coastal hydrographic and meteorological study: Texas Parks and Wildlife Dept., Coastal Fisheries Proj. Rept., p. 169-210.

_______ 1966, Coastal hydrographic and meteorological study: Texas Parks and Wildlife Dept., Coastal Fisheries Proj. Rept., p. 105-146.

_______ 1967, Coastal hydrographic and meteorological study: Texas Parks and Wildlife Dept., Coastal Fisheries Proj. Rept., p. 77-112.

Schools. See *topography.*

Shorelines, erosional nature—

Morton, R. A., 1974, Shoreline erosion, *in* Brown, L. F., Jr., and others, Natural hazards of the Texas Coastal Zone: Univ. Texas, Austin, Bur. Econ. Geology, 13 p., 7 maps.

U. S. Army Corps of Engineers, 1971, Texas coast shores—Regional inventory report: U. S. Army Corps Engineers, Galveston Dist., 26 p., plates, maps.

Shoreline processes, Texas coast—

Brown, L. F., Jr., Morton, R. A., McGowen, J. H., Kreitler, C. W., and Fisher, W. L., 1974, Natural hazards of the Texas Coastal Zone: Univ. Texas, Austin, Bur. Econ. Geology, 13 p., 7 maps.

Bullard, F. M., 1942, Source of beach and river sands on the Gulf coast of Texas: Geol. Soc. America Bull., v. 53, no. 7, p. 1021-1044.

Hayes, M. O., 1965, Sedimentation on a semiarid, wave-dominated coast (South Texas) with emphasis on hurricane effects: Univ. Texas [Austin], Ph.D. dissert., 350 p.

Lohse, E. A., 1956, Dynamic geology of the modern coastal region, northwest Gulf of Mexico, *in* Finding ancient shorelines—A symposium: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. No. 3, p. 99-105.

McGowen, J. H., Groat, C. G., Brown, L. F., Jr., Fisher, W. L., and Scott, A. J., 1970, Effects of Hurricane Celia—A focus on environmental geologic problems of the Texas Coastal Zone: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 70-3, 35 p.

_______, and Brewton, J. L., 1975, Historical changes and related coastal processes, Gulf and mainland shorelines, Matagorda Bay area, Texas: Univ. Texas, Austin, Bur. Econ. Geology Spec. Pub., 72 p., 16 maps.

Morton, R. A., 1974a, Shoreline erosion, *in* Brown, L. F., Jr., and others, Natural hazards of the Texas Coastal Zone: Univ. Texas, Austin, Bur. Econ. Geology, 13 p., 7 maps.

_______ 1974b, Shoreline changes on Galveston Island (Bolivar Roads to San Luis Pass), An analysis of historical changes of the Texas Gulf shoreline: Univ. Texas, Austin, Bur Econ. Geology Geol. Circ. 74-2, 34 p.

_______ 1975, Shoreline changes between Sabine Pass and Bolivar Roads, An analysis of historical changes of the Texas Gulf shoreline: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 75-6, 43 p.

_______, and Pieper, M. J., 1975, Shoreline changes on Brazos Island and south Padre Island (Mansfield Channel to mouth of the Rio Grande), An analysis of historical changes of the Texas Gulf shoreline: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 75-2, 39 p.

Price, W. A., 1947, Equilibrium of form and forces in tidal basins of coast of Texas and Louisiana: Am. Assoc. Petroleum Geologists Bull., v. 31, p. 1619-1663.

Todd, T. W., 1968, Dynamic diversion: Influence of longshore current-tidal flow interaction on chenier and barrier-island plains: Jour. Sed. Petrology, v. 38, p. 734-746.

van Andel, T. H., 1960, Sources and dispersion of Holocene sediments, northern Gulf of Mexico, *in* Shepard, F. P., Phleger, F. B., and van Andel, T. H., eds., Recent sediments, northwest Gulf of Mexico: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 34-55.

_______, and Poole, D. H., 1960, Sources of Holocene sediments in the northern Gulf of Mexico: Jour. Sed. Petrology, v. 30, p. 91-122.

Watson, R. L., 1968, Origin of shell beaches, Padre Island, Texas: Univ. Texas, Austin, Master's thesis, 121 p.

_______ 1971, Origin of shell beaches, Padre Island, Texas: Jour. Sed. Petrology, v. 41, no. 4, p. 1105-1111.

_______ 1972, Longshore variations in beach sediment and origin of the shell beaches, *in* Modern depositional environments and processes, northern and central Padre Island, Texas: Gulf Coast Assoc. Geol. Socs., Padre Island Natl. Seashore Field Guide, pt. I, p. 17-24.

_______, and Behrens, E. W., 1970, Nearshore surface currents, southeast Texas Gulf Coast: Univ. Texas, Marine Sci. Inst., Contr. Marine Sci., v. 15, p. 133-143.

Sludge pits. See *topography.*

Soil data, engineering information, maps, soil-test data—

Franki, G. E., Garcia, R. N., Hajek, B. F., Arriaga, D., and Roberts, J. C., 1965, Soil survey of Nueces County, Texas: U. S. Dept. Agriculture, Soil Conserv. Service, ser. 1960, no. 26, 65 p., 79 aerial photographic maps.

Hawker, H. W., and Simmons, C. S., 1926, Soil survey of Willacy County: U. S. Dept. Agriculture, Bur. Soils, 57 p.

Kier, R. S., and Bell, D. L., 1974, Quantification of resource capability units, Corpus Christi area, *in* Wermund, E. G., ed., Approaches to environmental geology: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 81, p. 152-183.

U. S. Department of Agriculture, 1972, Soils of the Texas coastal basins—Their characteristics, uses, and problems, Appendix A of Texas Coastal Basins, V. 2: U. S. Dept. Agriculture, Soil Conserv. Service, 261 p.

Soil-test data. See *soil data.*

Solid-waste disposal site. See *waste disposal sites, solid.*

State Parks, location—

Texas Parks and Wildlife Department, Unpublished data: Austin, Texas Parks and Wildlife Dept.

Stream discharge, historical records—

U. S. Geological Survey, 1965, Water resources data for Texas, Part 1, Surface water records: U. S. Geol. Survey, Water Resources Div., 509 p.

_______ 1966, Water resources data for Texas, Part 1, Surface water records: U. S. Geol. Survey, Water Resources Div., 495 p.

_______ 1967, Water resources data for Texas, Part 1, Surface water records: U. S. Geol. Survey, Water Resources Div., 536 p.

_______ 1970, Index of surface water stations in Texas, October 1970: U. S. Geol. Survey, Water Resources Div., 27 p.

Temperatures. See *climatic data.*

Topography, base map, culture, drainage, schools, sewage sites, sludge pits, some pipelines, other data—

U. S. Geological Survey, Topographic maps of Texas: Denver, Colo., U. S. Geol. Survey.

Urban land, undifferentiated. See *land use information.*

Utility lines or cables. See *topography* and *power-generation plants.*

Waste disposal sites, solid—

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

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

Water resources. See *ground water, aquifers.*

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

Wind. See *climatic data.*

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KINGSVILLE AREA

GENERAL SETTING

The Environmental Geologic Atlas of the Kingsville area covers a region of 2,324 square miles, excluding offshore areas. Included in the map area are major parts of Kenedy and Kleberg Counties and a small part of eastern Brooks County, Texas. The area includes the city of Kingsville, Kingsville Naval Air Station, and the small towns or hamlets of Sarita, Mifflin, Norias, Ricardo, Riviera Beach, Riviera, Loyola Beach, Armstrong, and Rudolph. Numerous large ranches, including various divisions of the Kenedy and King Ranches, occupy most of the area; these include the King, Armstrong, Ball, San Pedro, Los Indios, Carnestolendas, Parra, Aqui Paso, Santa Rosa, Crocker, La Paloma, Santa Cruz, and Jabancillos Ranches. Approximately 100 square miles of Padre Island National Seashore occur within the Kingsville map area, including Malaquite Beach Development.

Approximately 2,127 square miles of land occur within the Kingsville map area. The Kingsville area is a region of broad, dune-covered mainland prairies and extensive coastal wind-tidal flats; the distinctive Padre Island lies gulfward of Laguna Madre and Baffin Bay. The area, which has been defined as part of the Coastal Bend of Texas, is an arid, desertlike region where wind (eolian) erosion and wind-transported sediment have determined much of the area's character and distinctiveness. The Kingsville area owes much of its uniqueness to a climate of low rainfall, high evaporation, and persistent onshore winds. The region south of Baffin Bay and Olmos Creek, where wind processes dominate, has been called the "South Texas sand sheet" because it is predominantly a region of loose, sandy soils and active and relict sand dunes.

Extensive, hummocky prairies within the South Texas sand sheet are underlain by relict sand dunes and wind-deflated depressions which extend inland from broad wind-tidal flats along the landward margin of Laguna Madre and parts of Baffin Bay. Numerous active sand dunes are distributed throughout the eastern part of the rough, sandy prairie. Relict dune fields and wind-deflated prairies extend westward far beyond the boundary of the Kingsville map area. Flat upland clay prairies north of the sand sheet extend southward from the Corpus Christi area into the region north of Baffin Bay.

Sandy prairies within the South Texas sand sheet are occupied by sparse grasses, but the clay prairies north of Baffin Bay are characterized by better developed grass cover. Thick stands of live oak (mottes) occupy extensive areas underlain principally by relict, wind-sculptured sand dunes. A large area of oak mottes occurs immediately east and southeast of Sarita; another major oak forest extends from the vicinity of Norias southeastward to Port Mansfield (Brownsville-Harlingen map area). Other smaller areas of live-oak mottes occur west of U. S. Highway 77 between Sarita and Norias. Large tracts of dense brushland extend southward from Norias to the vicinity of Raymondville in the northern part of the Brownsville-Harlingen map area. Other areas of brushland occur north of Olmos Creek and west of San Fernando Creek in the northwestern part of the map area; smaller tracts of brush occupy local sandy areas north of Baffin Bay.

Live-oak mottes, stands of brushland, and active sand dunes break the widespread sandy prairies of the Kingsville area into many local, discontinuous patches of rangeland. A few small ephemeral streams that extend coastward across the northern and northwestern parts of the area discharge into Baffin Bay. These stream courses are flanked by sparse tree vegetation. A very narrow (unmapped) belt of salt- and fresh- to brackish-water marsh occurs along the landward shore of Laguna Madre and Baffin Bay. Small patches of seasonal fresh-water marsh and poorly drained depressions occupied by high-moisture plants occur in the northernmost part of the Kingsville map area; fresh-water marsh occupies the margins of ephemeral ponds within blowout areas in the sand dune fields.

The coastal plain is gently but irregularly inclined gulfward at about 5 feet or less per mile; in many areas, slopes range from 1 to 3 feet per mile, and on the lagoonal wind-tidal flats, slopes less than 1 foot per mile are the rule. The topographic configuration of the South Texas sand sheet within the Kingsville area dramatically portrays the dominant effect of the southeasterly wind regime. Active and relict sand dunes and wind-deflation troughs within the sand sheet are aligned parallel with the southeasterly winds. Wind acting on the dry, sandy coastal plain has imposed a strong, northwest-southeast linearity to many topographic and vegetational features.

Maximum elevations of about 125 feet above mean sea level (MSL) occur in the extreme northwestern part of the area near Escondido and Tulosa Lakes; highest elevations are restricted to the western boundary of the map area. Local relief of 5 to 20 feet occurs along elongate, relict sand dune ridges, but greatest local relief is exhibited by conical-to-elongate clay and sand dunes that rise 30 to 40 feet above the coastal plain north and west of Baffin Bay. Active clay and sand dunes along the margin of Baffin Bay and adjacent to many playa lakes rise 15 to 25 feet above the surrounding tidal flats and prairies. A 2-mile-wide belt of relict barrier island sand along the mainland shore of Laguna Madre north of Baffin Bay rises 20 to 25 feet above the lagoon. For more than 8 miles along the relict sand deposit, the wind has sculptured the surface into elongate ridges and swales aligned parallel with the prevailing southeasterly winds.

Instead of extensive, low coastal marshlands and swamps that characterize the upper and middle Texas Coastal Zone, shorelines in the arid Coastal Bend region of Texas are dominated by sandy wind-tidal flats. Wind-tidal activity extends up to 3 or 4 feet above sea level along the western side of Padre Island and much of the mainland shoreline along Laguna Madre and Baffin Bay. The most extensive wind-tidal flats occupy the Land-Cut Area where Laguna Madre has been filled by sand transported from Padre Island by persistent southeasterly winds and short-lived hurricane tides. Both northerly winds and southeasterly winds may push water from Laguna Madre and Baffin Bay far across the tidal flats; hurricane tides invariably flood the wind-tidal flats.

Padre Island is a narrow strip of sand that separates Laguna Madre from the open Gulf of Mexico. Extending north-south across the Kingsville map area, Padre Island protects Laguna Madre, Baffin Bay, and the mainland from the full impact of Gulf storms. Padre Island extends less than 5 to 10 feet above sea level except along fore-island and back-island sand dunes which may locally exhibit 20 to 30 feet of relief. Grasses cover the barrier flats except where Padre Island has been breached by hurricane surge.

Olmos, Santa Gertrudis, San Fernando, Tunas, and Petronila Creeks, as well as several small unnamed streams, course eastward or southeastward to enter Baffin Bay via Laguna de los Olmos, Cayo del Grullo, and Alazan Bay. No creeks discharge directly into Laguna Madre in the Kingsville map area. All creeks in the Kingsville region are ephemeral streams occupying small valleys incised 5 to 15 feet into the coastal plain. Streams entering Laguna de los Olmos and Cayo del Grullo originate in the high region west and northwest of U. S. Highway 77; streams that discharge into Alazan Bay, on the other hand, head in the flat, clay prairies north of Baffin Bay beyond the north boundary of the Kingsville map area. No streams exist in the South Texas sand sheet south of Baffin Bay and Olmos Creek because the region is dominated by active wind erosion, transportation, and deposition. Existing drainage systems are small, localized, and not integrated. The volume of rainfall that accompanies hurricanes cannot be discharged by the small drainage systems and, therefore, broad areas of the sand sheet may be flooded for weeks following passage of a major storm. In the northern part of the Kingsville map area, discharge from ephemeral streams is limited principally to periods of intense hurricane-aftermath rainfall.

Approximately 85 percent of the map area is underlain by sandy sediments and various associated sandy soils of the South Texas sand sheet. In some areas, however, these sediments and soils are only a thin veneer covering muddy sediments. Highly impermeable mud and silt substrates and soils are principally restricted to the flat upland prairies north of Cayo del Grullo and Santa Gertrudis Creek. Sandy and silty sediments occupy ancient river courses 0.5 mile to 2 miles wide that trend coastward across these upland coastal prairies; the relict river deposits terminate into mud-veneered deltaic sediments along the northeast and northwest shores of Cayo del Grullo and Alazan Bay, respectively. These ancient river courses generally display less than 5 feet of local relief on the flat muddy prairies, but near their termini, such as in the vicinity of Madero Lake and Jabancillos Ranch, erosion has produced up to 15 feet of local relief.

In a broad area southwest of Santa Gertrudis Creek and Cayo del Grullo, mud and sand substrates are veneered by relatively thin airborne silt (loess) deposits that have settled out downwind from the large dune fields southeast of Sarita (called the Sarita eolian sand lobe).[2] Wind deflation or erosion of blowout areas within the Sarita dune field provides sand for the active dunes, as well as silt and clay particles which are picked up and transported northwestward by the prevailing winds. The silt or loess sheet overlies muddy sediments between U. S. Highway 77 and Cayo del Grullo and sandy and silty deposits west of U. S. Highway 77.

Relatively thick eolian or wind-deposited sands occur beneath active and relict dune fields of the South Texas sand sheet. The two largest dune fields, the Sarita and Norias eolian sand lobes, are underlain by extensive eolian sands. Other belts of similar, older eolian sand trend northwest-southeast across the Kingsville map area between Armstrong and Mifflin. A thick belt or relict shoreline sand about 2 miles wide occurs along the mainland side of Laguna Madre north of Baffin Bay. Padre Island is composed principally of sand and shell; active sand dune fields occupy large areas along the western or landward side of Padre Island. Most of the extensive tidal flats in the Kingsville area are sandy, although muddy sands occur locally on the flats between the Intracoastal Waterway and the mainland.

[2]Principal elements of the South Texas sand sheet have been informally named in this Atlas to facilitate their description and discussion. The reader may refer to p. 73-81 and figure 21 for a detailed description of these elements. Included in the informal names are the following: Sarita eolian sand lobe, San Pedro Ranch eolian sand lobe, Norias eolian sand lobe, Parra Lake deflation area, Candelaria Lake-Santa Rosa Ranch deflation complex, El Jardin deflation area, Riviera loess sheet, Lasara loess-veneered caliche, Rudolph sand and loess plains, and Raymondville alluvial plain. Some names (Sarita, Norias) come from usage of previous workers (Price, 1958).

Baffin Bay and Laguna Madre occupy approximately 185 square miles. Laguna Madre is generally less than 3 feet deep except for several areas along the center of the lagoon where depths locally reach 8 feet. The central part of Baffin Bay ranges from 6 to 11 feet, but much of the bay and its various arms range in depth from 3 to 6 feet. The Intracoastal Waterway extends north-south along the entire length of Laguna Madre. The channel has been dredged several feet into the bottom of the lagoon, except in the Land-Cut Area, where the channel cuts across more than 20 miles of subaerial sediment that fills a large part of Laguna Madre. Minor boat channels have been dredged from the Intracoastal Waterway to oil well sites in the lagoon and on the wind-tidal flats.

There are no tidal passes between Laguna Madre and the Gulf of Mexico; Yarborough Pass, which was dredged across Padre Island near the south end of Little Shell Beach, has not been maintained by dredging and is presently closed and partially filled with sediment. Laguna Madre and Baffin Bay are commonly hypersaline with salinity values considerably higher than normal marine salinity levels. High evaporation rates, low rainfall, and isolation from tidal passes combine to produce hypersaline conditions. North of the Land-Cut Area, Laguna Madre and Baffin Bay communicate with the Gulf via Corpus Christi Bay and Aransas Pass. South of the Land-Cut Area, Laguna Madre is connected to the Gulf through Mansfield Pass and Brazos Santiago Pass (Brownsville-Harlingen map area). The Intracoastal Waterway has decreased average salinities in northern Laguna Madre and Baffin Bay by improving circulation via Mansfield Pass. Flooding following hurricanes and tropical storms is the only mechanism for significant freshening of Baffin Bay and northern Laguna Madre.

RESOURCE ACTIVITIES

Land use within the area is restricted principally to ranching. Several large ranch corporations account for most of the beef production in the region. Cattle production occupies most of the land within the Kingsville map area including potreros and rincons on the wind-tidal flats.

Dense live-oak mottes and brushland, which may locally hinder effective ranch operations, are sites of abundant wildlife, including game animals and birds. Wind-deflated depressions or cayos provide water and marsh plants for migratory waterfowl, as well as water for deer and other wildlife. Active sand dunes are essentially barren of game, although a variety of wildlife occupies several habitats in the large dune fields. Some crops are grown southwest of Cayo del Grullo-San Fernando Creek on loess-covered prairies. These are principally grains and silage for local cattle production, although a variety of dryland truck crops and some fruits are grown for local markets. Extensive areas have been cleared of brush and reseeded with a variety of grasses by the large ranch corporations. Some areas originally cleared for crops lie fallow and now serve as pasture land.

Commercial and sport fishing in Laguna Madre and Baffin Bay is an important industry, although many fishermen operate out of Port Mansfield and Corpus Christi. Fishing and recreational facilities are locally available at Loyola Beach and Riviera Beach at the western end of Baffin Bay; these areas have public access from U. S. Highway 77 at Riviera. Extensive fishing operations occur along the Intracoastal Waterway where fishermen occupy camps built on dredge spoil mounds belonging to the State of Texas. Beach fishing and other recreational activities occur the length of Padre Island National Seashore.

Oil and gas fields with interconnecting pipelines are distributed throughout the Kingsville area, but no refining or chemical facilities occur in the map area. A few caliche pits southeast of Kingsville and along U. S. Highway 77 provide local road construction materials. Industries involved in processing agricultural products operate in the region. All public water supplies and most water used in ranching operations come from groundwater sources. The Goliad Formation is the principal aquifer within the map area. U. S. Highway 77 and the Missouri Pacific Railroad traverse north-south across the Kingsville map area. Other direct transportation connection with regions beyond the map area is via State Highways 285 and 141, which connect to the west with U. S. Highway 281. Kleberg County airport is the only public landing field in the area.

The Kingsville Naval Air Station is important to the economy of the immediate Kingsville vicinity. Texas A & I University at Kingsville is a major educational facility in South Texas. Headquarters of the famous King Ranch, with its well-known Santa Gertrudis cattle, is a major tourist attraction a few miles west of Kingsville along State Highway 141.

The region included in the Kingsville map area is principally rural and predominantly a ranching economy, except for petroleum production on the large ranches. Livestock and related products account for ten times the revenue derived from crop production. Population is less than one person per square mile, and most of the population is concentrated in Kingsville, the only trading and commercial center in the region.

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, river point-bar and flood deposition, and other processes.

Active and relict coastal systems in the Kingsville area (fig. 4) are divided into three principal groups based on their relative ages: (1) natural systems that originated more than 18,000 years B. P. (before present) during various interglacial periods of the *Pleistocene* ice age; (2) natural systems termed *Holocene* that originated between approximately 18,000 and 4,500 years B. P.; and (3) natural systems herein termed *Modern* that have been developing since about 4,500 years B. P. and are currently active (fig. 5). Carbon-14 dates (Nelson and Bray, 1970) indicate that, following numerous Late Pleistocene glacial and interglacial episodes, sea level began its final rise about 18,000 years B. P. (fig. 5C). Sea-level rise was punctuated by numerous stillstands and even some reversals. 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 it present level. At 4,500 years B. P., sea level stood approximately -10 feet MSL; it was at about this time that 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, point-bar, levee, and floodbasin deposits of Pleistocene or Holocene age can be interpreted as having been deposited in similar environments within an ancient river system. Many basic ideas about the geologic history of this region have been the result of studies by Price (1933, 1958).

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

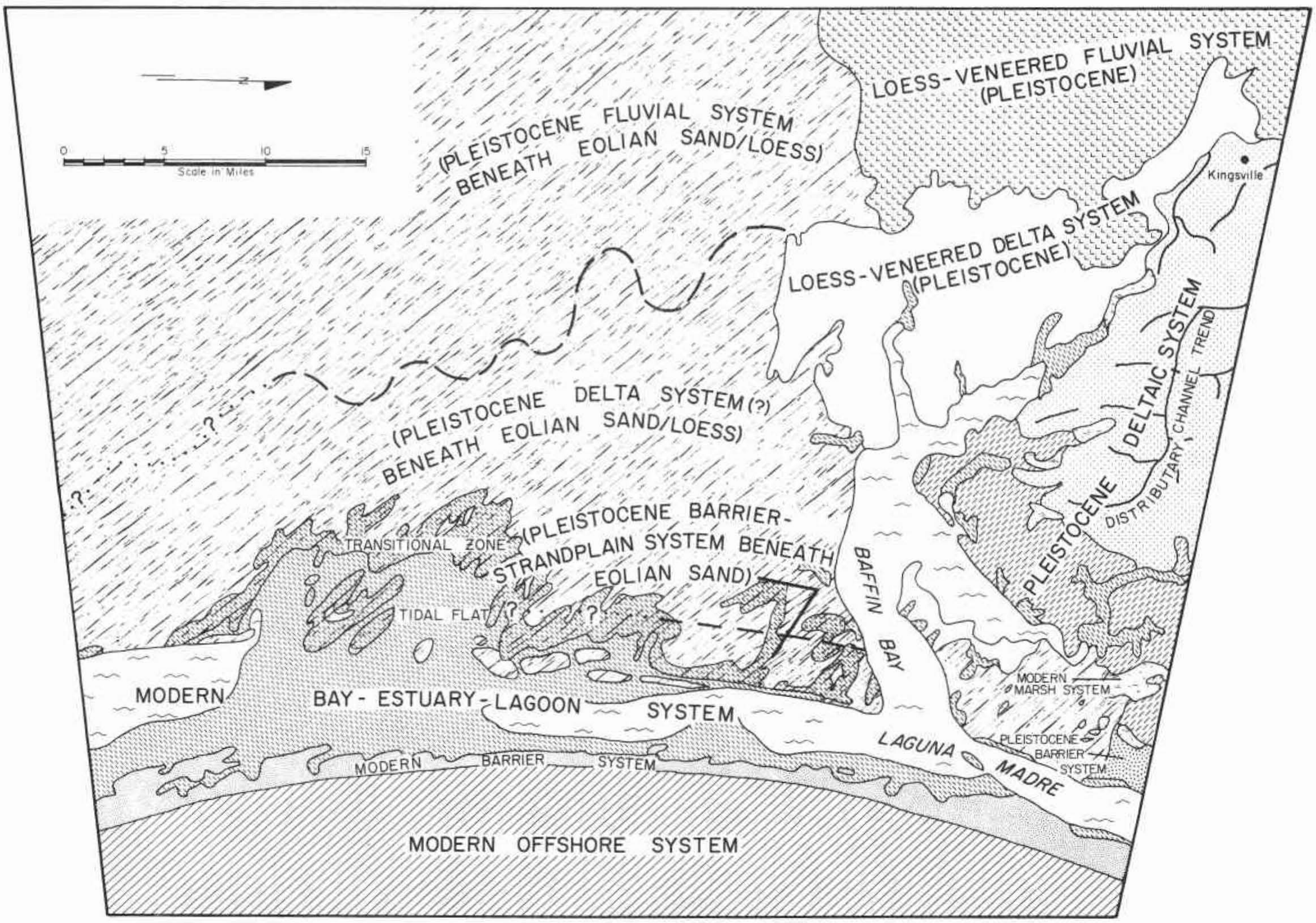


Figure 4. Natural systems defined by environmental mapping in the Kingsville area. These systems are composed of genetically related environments, sedimentary substrates, biologic assemblages, areas of significant physical processes, and man-made features. Refer to figure 21 for principal elements within the South Texas eolian system. Simplified from the *Environmental Geology Map* of the Atlas.

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

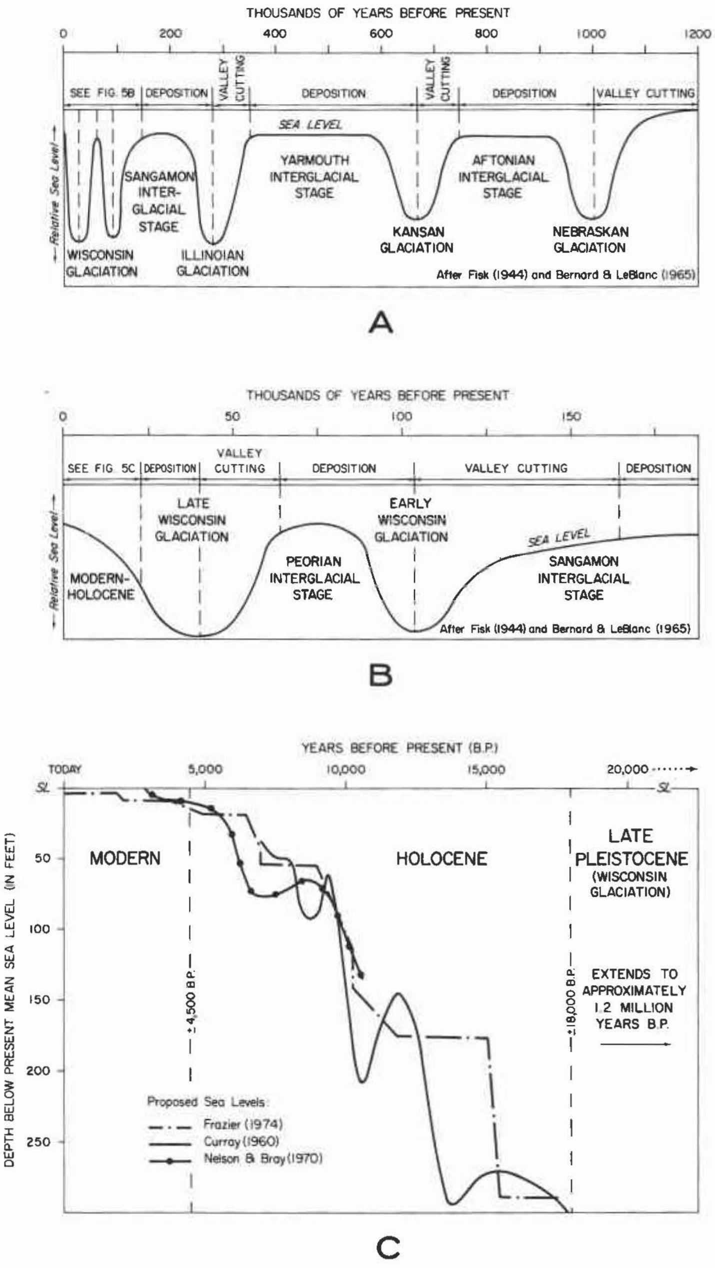


Figure 5. Sea-level changes related to glacial and interglacial stages. (A) Generalized Pleistocene sea-level variations and associated erosional and depositional episodes. (B) Generalized sea-level changes during late Wisconsin glaciation. (C) Proposed sea-level changes during the last 20,000 years;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

activities. Similarly, the sedimentary deposits of these older Pleistocene and Holocene systems dictate the character of soils, wildlife, vegetation, ground water, natural resources, and all manner of aspects that are important to the environmental quality of the region. For these reasons, it is critical that the nature of the environments, processes, and sediment substrates for all *active* coastal systems and the relict sedimentary substrates for all *ancient* coastal systems be determined and mapped so that a scientific basis for environmental management can be developed.

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

PLEISTOCENE HISTORY

The Pleistocene ice age encompassed more than a million years of complex glacial and interglacial climatic 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 interglacial 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 bedload 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 sands and floodplain mud deposits are presently covered by a thin, discontinuous veneer of loess (windblown silt) and sand within the Kingsville map area. Wind deflation has generated sand dunes, locally supplied with sand from underlying meanderbelt deposits. Playa lakes and clay dunes are concentrated in areas where wind deflation has eroded into shallow aquifers. About 160 square miles of Pleistocene fluvial facies possibly underlie a thin loess veneer west and southwest of Kingsville (fig. 4). An additional 350 to 400 square miles of Pleistocene fluvial facies probably underlie the eolian sand sheet, principally west of U. S. Highway 77; therefore, at least 500 square miles of Pleistocene fluvial sediments underlie loess and sand in the western one-third of the Kingsville map area. The Pleistocene river systems lie buried beneath the South Texas eolian system and extend inland beyond the western boundary of the Kingsville map area.

Meandering streams of the ancient Nueces River system changed coastward into relatively straight to slightly sinuous delta distributary courses extending across broad, low deltaic plains (fig. 4). Sand and mud deposits at the mouth of distributaries slowly extended the delta lobe into a broad embayment, 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 marine to brackish bays and lagoons fringed with salt marsh. Farther inland, interdistributary bays gave way to brackish- and fresh-water lakes and marsh and eventually to floodbasin swamps. Delta lobes became overextended as they built farther into the marine embayment. 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 exposed within the coastal upland prairies in the northern part of the Kingsville map area (fig. 4). The sand-filled distributary channel bodies are slowly subsiding into underlying delta mud, so that some segments are discontinuous and have been 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. Channel-mouth sandbars and prodelta mud deposits are now buried beneath younger floodbasin mud and silt. Approximately 140 square miles of exposed Pleistocene interdistributary and floodbasin mud and sandy distributary deposits occur within the Kingsville map area. Almost 65 square miles of delta-front mud and sand, principally veneered by thin loess, lacustrine muds, and clay-sand dunes, also occur on the north side of Cayo del Grullo and Alazan Bay (Baffin Bay); another 165 square miles of deltaic deposits underlie a thin veneer of loess principally between Baffin Bay and U. S. Highway 77 (fig. 4). At least 350 square miles of deltaic deposits lie buried beneath the extensive eolian sand sheet south of Baffin Bay and east of U. S. Highway 77. As much as 700 square miles of Pleistocene deltaic sediments are either exposed or buried beneath eolian deposits in the Kingsville map area.

The ancient delta presently exposed in the Kingsville area is the southeastern part of the late Pleistocene Nueces River system. It occurs principally in the Corpus Christi map area with several distributaries built southeastward into the area north of the present position of Baffin Bay. Age of the deltaic deposits presently exposed in the Kingsville area is questionable, but they were probably deposited during the Sangamon interglacial stage or possibly during a later Wisconsin interglacial stage such as the Peorian (fig. 5A, B). The Nueces delta system apparently terminated near the present Gulf shoreline, where distributary channel deposits plunge beneath mud-veneered deltaic deposits on the western side of Alazan Bay (Baffin Bay) and Laguna Larga (Corpus Christi map area). Near the boundary between the Corpus Christi and Kingsville map areas, deltaic sediments extend gulfward beneath the sands of the Pleistocene (Encinal-Ingleside) barrier-strandplain system (fig. 4); overlying Modern eolian sand deposits and fresh-water marsh locally obscure this relationship.

The trend of Pleistocene fluvial meanderbelts and deltaic distributaries beneath the eolian loess and sand sheets is speculative, but they probably are oriented essentially east-west in the Kingsville map area. Topographic grain in the loess-covered meanderbelt area southwest of Kingsville is oriented generally east-west. Some of the heavily vegetated, relatively inactive clay-sand dunes west of Baffin Bay are probably composed of sands locally deflated from these Pleistocene deposits by winds during unusually arid climatic cycles. Meanderbelt and distributary sand bodies of the Pleistocene Rio Grande delta system trend northeastward beneath the southeastern part of the Kingsville map area south of the Land-Cut Area; these deposits provide a local sand source for dunes of the Norias eolian sand lobe. Many of the banner dune fields and extensive dune trains in the central part of the Kingsville map area may be supplied locally with sand from subjacent Pleistocene meanderbelts and distributary channels.

Following abandonment of the Pleistocene Nueces delta in the region of the Corpus Christi and Kingsville map areas, marine destruction of the gulfward margin of the delta plain commenced as waves and currents reworked distributary and delta-front sands. Subsequent development of a cuspate delta at the mouth of the Nueces River (Corpus Christi map area) may have provided a significant supply of sand for the Gulf shorelines of the Coastal Bend region. Sands were redeposited locally as shoreface and beach deposits of a late Pleistocene barrier-strandplain system. Accretion of the shoreline resulted in deposition of successively younger beach ridges as the system built gulfward. Precise age of the barrier-strandplain system is uncertain, but it probably developed during a post-Sangamon Wisconsin interglacial stage, such as Peorian (fig. 5A, B). Age relations have been discussed by Bernard and LeBlanc (1965) and Lundelius (1972). Studies by Wilkinson (1973) indicate that the barrier-strandplain system north of Corpus Christi rests upon and is, therefore, younger than deltaic sediments along the lower coastal plain. Approximately 6 square miles of Pleistocene barrier-strandplain sands are exposed along the western shore of Laguna Madre north of Baffin Bay where the marine sand deposits compose an elongate topographic ridge up to 25 feet above mean sea level (fig. 4).

The Ingleside sands rest upon eroded Sangamon delta deposits; this surface, called the "Ingleside terrace" (Price, 1958), extends along the northwestern shoreline of Cayo del Grullo and into the Laguna Larga area. The terrace, which is about 10 feet above sea level, is veneered by Modern-Holocene loess and/or lacustrine muds. Price (1933) inferred that in the Kingsville area the terrace was the site of "Lake Baffin," a Pleistocene bay or lake landward of the Ingleside sand body.

For 7 or 8 miles north of Point of Rocks at the mouth of Baffin Bay, the barrier-strandplain sands have been intensively eroded by the prevailing, dry southeast wind. About 15 square miles of the system have been modified by wind deflation and sand dunes north of Baffin Bay. About 30 square miles of Pleistocene barrier-strandplain sands may have originally existed for more than 20 miles south of Baffin Bay, but little evidence of the barrier-strandplain sands remains except possible beach ridges along the Laguna Madre shore. The distribution of potreros on the wind-tidal flats west of The Hole indicates that the nuclei for clay-sand accretion may have been these relict beach ridges. This ancient barrier-strandplain system marked the approximate position of the Gulf shoreline just prior to the last episode of continental glaciation.

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 their courses. Dropping sea level caused extensive downcutting of streams into older, underlying deposits (fig. 5B). By the time sea level had dropped more than 400 feet, deep, broad, scalloped-shaped valleys were being cut across the earlier Pleistocene fluvial and deltaic plains. According to shallow seismic records, Baffin Bay occupies a partially filled valley eroded during this final drop in Pleistocene sea level (Behrens, 1963); the seaward extent of the valley now lies buried beneath younger deposits. Other buried valleys have been encountered by drilling (Fisk, 1959) in the vicinity of the Land-Cut Area (fig. 6). These valleys exhibit a dendritic, tributary pattern with depth of valley erosion ranging from about 80 feet in lower Baffin Bay to depths of 125 feet in valleys in the Land-Cut Area. Laguna Salada, Cayo del Grullo, and the various upper branches of Alazan Bay (Cayo de Hinoso and Cayo del Mazon) are partially filled tributaries that entered the valley now occupied by Baffin Bay. Rainfall was greater in South Texas during glacial stages because of the climatic effect of large masses of continental ice in Canada and the northern part of the United States. Valleys extended eastward to the position of the late Pleistocene shoreline, probably near the present continental shelf edge. Other valleys may underlie Modern-Holocene deposits in the area, but they can be

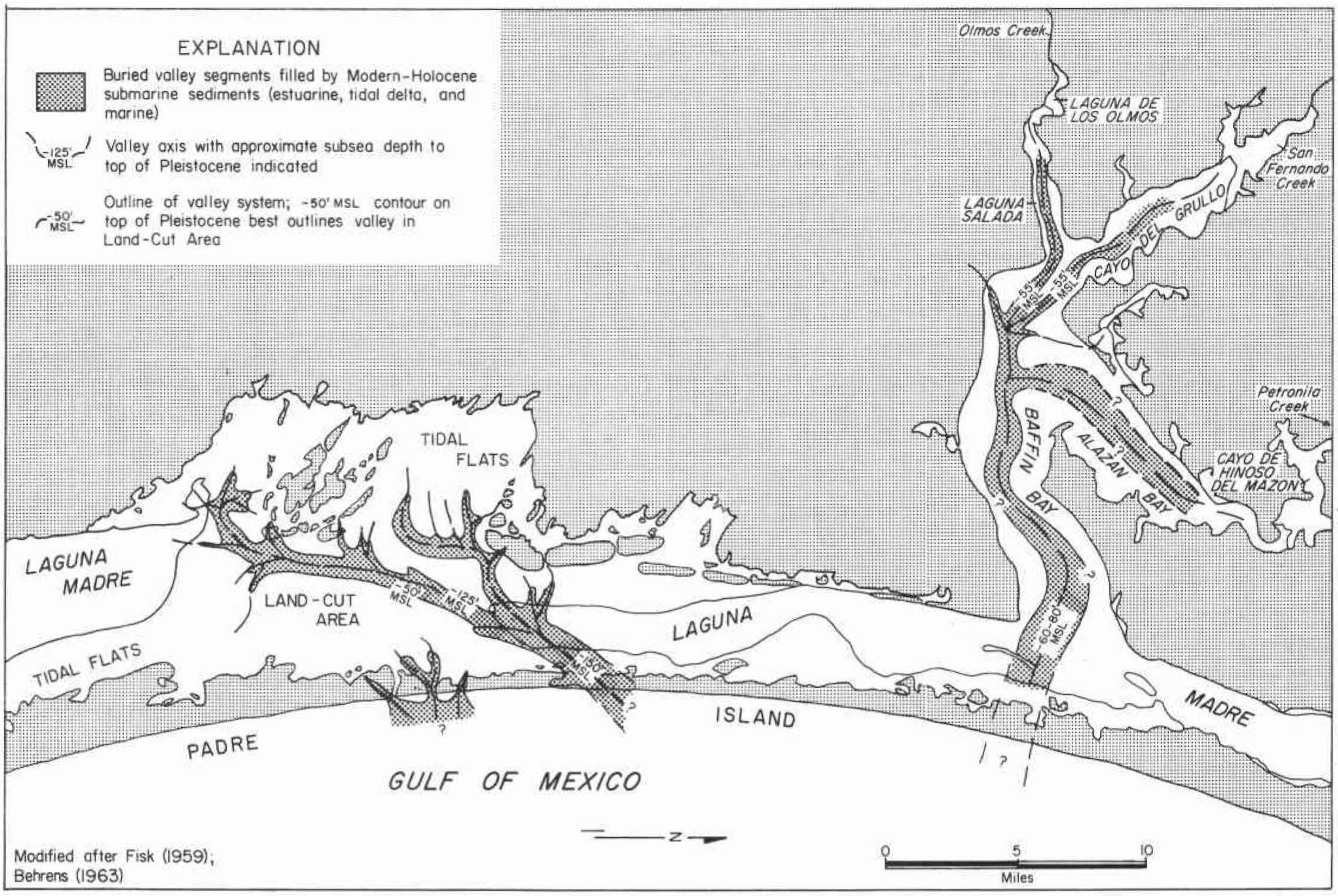


Figure 6. Late Pleistocene-Holocene valleys. Valleys were incised during last glaciation (low sea level) and progressively filled by Holocene and Modern fluvial, estuarine, tidal, and open marine sedimentation. Represents those valleys recognized to date by seismic and core data.

recognized and mapped only by seismic surveys or by extensive core-hole drilling.

HOLOCENE HISTORY

As final glacial episodes diminished about 18,000 years B. P. and meltwater began to reach the oceans, sea level began its last rise (fig. 5C). As sea level rose between 18,000 and about 4,500 years B. P., large point-bar sand bodies and extensive overbank muds were deposited by major rivers which continued to meander within the filling valleys. Smaller streams, such as the one that eroded Baffin Bay, continued to transport sand and mud to the major river systems. As sea level continued to rise, the deeply incised lower reaches of the fluvial system filled slowly with brackish to marine water. The resulting estuarine system occupied a broad, submerged valley now buried beneath the shelf, Padre Island, and Laguna Madre (fig. 6). That part of the river system now occupied by Baffin Bay remains only partially filled; wave erosion has widened the original valley. Sea level rose at varying rates and with several pauses, resulting from variations in glacial activity (fig. 5C). Pauses and minor reversals in sea-level rise are evidenced by submerged shoreline sands and cemented sandstone beachrock that occur on the shelf far from the present shoreline; these sands were deposited as beaches and offshore shoals that mark the temporary position of the Holocene strandline (Nelson and Bray, 1970).

The upper parts of estuaries were filled by fluvial sediments; marine sediments entered the lower estuaries through tidal connections with the open Gulf of Mexico. Holocene sediments within the buried valley streams include fluvial deposits, followed upward by successively younger swamp and marsh deposits, by brackish-water estuarine deposits, and finally by near-shore and open marine deposits. Baffin Bay, the principal estuary in the area, was later isolated from the open Gulf by development of Modern Padre Island.

As sea level rose, the Holocene climate became increasingly arid; persistent southeasterly wind systems began to develop. Eolian (wind) deflation or erosion of coastal plain sediments increased in intensity. Deflated sands accumulated in large, shifting dune fields that covered much of the mainland between Baffin Bay and the Rio Grande delta. The precise nature and distribution of Holocene eolian deposits are uncertain, but the Modern South Texas eolian system evolved from its Holocene counterpart.

MODERN HISTORY

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

When sea level approached its present level, 2,800 to 2,500 years B. P., several natural changes began along the coastline in the Kingsville area: (1) the various estuaries continued to fill with sediment eroded from the walls of drowned valleys, with mud and silt supplied by the short tributary streams to the uppermost parts of the estuaries, and, for a time, with marine sediment introduced into the lower reaches of estuaries by tidal transport; (2) short streams continued to erode headwardly into Pleistocene sediments of the coastal plain; (3) eolian processes slowly modified the coastal plain in response to prevailing southeast winds; (4) Baffin Bay and Laguna Madre developed as a restricted bay-estuary-lagoon system behind Padre Island, which formed as small sand islands grew and gradually coalesced due to spit accretion; (5) Padre Island was repeatedly subjected to intense eolian processes and locally breached by hurricane storm tides, which transported large volumes of shoreline sediment into Laguna Madre; and (6) extensive wind-tidal flats gradually developed along and within Laguna Madre.

Estuarine Erosion and Deposition

Near the end of the final Pleistocene glacial episode, about 20,000 years B. P., coastal plain streams flowed gulfward through deep valleys, which extended to a shoreline near the edge of the present continental shelf. In the Kingsville region, Olmos and San Fernando Creeks, flowing through incised valleys, joined at a point about 2 miles east of what is now Riviera Beach. The combined Olmos-San Fernando system was joined by the Petronila drainage system at a confluence about 2 miles southeast of present Kleberg Point (fig. 6). The Olmos-San Fernando-Petronila system flowed gulfward through a valley that now lies buried beneath Baffin Bay, Laguna Madre, and Padre Island. A remnant of this relict valley system, which was partially filled by Holocene river deposits and finally by estuarine and open marine sediments, is presently occupied by Baffin Bay. Extensive seismic profiling and coring will be necessary to outline precisely the deeper parts of the buried Pleistocene-Holocene valley beneath the bottom of Baffin Bay (fig. 6). The present shape of the Baffin Bay system, however, closely coincides with the relict valleys that existed before rising sea level submerged them several thousand years ago.

Since the end of the Holocene when sea level reached approximately its present level, much of Baffin Bay and the smaller associated Laguna Salada, Cayo del Grullo, and Alazan Bay have been partially filled by sediment eroded locally from valley walls and by stream-transported sediment introduced into the uppermost parts of each bay. Headward erosion of Olmos, San Fernando, and Petronila Creeks during the Holocene has contributed a significant volume of sediment. Smaller headwardly eroding arroyos and cayos have also contributed sediment to the estuary system. The upper parts of the estuary, which have been filled to sea level, are now occupied by extensive wind-tidal flats in Laguna de los Olmos, Cayo del Grullo, and Cayo de Hinoso-Cayo del Mazon. Erosion by wind-driven waves has widened the original drowned valleys of the estuary system to their present size and configuration. Sediment eroded from the estuarine shoreline was redistributed within the estuary. Relict annelid worm reefs occur along the margin of Baffin Bay; there is some evidence to suggest that oyster reefs thrived in the estuary before it was cut off from direct connection with the Gulf of Mexico.

As sea level approached its present level about 4,500 years B. P. (fig. 5), tidal currents were undoubtedly transporting some sediment directly into the lower part of Baffin Bay. The tidal sediment mixed with the estuarine sediment eroded from the margin of the estuary, as well as with some finer sediment transported down the estuary from Olmos, San Fernando, and Petronila Creeks. The tidal inlet or pass connecting the Baffin Bay estuary with the open Gulf was gradually restricted by development of offshore sand shoals which soon coalesced to form the barrier island now known as Padre Island. Once Padre Island had formed, the estuary was effectively cut off from open marine sediment.

Today, very little sediment enters Baffin Bay. The streams that enter into the bay are small with low discharges; significant discharge occurs only when tropical storms or hurricanes cause catastrophic flooding. Very little sediment enters the bay from Laguna Madre. The bay margins are occupied by sandy shoals, 0 to 4 feet deep, composed principally of sediment eroded from the shoreline; the floor of the bay from 4 to 10 feet is covered by a thick blanket of very fine mud deposited from suspension. Baffin Bay is now a sediment-starved bay-estuary system.

Headward-Eroding Streams

Because of low rainfall and stream discharge, small ephemeral streams in the Kingsville area have been ineffective in eroding relict Pleistocene deposits. The upper reaches of Olmos, Santa Gertrudis, San Fernando, Tunas, and Petronila Creeks, and other small, unnamed tributaries occupy about 10 square miles of the map area, but collectively they are eroding a very small part of the map area. The principal erosional agent in this region is wind deflation.

Post-hurricane rainfall normally produces flooding along the small river systems; these headward-eroding streams may be active for several days to two weeks following passage of a tropical storm or hurricane. The small streams are locally eroding Pleistocene fluvial and deltaic sediments, as well as some Modern-Holocene eolian deposits.

These streams began developing by headward erosion when late Wisconsin sea level began to drop during a final glacial episode (fig. 5). The streams cut deep valleys in their lower reaches; upper reaches exhibited relatively steep gradients (fig. 6). Since sea level reached its Modern position, headward-eroding streams have continued cutting into Pleistocene coastal plain sediments, but at a much slower rate as stream discharges diminished. The streams are fed principally by rainfall runoff from the highly impermeable deltaic coastal plain. Some alluvium occurs along the stream course, but upper reaches are principally erosional. Bedload sediment deposited by these ephemeral streams in the upper parts of Baffin Bay is reworked and redistributed by wind-tidal and eolian processes to form broad sandy flats transitional between the stream and the bay.

Eolian Deflation and Dune Development

The nature of eolian or wind processes in South Texas during the Pleistocene is difficult to assess. Study of subsurface Pleistocene deposits may show that wind was an important agent in South Texas during the various interglacial stages (fig. 5); however, at this time, its importance during the Pleistocene is purely conjecture. Studies by Fisk (1959) indicate that eolian sediments are among the oldest Holocene deposits in the Land-Cut Area. Wind-deposited sediments lie directly upon late Pleistocene soils and intertongue with or underlie the earliest Laguna Madre sediments. A sample near the middle of the eolian sheet was dated by carbon-14 at 11,450 years B. P. (Fisk, 1959); eolian activity probably dates back as far as early Holocene.

As glaciation diminished and sea level rose, the Holocene climate in South Texas became increasingly arid. This aridity, coupled with persistent southeasterly onshore winds, led to wind deflation and development of extensive dune fields in South Texas. Late Pleistocene barrier-strandplain (Ingleside) sands and deltaic distributary sands were deflated by winds producing large dune fields. South of Baffin Bay, Pleistocene barrier-strandplain sands provided the source for much of the San Pedro Ranch and Sarita dune fields, as well as for the stabilized dunes north of Baffin Bay. Dune fields south of the Land-Cut Area (Norias lobe) were supplied principally from fluvial deposits of the Pleistocene Rio Grande delta (Brownsville-Harlingen Map area).

Distribution of the Modern-Holocene eolian dunes was affected principally by variable depth of local ground-water table, average orientation of the southeast wind regime, and distribution of deflatable sand source deposits in the region. During the past several thousand years, rainfall variations during climatic cycles resulted in alternating periods of extensive dune activity and of moderate stability accompanied by the spread of vegetational cover. Older, stabilized dunes are covered with live-oak mottes; active dune fields are barren to sparsely grass covered. Cyclic reactivation of dune fields has developed large eolian sand lobes characterized by hummocky topography dominated by strong northeast-southwest blowout ridges and deflation troughs. Silt, winnowed from the dune field by wind deflation, is blown downwind and deposited as a thin, locally discontinuous loess sheet covering Pleistocene fluvial and deltaic deposits.

Barrier Island and Lagoon Development

At about the time that sea level reached its Modern position (4,500 years B. P.), sands eroded from submerged Pleistocene sediments on the adjacent shelf were concentrated in shoals from 3 to 8 miles offshore by waves breaking on the gently sloping inner shelf. During tropical storms and hurricanes, sands eroded from the inner shelf by large waves were redeposited on the submerged shoals or offshore bars. The shoals soon became a series of emergent, low, discontinuous sandy islands aligned parallel with the mainland shoreline. Wind-driven waves approaching the emerging islands generated longshore currents. Sandy sediments were moved by longshore drift along the gulfward side of the islands and were deposited as shallow spits at the downcurrent end of each island. Spit accretion continued as more sediment from the inner shelf, as well as from local erosional headlands along the mainland, became entrained within the longshore drift system. Slowly, the islands within the discontinuous chain coalesced to form Padre Island, a relatively continuous offshore barrier bar or island. Early in the history of Padre Island, before the barrier bar became a continuous island, the individual islands were separated by broad tidal passes, which were slowly closed by continued spit accretion.

As the various offshore islands and shoals were joined to form Padre Island, a broad lagoon (Laguna Madre) formed landward of the offshore island. Baffin Bay, the estuary formed by the submergence of Pleistocene stream valleys, similarly was gradually cut off from the open Gulf as spits closed its tidal inlet. Final closing of the lagoon probably occurred early in the 19th century. In the Kingsville map area, the bay-estuary-lagoon system landward of Padre Island presently covers 185 square miles, but its size was significantly larger before Laguna Madre began to fill with sediment derived from Padre Island.

Carbon-14 dates (Fisk, 1959) indicate that Padre Island and Laguna Madre began to form about 5,000 years B. P. and that Padre Island became a barrier at least 3,700 years B. P. In the Land-Cut Area, cores drilled across Padre Island (Fisk, 1959) indicate that the island is about 35 to 40 feet thick and that perhaps the island has accreted at least 0.75 mile during approximately the past 4,000 years, although subsequent erosion of the gulfward side of the barrier may have removed some of the island. During the past several decades, Gulf shorelines within the Kingsville map area have exhibited slight erosion, equilibrium, and some accretion. It is impossible to determine the precise history of the shoreline prior to man's arrival except to say that the present shoreline is 0.75 mile gulfward of the shoreline position at about 3,700 years B. P.

As Padre Island accreted gulfward during the past several thousand years, hurricanes and tropical storms washed sediment from the island landward into Laguna Madre. These washover sands built as much as 2 or 3 miles into Laguna Madre, although they were repeatedly covered by lagoonal sediments.

Although Padre Island accreted moderately gulfward and extensively landward, it has remained a low island near sea level. Locally, fore-island dunes have become elevated to 35 or 40 feet above sea level. The island is in delicate balance with regard to sediment supply, wind, aridity, and vegetation. It is breached by hurricane storm tides, and beach sand is blown landward to produce extensive back-island dune fields. Geologically, Padre Island is an ephemeral coastal feature, and its continued existence depends upon the effective capture of an adequate sand supply.

Lagoon Deposition

Entrenched stream valleys in the Coastal Zone, such as Baffin Bay, were flooded by rising Holocene sea level between 5,000 and 10,000 years B. P. Later, lagoonal sediments in the Kingsville area were deposited landward of the Padre Island offshore bar within relatively open lagoons or bays with direct connection with the Gulf of Mexico (Fisk, 1959). About 3,700 years B. P., sedimentation in Baffin Bay and Laguna Madre became increasingly restricted as the Padre Island chain coalesced into an offshore barrier island with limited tidal openings between the Gulf and the bay-estuary-lagoon system. Sediments and fauna reflect this shift to a closed lagoonal system (Fisk, 1959).

The deeper, open lagoon system evolved into the shallow, closed or restricted Laguna Madre system in which salinity began to exceed normal marine water. Hurricanes and wind-driven dunes transported large volumes of sand across Padre Island into Laguna Madre;

the width of the original lagoon narrowed as it slowly filled with sand. Slow deposition of suspended clays was dominant in the lagoon center.

Fisk (1959) estimated that central Laguna Madre became completely filled with sediment derived from Padre Island about 150 years ago. This Land-Cut Area divides Laguna Madre into northern and southern lagoons. The lagoon has almost filled in the Middle Ground area; filling has also significantly restricted Laguna Madre east of Point of Rocks near the mouth of Baffin Bay. Fisk has estimated that the wind-tidal flat deposits are being vertically accreted at approximately 1 foot per 50 years; these rates generally agree with those proposed by Lohse (1958).

Lagoons and complementary barrier islands are short-lived geologic features which depend upon a delicate balance between various coastal processes. Laguna Madre is filling rapidly in the central part of the South Texas coast. No doubt, the lagoon will eventually be filled from the Land-Cut Area to Baffin Bay. Extensive dune fields on the landward side of Padre Island, along with the continued impact of hurricanes on the poorly vegetated island, will be key factors leading to the continued filling of Laguna Madre.

Wind-Tidal Flats

Broad, low wind-tidal flats have developed during the past several thousand years in the Kingsville map area. These rather unique geologic environments and processes have become important in the geologic history of the region because of the dominant influence of winds on the low, poorly vegetated barrier islands and adjacent mainland.

Wind-tidal flats within Laguna Madre occupy sandy flats composed of sediment transported from Padre Island by hurricane-tidal surge and by dunes driven by southeasterly winds. Other wind-tidal flats have developed along the mainland side of Laguna Madre where wind deflation has extensively eroded the shoreline. Wind-tidal flats associated with Laguna Madre, and to a lesser extent with Baffin Bay, are less than 3 feet above mean sea level. Wind-driven tides may flood as much as 200 square miles of low-lying lagoonal margin. Fluctuating winds and related tides preclude a precise shoreline position along the lagoon margin, since shoreline can shift several miles in a matter of hours. Both short-lived northerly winds and long-duration southeasterly winds may generate the tides, but the persistent southeasterly winds produce the most prolonged tidal flooding. Tides rarely rise more than 2 feet except during storms.

The wind tides smooth and redistribute sediments contributed to the flat by washover fans and sand dunes. In addition, flood-tidal waters transport suspended clay which settles out on the flats, especially within local, depressed shallow basins.

Algae bloom on the shallow, submerged flats, but die when the wind tide ebbs and the flats are drained. Tidal flat sediments are, therefore, composed of intercalated laminae of sand, clay, and algal mats; evaporite minerals develop below the surface of the hypersaline sediments in the poorly drained parts of the tidal flat. Long periods of intertidal desiccation produce mud cracks which the wind abrades into sand-sized pellets that are transported landward to produce extensive clay dunes. Subaqueous marine grassflats may occur below tidal range adjacent to the tidal flats, but marsh is essentially absent along the margins of the tidal flats because of the erratic fluctuations of tidal level, including long periods of subaerial exposure. Broad tidal flats are a unique part of the coastal environment along this arid South Texas coastline.

HISTORICAL SUMMARY

Extensive sandy prairies and broad belts composed of active and inactive sand dunes overlie Pleistocene or ice age river, delta, barrier-strandplain, and, perhaps, eolian sediments deposited during one or more interglacial periods more than 30,000 years ago. River-fed deltas built gulfward across marine embayments where the South Texas sand sheet now occurs. Sediments delivered to the Gulf of Mexico by the Pleistocene Nueces River were reworked by marine waves and currents to produce the shoreline sands of the Ingleside barrier strandplain. The Ingleside sand extends southward into the Kingsville map area along the present mainland shore of northern Laguna Madre.

About 30,000 years B. P., in response to continental glaciation, sea level was again lowered about 450 feet resulting in the erosion of deep valleys (fig. 6) by coastal plain streams such as Olmos, San Fernando, and Petronila Creeks. When sea level reached its lowest point, rivers extended through deep valleys across many miles of exposed continental shelf to the temporary shoreline. Tributaries of these streams crossed the exposed shelf and extended westward into the present Land-Cut Area, where their valleys now lie buried beneath Padre Island and Laguna Madre.

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. Increasing aridity in the South Texas region during the Holocene led to the gradual development of extensive fields of migrating sand dunes south of the Baffin Bay estuary. Sea level reached its approximate present position about 2,800 to 2,500 years B. P., essentially marking the end of Holocene sea-level rise and the beginning of Modern geologic processes that have created the present Texas Coastal Zone (fig. 5).

Modern sedimentation has partially filled the Olmos - San Fernando - Petronila estuary (Baffin Bay) with sediments supplied by Modern streams and tidal currents and eroded from the shoreline of Baffin Bay. Beginning about 3,700 years B. P., sand shoals and low islands lying from 3 to 8 miles offshore began to coalesce by spit accretion to produce Padre Island. During the past 3,000 years, Padre Island has accreted slowly gulfward, supplied by sediment entrained in longshore currents and brought onshore from the inner shelf in the form of storm deposits. At the same time, the island built landward in a series of broad washover fans supplied by hurricane-tidal surge that repeatedly breached the island. At the present time, the Gulf shoreline of Padre Island exhibits slight erosion to slight accretion; the landward side of the island is accreting rapidly into Laguna Madre.

As Padre Island slowly developed, a broad, open lagoon was created landward of the offshore barrier chain. Wide tidal channels, which connected the lagoon with the open Gulf, were eventually closed as Padre Island became a single barrier bar more than 100 miles in length. The final tidal pass to close was probably the channel that connected Baffin Bay with the open Gulf.

As tidal passes across Padre Island closed, the lagoonal system, cut off from a direct connection with the open Gulf, soon became the restricted, hypersaline system called Laguna Madre. The hypersalinity induced by restricted circulation and high evaporation gave rise to unique fauna, sediments, and geologic processes.

The central part of Laguna Madre in the Land-Cut Area was completely filled about 150 years ago; other areas are filling rapidly. Broad wind-tidal flats composed of laminated sand, clay, and relict algal mats have developed on the emergent fill of Laguna Madre. Within hours, wind-generated tides may flood tens of square miles of the low-lying flats. Evaporite minerals form within shallow depressions where hypersaline tidal waters are trapped during ebb tides; gypsum, halite, and dolomite are some of the minerals which form just below the sediment surface.

Climatic changes that accompanied the decline of worldwide glaciation slowly led to increasingly arid conditions in South Texas. Consequently, eolian processes soon became dominant in the Kingsville map area. While Holocene sea level was rising, persistent winds deflated poorly vegetated Pleistocene sand deposits on the mainland, giving rise to extensive dune fields. Repeated, perhaps cyclic, arid episodes of dune development alternated with wetter periods of diminished activity during which time dune fields were stabilized by vegetation.

Persistent onshore, southeasterly winds repeatedly sculptured the mainland shore, generating large sand dune trains that migrated inland for tens of miles. The relict Pleistocene (Ingleside) barrier-strandplain sand body, as well as fluvial and deltaic sands and Holocene eolian deposits, provided the sediment necessary to maintain the eolian system. Finer grained, airborne sediment was carried further inland where it settled to form thin blankets of loess.

The South Texas eolian system, along with the hypersaline Laguna Madre and Padre Island systems, have combined to produce a unique section of the Texas Coastal Zone. The arid climate, sparse vegetation, persistent onshore winds, and occasional hurricanes are principal natural factors that are responsible for the present natural systems of South Texas: delicately balanced Padre Island, hypersaline Laguna Madre, extensive wind-tidal flats, and a mainland sculptured by eolian processes. The distinctive active processes of South Texas, combined with inevitable sediment compaction and tectonic subsidence, will continue to operate in this dynamic region.

HUMAN IMPACT ON COASTAL GEOLOGY

During the past 100 years, man has significantly modified much of the Texas Coastal Zone. The Kingsville region, principally an area of large ranches, has experienced perhaps the least of man's impact. Man's principal effect on coastal geology has been the extensive dredging of channels and passes with resulting discharge of spoil into bays and lagoons. Spoil discharge has modified the natural circulation patterns in Laguna Madre and the Land-Cut Area. Sediment supplied by dredging activities during the past few decades has far surpassed the volume of sediment supplied by natural erosion. About 4 square miles of spoil on the bottom of Laguna Madre in the Kingsville area are presently being redistributed, while almost 14 square miles of spoil that was piled above sea level, principally on wind-tidal flats, are now undergoing erosion and redistribution within Laguna Madre. Very little made land occurs in the Kingsville map area.

In the highly rural Kingsville area, there is minor erosion and sediment transport by headward-eroding streams. Limited cultivation, absence of irrigation and drainage canals, and minimal urban paving preclude significant runoff into these small coastal streams. Expansion of Kingsville and the Naval Air Station may have had some minor impact on the Santa Gertrudis and San Fernando systems, but there has been little need to straighten or to pave stream courses. Only extensive development in the Kingsville vicinity, however, would affect these small ephemeral streams.

Large areas of brushland in the region have been cleared and reseeded with forage grasses. Excellent land management practices have been followed by ranchers. In the absence of significant irrigation, a long period of unusually severe drought might result in wind damage to reseeded pasture land. Such a problem can probably be precluded, however, by limiting the intensity of grazing on such tracts.

There is no evidence of significant land subsidence in the Kingsville area. Heavy use of ground water by the Kingsville public water system has resulted in a local decline in the water level within the Goliad Sand. According to Shafer and Baker (1973), ground-water supplies in the region are limited. Because of the limited volume of potable ground water within the Kingsville area, land subsidence is not a serious threat to the region.

Limited tidal exchange with the open Gulf coupled with very low stream discharge make the northern part of Laguna Madre and Baffin Bay a highly restricted system. For this reason, it is critical that industrial or urban waste materials not be released into the system unless their quality is equal to the natural bay quality. The bay-lagoon system is thoroughly flushed only by hurricane-tidal surge and hurricane-aftermath rainfall. Since hurricanes cause bay water and some sediment to be flushed from the bay-lagoon system, storms provide the principal means for exchanging Gulf and bay-lagoon water. Man-made structures designed to block hurricane storm surge may severely limit this flushing mechanism. Similarly, the placement of oil-field sludge pits and solid-waste disposal sites on sandy substrates can be a threat to ground-water purity; leachate from solid-waste sites also poses a threat to the bay and lagoon system.

There is a steady trend toward filling or modifying marine grassflats. Elimination of grassflats may destroy a critical link in the production of food for bay and shelf organisms and critical spawning grounds for many species. A principal problem in the Kingsville area is the elimination of grassflats within Laguna Madre by spoil disposal along the Intracoastal Waterway and along many channels that were dredged to provide access to oil well locations.

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 Kingsville area are directly tied to Modern geologic processes and deposits, as well as to relict geologic deposits of the past several hundred thousand years (fig. 5). 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 these systems and deposits must be understood. Within the region, the physical properties of sediment substrates are highly variable, 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. Principal factors are the direction and intensity of persistent winds that control the orientation and size of wave trains approaching the shoreline. In turn, the angle at which waves strike the coast affects the nature of longshore drift. In the arid South Texas region, the duration and intensity of dry southeasterly winds and wet northerly winds contribute to the unique character of this wind-dominated part of the State.

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. Bay shorelines strongly reflect the depositional or erosional character of currents, just as longshore drift smooths the seaward side of strandplains and barrier islands. The nature and duration of various wind regimes are also critical in determining the importance of wind-tidal processes. In the southern part of the Texas Coastal Zone, as evidenced by the distribution of eolian deposits and landforms, wind becomes the dominant factor in erosion, transportation, and deposition of sediment, not only within the bay-lagoon system but throughout the entire region (fig. 4).

Wind is important in controlling coastal processes, but the combined and interrelated effects of rainfall, evaporation, humidity, and temperature make the wind an even more critical factor. Effective precipitation controls the nature and density of coastal vegetation, which is critical 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 wind (eolian) 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 KINGSVILLE AREA

Average annual rainfall in the Kingsville map area is 26.55 inches; average annual rainfall for Kenedy County is 26.61 inches and the average value for Kleberg County is 26.50 inches. The average annual rainfall from 1931 to 1960 varies from 34.5 inches in the northeastern part of the map area to 26.0 inches in the more arid southwestern corner of the area (fig. 7A). Along the coastline in the Kingsville area, the annual rainfall varies from 34.5 inches in the north to about 29.0 inches in the south.

Precipitation values alone are not necessarily significant until compared with precipitation deficiency (fig. 7C). Between 1931 and 1960, the Kingsville area experienced approximately 19 to 28 inches of moisture deficiency from precipitation because of the excessive potential evaporation and plant transpiration. Coupled with a low annual rainfall budget is the relatively nonuniform rainfall distribution throughout the year, a characteristic very different from areas farther northeast along the Gulf coastline. Rainfall is generally concentrated during the late summer and fall months of August, September, and October; occasionally, spring and early summer rains are significant. Some moisture accompanies winter northers, but this precipitation generally is unimportant to the yearly rainfall budget. Another factor affecting the precipitation deficiency value for the Kingsville area is its 95° and 96° F summer temperature maxima for Kenedy and Kleberg Counties, respectively. Temperatures range from a January or average winter minimum of 48° F to a July or average summer maximum of 96° F. Between 1931 and 1960, the average annual mean free-air temperature in the Kingsville area was about 73° F.

The importance of a negative effective precipitation value for the area is indicated by the sparse coastal vegetation, high density of hurricane-washover channels or breaches, the meager supply of fresh-water and fresh- to brackish-water marshes, the absence of swamps, and the dominance of wind processes. High, relatively continuous, sparsely to moderately vegetated fore-island dunes occur on Padre Island in the northern part of the Kingsville area. Southward, the fore-island dune chain becomes discontinuous as effective rainfall and consequent vegetational cover diminishes. Similarly, wind deflation of the mainland area in the region increases

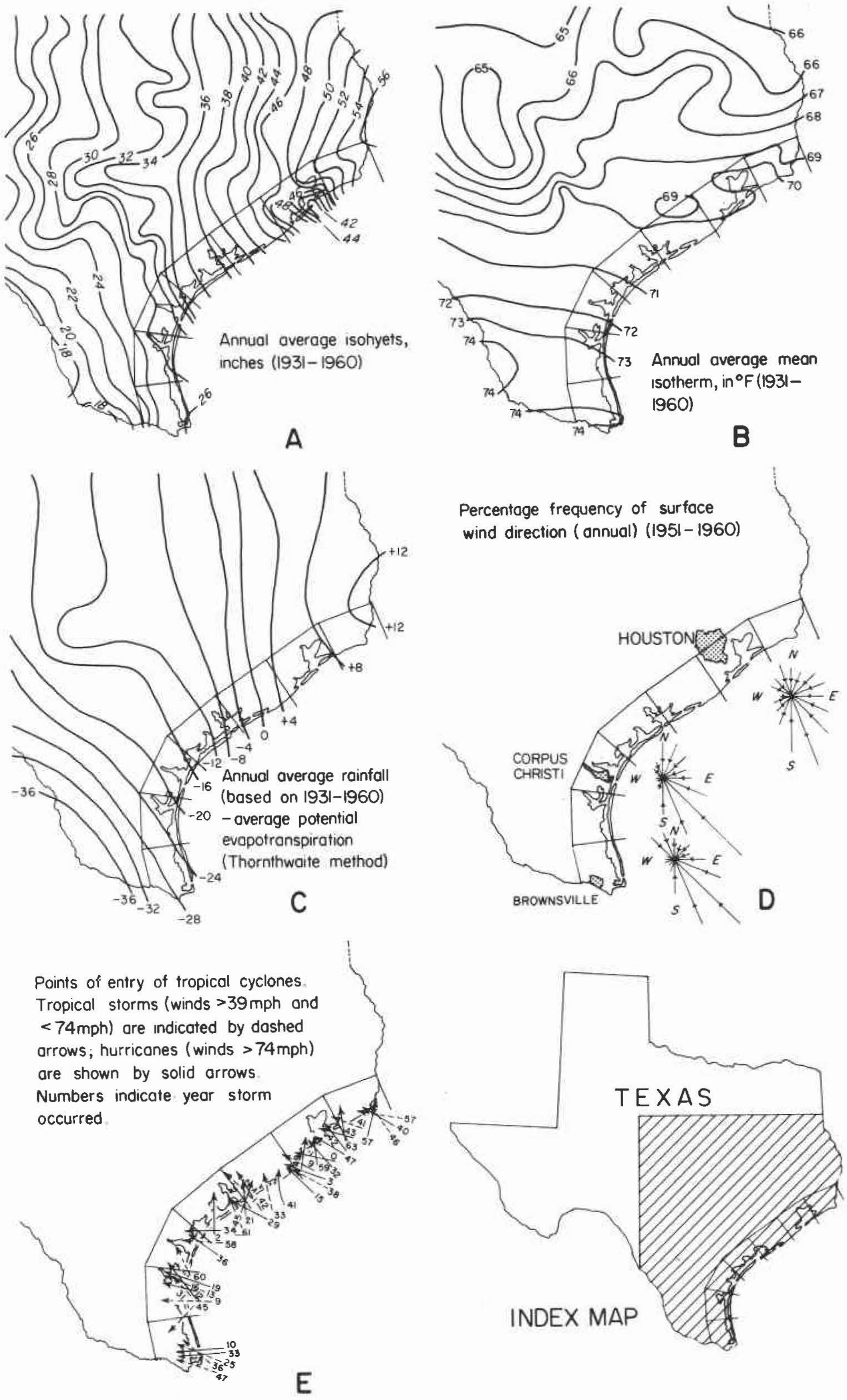
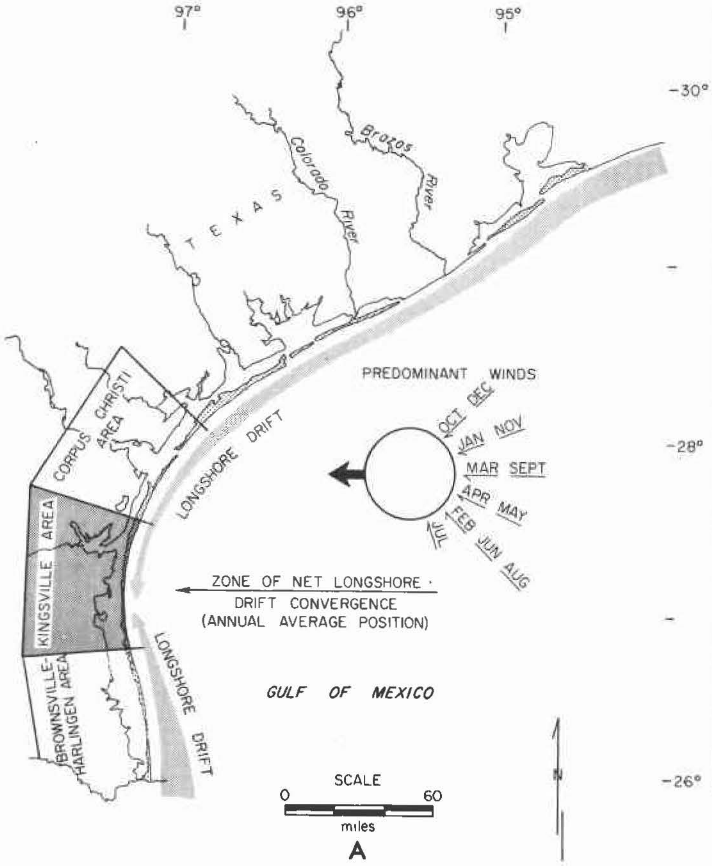


Figure 7. Regional climatic data, Texas Coastal Zone. (A) Average annual precipitation (after Carr, 1967). (B) Average annual temperature (after Carr, 1967). (C) Precipitation deficiency (after Orton, 1969). (D) Prevailing winds; frequency of surface wind direction (after Orton, 1964). (E) Hurricane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



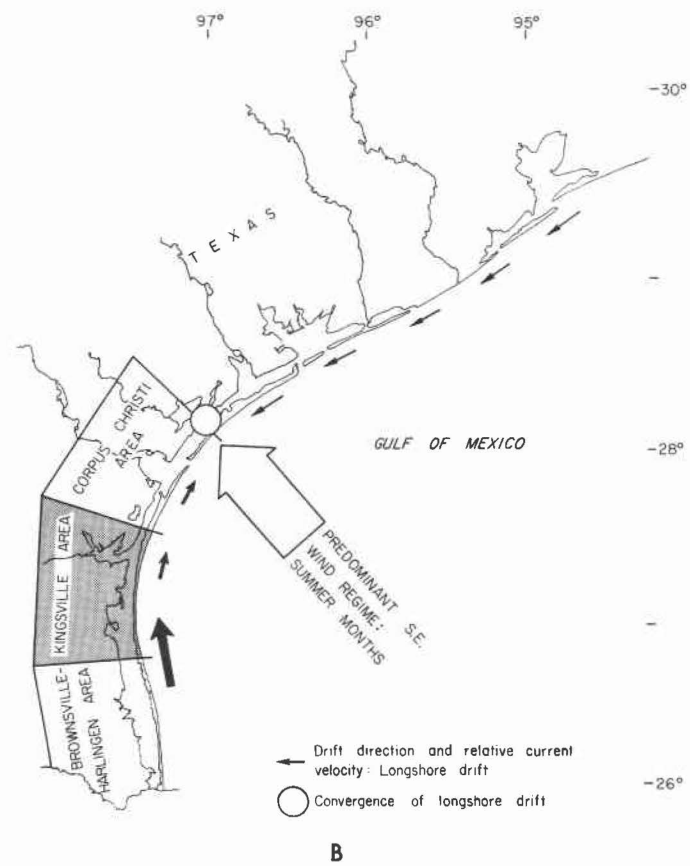


Figure 8. Relationship between wind regimes and longshore current circulation, Texas Coastal Zone. (A) Effect of net annual predominant winds on convergence of longshore drift. (B) Longshore drift convergence during typical summer months. Modified from Lohse (1952).

southward, giving rise to extensive dune fields and dominant eolian processes. Rainfall deficiency leads to low soil moisture, an important factor that determines whether or not the vegetation cover will survive drought cycles. The effectiveness of vegetation in protecting loose sand deposits against erosion by wind and storm-tidal surge can be shown by observing the decrease in dune stability and the increase in washover channels southwestward along the Texas Gulf coast.

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. 7D) for Corpus Christi and Brownsville (1951-1960) illustrates the percentage frequency or prevailing nature of various wind directions in the lower Texas Coastal Zone. Much more important than prevailing wind direction, however, is the predominance of the wind as defined by duration and velocity (figs. 8, 9). If wind duration and velocity are both considered, the predominance of winds from the southeastern quadrant and, to a lesser extent, from the north is even more outstanding.

Winds with the greatest frequency or duration during the year are *prevailing winds* (fig. 7D); reference is to the length of time that the wind blows from a particular direction. The amount of wind energy expended or available for work such as dune migration, generation of waves and longshore drift, and deflation or erosion is characteristic of the *predominant winds* (fig. 8). Wind predominance involves both duration and velocity (or strength) of the wind. Price (1933) noted the importance of this concept and presented an equation for relative strength of the wind: $RW = D \times V^2$ (where RW = relative wind, D = average duration in percentage of time, and V^2 = square of average hourly velocities). Other workers including Lohse (1952), Watson (1968), Andrews (1970), and Hayes (1967) also have addressed the significance of winds in the Coastal Zone using similar concepts.

In this report, the equation is modified to illustrate the importance of both wind duration and velocity as simply as possible. For example, duration (D) is given in hours and velocity (V) in miles per hour; one can readily grasp the importance of predominant wind (PW). The use of PW = D x V in the following example is for simplification and is not intended to preclude the validity of Price's (1933) equation: $RW = D \times V^2$.

During passage of a severe polar front, for example, a north wind may blow for 24 hours at average wind velocities of perhaps 30 to 40 miles per hour. The effectiveness or predominance of the wind (PW) is duration (D) x velocity (V), or 24 hours x 30 miles per hour = 720 units. In contrast, a weak wind from the southwest may blow for long periods with less effectiveness; for example, D = 100 hours, V = 5 miles per hour, and D x V = 500 units. The dry, southeasterly winds, which are the predominant winds in the region, do most of the eolian deflation, transportation, and deposition. Their predominance can easily be understood when it is recognized that they may blow at averages of 15 to 20 miles per hour for 2 or 3 months per year: D = 1,680 hours (for example, 70 days = 1,680 hours); V = 15 miles per hour average; 1680 x 15 = 25,200 units. The northwest-southeast orientation of most eolian deposits and landforms in the region is evidence of the dominance of the southeasterly wind regime (figs. 8, 9). Northerly winds are wet and short

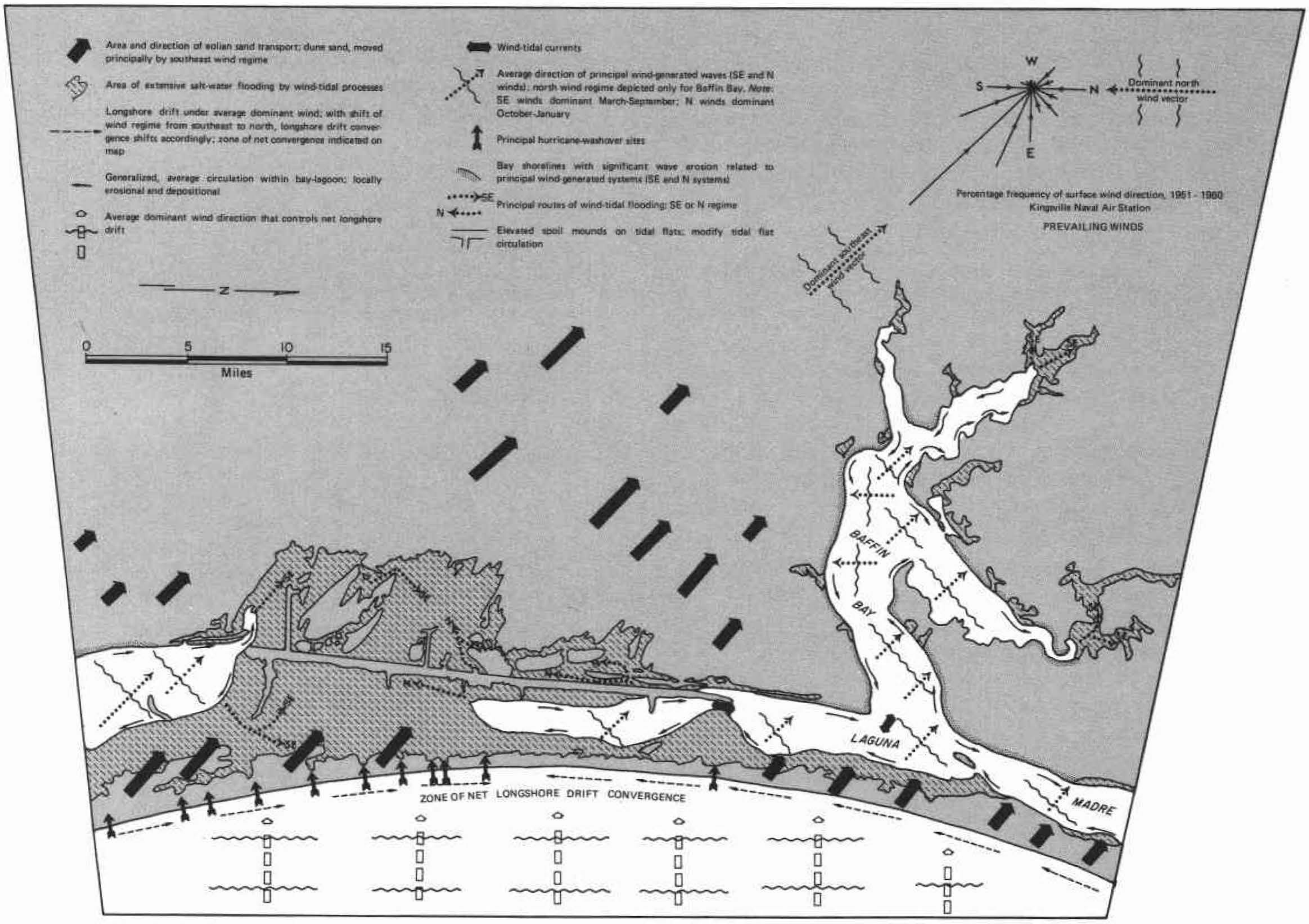


Figure 9. Circulation, waves, sediment transport, and other physical processes, bay-estuary-lagoon and offshore systems, Kingsville area.

lived, resulting in lesser impact on the Texas coast. Other winds add their impact on the Coastal Zone, but they are significantly less effective in generating waves, currents, tidal effects, and landforms.

Within the northwestern Gulf of Mexico, the annual *average* predominant wind is from the east (fig. 8A). This easterly wind vector gives rise to longshore drift along the concave shoreline; net annual convergence occurs near latitude 27°N within the Kingsville map area. The southeasterly winds, however, which are generally dry and persistent during the summer months (fig. 8B), are the most important in the South Texas coastal region. They generate a northward longshore drift (fig. 8A), a northwestward migration of dunes, and erosion of headlands on the western side of Laguna Madre and Baffin Bay (fig. 9).

Persistent Southeasterly Winds

Prevailing and predominant 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. 9). These wave trains result in secondary waves and currents that control deposition and erosion along barrier islands. Wave crests oriented northeast-southwest, for example, 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 longshore drift is generated. Essentially, this net drift results in sediment particles being repeatedly moved onshore and offshore, but with a slight coastwise drift or vector resulting from the slight angular wave approach (figs. 8, 9). Under the dominant 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; the longshore drift vector is to the north under this regime. 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 by vegetation as beach ridges.

If a significant sand supply is available from longshore drift and/or from sea floor sources on the nearby inner continental shelf, the sandy beach and shoreface will slowly build seaward. If sand is in short supply, perhaps because little is available from offshore, beaches may become sand starved and may be composed predominantly of broken shell and rock fragments which constitute the dominant available sediment. Beaches that are sand starved normally shift landward in the absence of sufficient sand nourishment. Such 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 a beach, it is considered to be *in equilibrium*.

Along the upper or northeastern part of the Texas coast, longshore drift is principally to the southwest; longshore drift is generally to the north and northeast along the lower (southern) part of the coastline (fig. 8). As the predominant winds shift throughout the year, the direction of longshore drift also changes accordingly. Winds blowing from the northeastern quadrant generate principally southwestward longshore drift, whereas winds from the southwestern quadrant generate north/northeastward longshore drift (fig. 8A). Winds from the north and northwest blow principally offshore and do not result in significant longshore currents.

Dominant winds along the Texas coast are the dry, moderately strong winds from the southeast. Winds from the east and southeast generate opposing longshore drift systems: southwestward and northward, respectively (fig. 8B). These two drift systems converge at a point along the coast, which shifts with the wind regime. For example, southeasterly winds produced convergence near St. Joseph Island (fig. 8B); during a year, the average predominant wind, however, is from the east, so that *net longshore drift convergence* occurs near latitude 27°N along Little Shell and Big Shell Beaches in the Kingsville area (fig. 8A). Northward and southwestward longshore currents converge along this recurved stretch of South Texas shoreline longer than any other area during each year. Sediment moved along the Texas coast by longshore drift, therefore, is concentrated along the central part of Padre Island because average predominant wind is easterly and the recurved coastline focuses both longshore drift cells along central Padre Island. Price (1933, 1958), Lohse (1952), Hayes (1967), and Watson (1968) ably and comprehensively discuss and analyze the nature of longshore drift along the Texas coast. Bullard (1942) first recognized that heavy minerals collected on Padre Island indicated both a northern and southern source, leading to the concept of convergence along central Padre Island.

Despite the location of net longshore convergence in the Kingsville map area, the predominant wind vector that does most of the deflation, transportation, and deposition of on-land sediment is the southeasterly system because of its persistence, velocity, and aridity (fig. 8B). When on-land eolian activity is at its peak during dry summer months (fig. 9), the longshore drift along Padre Island is northward toward a convergence near Corpus Christi (fig. 8B).

The southeasterly winds, along with occasional hurricanes, transport sand across Padre Island to form large back-island dune fields. These large dune fields, in turn, supply sediment to Laguna Madre or to broad wind-tidal flats in the area. Lack of vegetational stability of central Padre Island, due to low rainfall and presence of abundant hurricane-washover channels, accelerates the transport of sediment across the barrier island.

The ultimate sources of sediment within the longshore drift system of Texas include: (1) erosional Pleistocene headlands; (2) Modern-Holocene Brazos, Colorado, and Rio Grande deltaic headlands; (3) direct supply by Modern Colorado and Brazos Rivers, and the Rio Grande; (4) reworked Pleistocene-Holocene sediment on the inner shelf; and (5) sediment introduced from Louisiana. Each of these sources appears to be slowly diminishing with concomitant decrease in Modern barrier-strandplain accretion and increase in shoreline erosion. Independent studies by McGowen and Brewton (1975) and by Brown and others (1974), using sequential survey charts and serial photographs, indicate that between 50 and 60 percent of the Gulf shorelines (excluding bays and lagoons) during the past century has undergone net erosion; almost 70 percent of the Gulf shorelines has undergone short-term erosion during the past 7 to 23 years. The remaining shorelines have accreted or remained essentially in long-term equilibrium. Many short-term variations involving both erosion and accretion may occur, with little net long-term change. Since the 1850's, Padre Island in the Kingsville map area has exhibited slight accretion or equilibrium. Short-term changes covering the past two or three decades, however, indicate slight erosion along most of the shelly central Padre beaches and the beaches of north Padre Island (north of Yarborough Pass). The impact of recent hurricanes on the low-lying, poorly vegetated part of central Padre Island may be an important factor in short-term erosion in the area of net longshore convergence.

Sediment supplied to central Padre Island via longshore currents is derived from erosional shorelines of southern Padre Island and from erosion along the Brazos River deltaic headlands and Modern barrier islands to the northeast (fig. 8). A significant amount of sediment may also be carried to the shoreface of central Padre Island by tropical storms and hurricanes (fig. 7E).

There are various theories on the origin of Big and Little Shell Beaches. Since the beaches occur generally within the zone of net longshore convergence (fig. 8A). longshore drift has been invoked to explain the unusual concentration of shells. Another plausible theory holds that the shells are a lag concentration left behind on the shoreface and beach by the predominant easterly winds which sweep the beaches for long periods (Watson, 1971, 1972) and by periodic hurricane surges which breach the island in many places (fig. 9). Large shells of shoreface and inner shelf molluscs, especially clams, require significantly more wind or storm-surge energy for transport than do the sand and silt of the shoreface and beach. Consequently, the large heavy shells are concentrated on the beach, whereas large volumes of associated sands are transported landward. Cores of central Padre Island (Fisk, 1959) indicate that large shells occur in older beach deposits. If there has been an increase in beach shell deposits during the history of Padre Island, this could indicate a gradual decline in sand delivered to the central Padre Island convergence zone. Only detailed coring can provide this evidence.

A tidal pass may have connected Baffin Bay and the open Gulf during the past several hundred years, but if so, it has been closed for more than a century. If the pass existed, it probably occurred along Little Shell Beach.

Baffin Bay is a very narrow estuary when compared with others along the Texas coastline; its river valley shape has been reasonably well preserved (fig. 9). Southeasterly winds pump water into Baffin Bay through the Point Penascal Pass. Northwestward across the bay, especially between Black Bluff and Kleberg Point, fetch generates sufficient wave energy to erode the straight northwestern shore of Alazan Bay. Similar erosion is active for about 8 miles southwestward from Point of Rocks and near Riviera Beach. Various shell berms and spits have been generated by waves and currents driven by southeasterly winds and hurricane winds, for example, Kleberg Point and Starvation Point on opposite sides of the mouth of Alazan Bay. The high persistent wave energy striking northwestern shores of Baffin Bay and Alazan Bay has resulted in formation of aragonite-coated grains; oolites have formed near Kleberg Point where the most intense and persistent waves strike the Pleistocene headlands. Waves generated by prevailing southeasterly winds drive water far up Cayo del Grullo which is aligned with the predominant wind. Sandflats are flooded by wind tides for several miles up San Fernando Creek. Similarly, wind-generated tides from the southeast flood broad areas of Laguna de los Olmos, Cayo de Hinoso, and Cayo del Mazon.

Southeasterly winds push waves against the mainland shore of both northern and southern Laguna Madre, eroding the Pleistocene headlands, producing some sand shoals containing oolites and aragonite-coated grains, and generating currents that move northward along the mainland shore (fig. 9). Winds from the southeast push water in northern Laguna Madre northward into Corpus Christi Bay; similarly, waters in The Hole are pushed northward through the narrow restriction at Middle Ground. In southern Laguna Madre, southeasterly winds drive water northward into its narrow termination near Rincon de San Jose, where the wind tides spread extensively across the Land-Cut Area. These wind tides may flood most of the region below 2 feet in elevation. Persistent southeasterly winds, blowing at moderate strength for more than a week, can flood up to 200 square miles of low-lying coastal areas in the Kingsville map area. These same winds produce a head that forces water from southern Laguna Madre northward along the Intracoastal Waterway into northern Laguna Madre.

In summary, a predominant easterly wind on the Texas coast generates longshore drift currents that lead to a longshore convergence in the Kingsville map area near latitude 27°N. A dry southeasterly wind regime during the summer, however, is the principal factor that controls deflation, dune migration, and eolian deposition in the extensive South Texas eolian system. Although Padre Island beaches exhibit slight long-term accretion or equilibrium, short-term changes point to an incipient erosional phase. Abundant shell along central Padre Island beaches may indicate that sand supplied by converging longshore currents is being moved landward by persistent southeasterly winds and short-lived hurricane storm surge at a rate that is slowly exceeding supply by longshore currents. Whether erosion will become a long-term trend along central Padre Island is only speculative. Southeasterly winds generate the currents responsible for erosion and redistribution of sediment within Baffin Bay and Laguna Madre. Much of the tidal exchange between Baffin Bay, Laguna Madre, The Hole, and Corpus Christi Bay is dependent upon tides driven by winds from the southeast. Almost 200 square miles of tidal flats are subject to flooding by this wind regime.

Northerly Winds

During December, January, and February, 15 to 20 northers or rapidly moving polar fronts pass through the coastal area. Rain and winds up to 50 miles per hour may accompany these sudden 24- to 36-hour storms. North winds generate intense wave activity within Baffin Bay (fig. 9), which results in erosion of a segment of the southern shoreline. Because of the broad fetch across the central part of Baffin Bay, breaking waves driven by northers erode the shoreline and generate sufficient agitation to produce shallow shoals composed of oolites and aragonite-coated grains. Suspended fine-grained sediments slowly settle out within the deeper, low-energy bay center. Northerly winds blow essentially parallel to the length of Laguna Madre and, therefore, little erosion of the Laguna Madre shoreline occurs.

North winds establish a complex circulation system within Baffin Bay as well as within Laguna Madre. These winds generate currents which move water out of Alazan, Cayo del Grullo, Laguna Salada, and Laguna de los Olmos into Baffin Bay proper where an easterly current system moves along the southern shoreline into Laguna Madre (fig. 9).

Northers provide a mechanism for exchanging water in Baffin Bay with that of Laguna Madre and are commonly accompanied by rains which may result in some fresh-water discharge by ephemeral streams into the upper reaches of the Baffin Bay system. Northerly winds accelerate the exchange of water between southern Laguna Madre and the Gulf via Mansfield and Brazos Santiago Passes (Brownsville-Harlingen map area). North winds generate currents that move southward along the margins of northern Laguna Madre with some return flow to the north concentrated in the center of the lagoon along the Intracoastal Waterway; however, spoil and shallow shoals tend to baffle flow in the lagoon. Broad areas of wind-tidal flats in the northern part of the Land-Cut Area are commonly flooded by northerly winds. Northerly winds push large volumes of lagoon water into The Hole through the narrow opening at Middle Ground, the restricted southern extremity of northern Laguna Madre. This exchange is the principal mechanism supplying lagoon water to The Hole.

Northerly winds have minimal effect on Gulf shorelines in the Kingsville area. They may generate southward-moving longshore currents along the barrier island, but the currents are relatively short lived. In summary, waves and currents generated by northers are an important but short-lived process causing short-term shoreline erosion in parts of Baffin Bay and promoting water exchange between northern Laguna Madre, The Hole, and southern Laguna Madre across the wind-tidal flats in the Land-Cut Area.

TIDAL CURRENTS

Compared with the effects of wind-generated tides, astronomical tides assume a role of secondary importance in Laguna Madre and Baffin Bay. Once or twice a year, astronomical tides may reach a magnitude (for example, 0.5-0.8 foot) that temporarily matches or exceeds the more common wind tides. Tides of only 0.3 foot are typical of the bay-lagoon system. Because no tidal pass exists today between the open Gulf and Baffin Bay or northern Laguna Madre, tidal exchange occurs via Corpus Christi Bay through Aransas Pass or Fish Pass (Corpus Christi map area). Southern Laguna Madre has a direct tidal connection with the open Gulf through Mansfield and Brazos Santiago Passes (Brownsville-Harlingen map area). A tidal pass through Padre Island opposite the mouth of Baffin Bay may have existed as late as 150 years ago (Breuer, 1957).

Within the Baffin Bay-Laguna Madre system, tidal exchange occurs through the narrow channel connecting Baffin Bay and Laguna Madre about 0.6 mile north of Point Penascal. Similarly, tides are funneled into The Hole through the shallow, narrow opening between Middle Ground and the Intracoastal Waterway. Exchange through these passes may be related to astronomical tides, but more commonly the tides are wind generated.

Wind-tidal flooding of the broad Land-Cut Area tidal flats, as well as other lesser flats in Laguna Madre and upper Baffin Bay, occurs at rates directly related to the strength and persistence of the winds. Fisk (1959) reported that southeasterly winds from 8 to 10 miles per hour forced water over the northern and western Land-Cut Area flats at rates of 0.3 to 0.6 mile per day. With southeasterly winds of 19 to 30 miles per hour, wind-tidal surge moved 2.6 to 3.8 miles per day. Fisk noted that strong northerly winds pushed water completely across the Land-Cut Area in 36 hours at rates of 7.6 miles per day.

RIVER DISCHARGE

The combined discharge of the Olmos, San Fernando, Santa Gertrudis, and Petronila Creeks into Baffin Bay is less than the discharge into any other Texas bay system. These ephemeral streams discharge small quantities of muddy sediments into the upper reaches of the Baffin Bay system; moderate quantities of sandy bedload are transported onto and across the tidal flats in Laguna de los Olmos, Cayo del Grullo, Cayo del Mazon, and Cayo de Hinoso. Floods resulting from hurricane rainfall may spread over and eventually flush Baffin Bay with fresh water, reducing salinities from 70 to less than 10 parts per thousand (ppt). These rare floods also freshen Laguna Madre. As flooding recedes, suspended clay and organic particles slowly settle into the low-energy bay and lagoon centers. Sand introduced to the upper parts of Baffin Bay is reworked by wind-tidal currents and eventually by eolian processes during the months or years between floods.

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 (Brown and others, 1974). Most hurricanes strike the coast from the southeast, although they may veer along the coast, striking it at any angle (fig. 7E). Hurricanes become a more serious problem every 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 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, passes, and upper bay areas; (4) degree of vegetative cover in the area of impact; and (5) angle at which the storm cell strikes the coastline. These factors determine how much of the storm-tidal surge will be dissipated upon striking land and how much energy will remain to inflict damage.

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

The storm approach is marked by rising tides and increased wind velocities (fig. 10B). The longer the storm remains offshore in the Gulf, the greater will be the storm surge. Storm tides are higher in narrow, funnel-like bays than along the straight barrier shoreline; storm tides may reach 25 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 barrier island through 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. 10C). On the left or south side of the eye, water and sediment are flushed from the bays through tidal passes and storm channels; on the right or north side of the eye, water is stacked in bays, and bay shorelines are eroded. Currents along the barrier island 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 generating numerous tornadoes (fig. 10D). Water stacked in bays during the storm approach and impact drains gulfward through passes and storm channels. Heavy rains normally persist inland with 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.

A hurricane striking the Kingsville area at a high angle to the coast results in maximum storm-tidal flooding of the broad wind-tidal flats on the back side of Padre Island and of the Land-Cut Area and Middle Ground. Wind-tidal flats and other low-lying areas around the margin of Baffin Bay are also flooded. Storm-tidal surge may reach U. S. Highway 77 along Olmos Creek and the Kingsville Naval Air Station along Santa Gertrudis and San Fernando Creeks. Most of the peninsula between Alazan Bay and Baffin Bay, as well as Penascal Rincon, is subject to severe flooding. In the Land-Cut Area, a large number of hurricane-washover channels breach Padre Island.

South of Olmos Creek, the hummocky, wind-modified prairies have no organized drainage systems. For this reason, hurricane-aftermath rainfall may lead to extensive flooding. Thin, eolian sand deposits resting upon impermeable Pleistocene deposits cause widespread ponding and development of shallow water tables. U. S. Highway 77 and the Missouri Pacific Railroad impound large areas of water in areas west of the highway and railroad grades. Approximately 22 percent of the Kingsville map area was inundated by Hurricane Beulah (1967) rainfall flooding and 12 percent of the area was flooded by the Beulah storm-surge tides, resulting in flooding of about 35 percent of the entire Kingsville area. A 50- or 100-year hurricane that generated maximum winds, flood tides, and rainfall could inundate from 40 to 60 percent of the map area with storm surge and rainfall flooding.

HOW TO USE THE ATLAS

GENERAL MAP INTERPRETATION

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

Map Orientation

The maps in the Atlas are oriented parallel to the curving Gulf coast shoreline rather than having the standard orientation with north at the top and east and west to the right and left, respectively (fig. 1). *North-south direction* on the maps parallels *longitude lines* that can be projected across the map from values printed at the map margin: 97°30′ and 97°45′. The 97°30′ longitude line, for example, is 97 degrees and 30 minutes west of the Prime Meridian at Greenwich, England. In the Kingsville area, 1 degree of longitude equals about 62 miles, or 1 minute of longitude equals

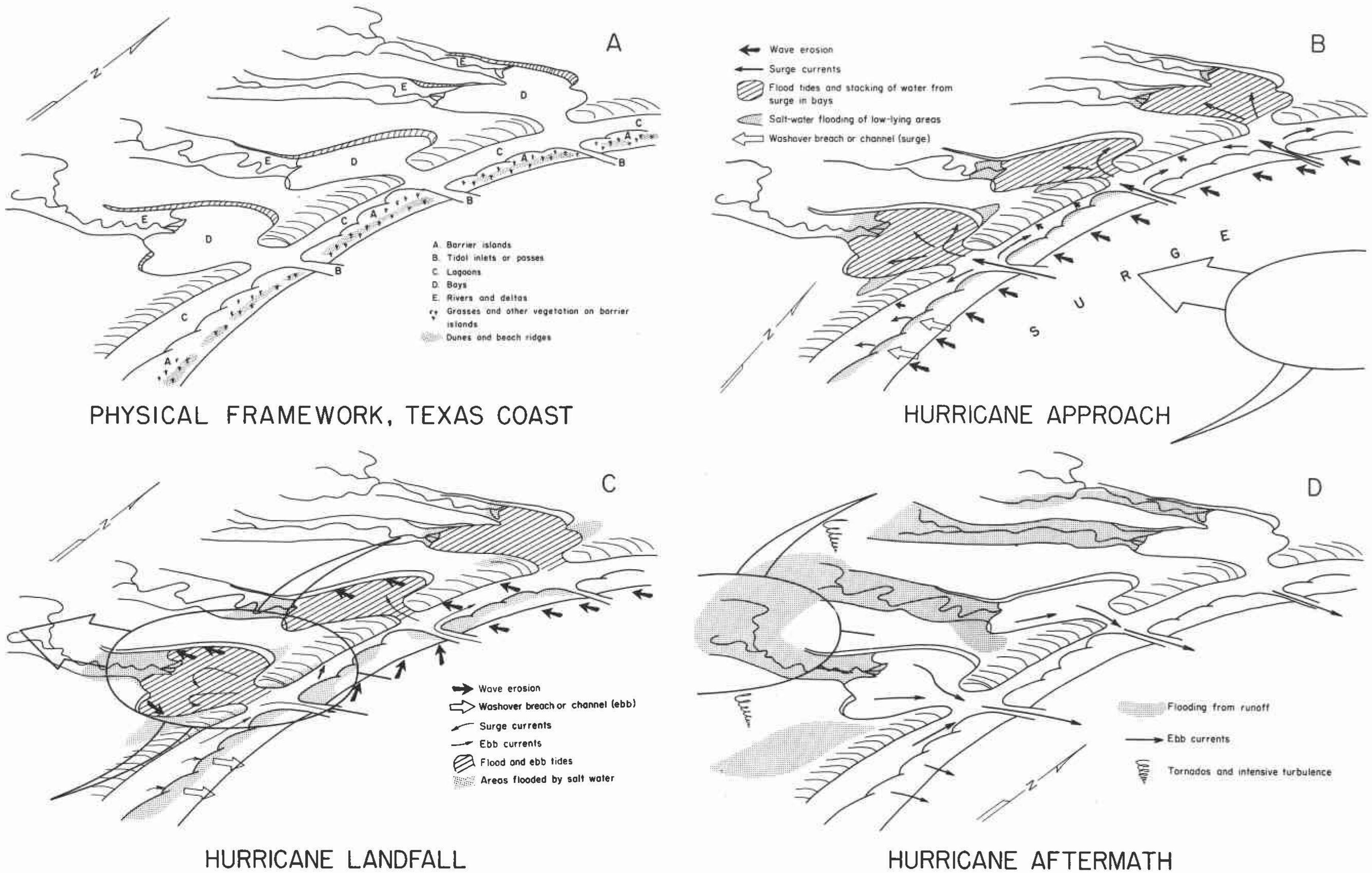


Figure 10. Schematic model of hurricane effects on the Texas Coastal Zone. (A) Physical features characterizing Texas Coast. (B) Effect of approaching hurricanes. (C) Effect of hurricanes upon impact with coast. (D) Aftermath effects of hurricanes. After McGowen and others (1970).

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: 26°45′, 27°00′, 27°15′, and 27°30′. The 26°45′ latitude line is 26 degrees and 45 minutes north of the Equator. One degree of latitude equals 69 miles and one minute of latitude equals 1.15 miles. When using the maps, therefore, it is important to be aware of the cardinal directions of north, south, east, and west; the small index map at the lower right of each map provides immediate visual orientation of the Kingsville area within the Coastal Zone.

Magnetic declination in the center of the Kingsville 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 Kingsville 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 7.

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 a bay 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 or oak mottes, 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 Kingsville map area are noted in tables 3, 7, and 9-14. 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 Kingsville 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

Table 1. Index of map units, Kingsville map area, Texas.

In the following alphabetical list of map units used in the Kingsville 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

Abandoned channel and course, mud-filled (Pleistocene and Modern-Holocene): I; 17, 45, 48, 84, 85
Active dune blowout areas, sand: I; 47, 55, 56, 63, 69-79, 85, 87, 90, 99, 115, 117, 119
Active dune complex, physical properties: II; 83, 85, 87, 90, 94
Active dune complex, sand: I; 47, 56, 63, 69-79, 85, 87, 90, 93, 99, 108, 110, 115, 119
Active dunes, coppice dune, blowouts, back-island dunes, and inland dunes: III; 95-97, 99, 100
Active processes: VI; 26-35, 106-111
Agriculture, cultivated land and orchards: IV; 101, 102
Airfield: IV, VII; 101, 102, 112
Area inundated by marine water, Hurricane *Beulah* storm surge tide only: VI; 107, 108
Area inundated by marine water, Hurricanes *Carla* and *Beulah* storm surge tide; VI; 107, 108
Area inundated by river flooding and rainfall runoff, Hurricane *Beulah* rainfall and aftermath storms: VI; 107, 108
Area of intensive wind deflation covered by Hurricane *Beulah* river or rainfall flooding: VI; 107, 108
Area of intensive wind deflation covered by Hurricane *Beulah* storm surge tide: VI; 107, 108
Artificial reservoir: VII; 111, 112, 114

Back-island dune field and fore-island blowout dune, active: I; 46, 54, 55, 69, 85, 87, 90, 94, 96, 97, 99, 108, 110, 117, 119
Back-island sandflats with small migrating dunes: I; 46, 53, 54, 57, 69, 85, 87, 90, 94
Barchan dune orientation in banner dune complexes: I; 47, 70-76
Barren land, active dunes and coppice dune fields: IV; 101-103
Barren land, wind-tidal flats: IV; 97, 99, 100
Barrier flat, sand and shell, grass-covered: I; 45, 53-56, 84-87, 96, 97, 99, 100, 117, 119
Barrier flat, sand and shell, very sparse grass: I; 46, 53, 55, 56, 84-87, 96, 97, 99, 100, 117, 119
Barrier-strandplain sand, grass-covered (Pleistocene): I; 44, 45, 50, 51, 84-86, 88
Barrier-strandplain system (Pleistocene): I; 15, 18, 23, 44, 45, 50, 51, 71, 72, 110, 119
Barrier system (Modern-Holocene): I; 15, 20, 22, 24, 44, 45, 46, 52-57, 69, 107, 109, 110, 119
Bathymetry: IX; 115, 116
Bay and lagoon margin, restricted hypersaline: III; 97, 98, 100
Bay and lagoon margin, seasonally hypersaline shoal water bordering mainland: III; 97, 98, 100
Bay and lagoon mud, mottled, some mixed shell: I; 46, 54, 61, 62, 68
Bay and lagoon sand, muddy: I; 46, 61, 62, 66
Bay center, restricted, barren: III; 97, 98, 100
Bay-estuary-lagoon system (Modern-Holocene): I; 20, 21, 46, 59-69, 117, 119
Bay-margin oolites and quartz sand: I; 46, 61, 64, 65
Bay-margin quartz sand and calcite-coated grains: I; 46, 61, 64, 65
Bay mud, laminated: I; 46, 54, 61, 62, 68
Bay or lagoon center, enclosed hypersaline, abundant mollusks: III; 97, 98, 100
Bay- or lagoon-margin sand or shell berms, accretionary, relict depositional grain: I; 46, 59, 62, 64
Bay- or lagoon-margin sand, subaqueous sheet or bar: I; 46, 62, 64
Beach ridges, accretionary, relict (barrier-strandplain): I; 18, 47, 50, 51
Beach, sand and shell: I, III; 45, 53-55, 96, 97, 99
Berms along bay-lagoon margin, storm deposits: III; 97, 99
Brushland, moderately stabilized dunes, inactive clay-sand dunes, some loess deposits: III; 96, 97, 99, 100

Canal and channel, transportation: VII; 111, 112, 114
Clay and mud, physical properties: II; 83-86, 93, 94
Clayey sand and silt, physical properties: II; 83-86, 88, 94
Clay-sand dune complexes, inactive: I; 47-50, 52, 69-71, 81
Clay-sand dunes, accretionary, active: I; 47, 49, 50, 52, 69-71, 77, 80, 81
Clay-sand dunes and dune complexes, physical properties: II; 85, 87, 89, 90, 93, 94

Delta-front mud and sand, lacustrine mud or loess veneer removed by erosion (Pleistocene): I; 45, 50
Delta-front mud and sand, veneered by thin marsh-lacustrine mud or loess (Pleistocene): I; 45, 49, 50
Deposition within bay, slow to moderate, area of: VI; 107, 108, 111
Discharge measurement station supplying monthly data for graph: VIII; 114, 115
Distributary and fluvial sands and silts (Pleistocene): I; 45, 48-50, 84, 86, 88, 93, 94

Education site, public school, college, university: IV; 102
Environmental geology: I; vii, 1, 2, 4, 5, 14-16, 44-81, 118, 123
Environments and biologic assemblages: III; 95-100
Eolian accretionary bars and ridges, sand and clay: I; 46, 59, 63, 64
Eolian ridges and active clay-sand dunes: III; 96, 97, 99, 100
Eolian sand, area of active transport and deposition: VI; 107, 108, 110
Eolian sand dunes covered by Hurricane *Beulah* river or rainfall flooding: VI; 107, 108
Eolian sand dunes covered by Hurricane *Beulah* storm surge tide: VI; 107, 108
Eolian sand dunes covered by Hurricane *Carla* storm surge tide: VI; 107, 108
Eolian sand sheet, physical properties: II; 83, 85, 87, 90, 91, 94
Eolian system (Modern-Holocene): I; 19-22, 26-32, 69-81, 119

Fault, active or potentially active, based on lineament or grain displayed on aerial photographs: II; 82, 83, 87, 90-93, 123
Fluvial-deltaic system (Pleistocene): I; 44, 45, 48-50
Fluvial system (Modern-Holocene): I; 45, 51, 52
Fluvial woodland: III; 97, 99, 100
Fore-island dune ridge, sand: I; 45, 53-55, 85, 87, 90, 94

Government land, Federal and state: IV; 101-103
Grassflat, muddy sand with shell, hypersaline: I; 46, 59, 62, 64, 67, 68, 117, 119
Grassflats, hypersaline: III; 62, 67, 68, 96-98, 100

Hurricane *Beulah* recording tide or river gage: VI; 107-108
Hurricane *Beulah* storm surge and river flooding debris or driftline elevation: VI; 107, 108

Industrial, municipal works, refineries-chemical plants, agricultural plants, and other facilities: IV, VII; 100, 102, 103, 111, 112
Interdistributary mud (Pleistocene): I; 45, 48-50, 52

Jetty or pier: VII; 112, 113

Lagoon, bay, or estuary: VII; 112, 113
Lake or pond, coastal, mud-filled (Pleistocene and Modern-Holocene): I; 45, 48, 49
Lake or pond, perennial: VII; 112, 113
Lake or pond playa, ephemeral: VII; 112, 113
Land use, current: IV; 100-104
Live-oak mottes, stabilized sand dunes and ridges: III, IV; 96, 97, 99-102
Loess sheet, physical properties: II; 83, 85, 87, 90, 94

Loess sheet, thin, silty, discontinuous, overlies Pleistocene deltaic mud and calichified sand: I; 45, 48, 49, 69-71, 76, 77, 81
Loess sheet, thin, locally discontinuous, overlies calichified Pleistocene fluvial sand: I; 45, 48, 49, 69-71, 76, 77, 81
Longitudinal dune orientation in back-island dune field: I; 47, 54-56, 78
Loose sand and loess prairies: III; 97, 99, 100

Made land: I, III, IV, VII; 47, 81, 97, 99-103, 111, 112, 117, 119, 120
Made land and spoil, physical properties: II; 84, 86, 89, 94
Man-made features: VII; 111-113
Marginal residual sand apron on windward side of rincons and potreros: I; 46, 63, 64
Marsh, coastal, fresh to brackish, physical properties: II; 84, 86, 88, 94
Marsh, fresh-water, and poorly drained depressions: I; 46, 49, 50, 58, 59
Marsh, inland fresh-water: III, IV; 96, 97, 99, 101-103, 117, 119
Marsh, inland fresh-water, physical properties: II; 84, 86, 88, 89, 94
Marsh system (Modern-Holocene): I; 46, 49, 50, 58, 59, 117, 119
Mineral and energy resources: V; 104-106
Moderately stabilized dunes, sand and loess (silt) sheet, brush-covered: I; 47, 69-77, 79
Modern-Holocene systems: I; 19-23, 25-35, 44-47, 51-82
Mud, mineral resource: V; 104-106

Offshore petroleum production platform, bay or Gulf: IV, V, VII; 101-105, 111, 112
Offshore system (Modern-Holocene): I; 28, 29, 45, 46, 51, 54, 55, 57, 58
Oil or gas field: IV, V; 101-105
Open ocean: VII; 111-113

Park and recreational facility: IV; 100-103
Physical properties: II; 82-95, 116-120
Pipeline: IV, V, VII; 101, 102, 104, 105, 111-113
Pit or quarry: II, IV, V; 87, 101, 102, 104, 105
Pleistocene systems: I; 14-19, 23, 44, 45, 48-51
Poorly drained depressions, mud substrate: III; 96, 97, 99
Poorly drained depressions, sand substrate: III; 96, 97, 99
Prairie grasslands: III, 96, 97, 99, 100

Rainfall data: VIII; 114
Rainfall recording station supplying monthly data for graph: VIII; 114
Range-pasture, uncultivated or permanently removed from crop use: IV; 101, 102
Residential-urban, commercial and residential development: IV; VII; 100-103

Salinity data, surface: VIII; 114, 115
Salinity measurement station in Baffin Bay supplying data for contouring: VIII; 114, 115
Salinity measurement station in Laguna Madre supplying additional data for contouring: VIII; 114, 115
Salinity measurement station in Laguna Madre supplying monthly data for graph: VIII: 114, 115
Salinity, surface, calculated average in Baffin Bay, September 1951 to March 1953: VIII; 114, 115
Salinity, surface, calculated average in Laguna Madre, 1965-1967: VIII; 114, 115
Salinity, surface, extreme high in Laguna Madre, 1965-1967: VIII; 114, 115
Salinity, surface, extreme low in Laguna Madre, 1965-1967: VIII; 114, 115
Salinity, surface, high in Baffin Bay, September 1951 to March 1953: VIII; 114, 115
Salinity, surface, low in Baffin Bay, September 1951 to March 1953: VIII; 114, 115
Sand and loess (silt) sheet deflation area, active: I; 47, 69-71, 74-77, 80
Sand and loess (silt) sheet with no relict grain: I; 47, 63, 69-71, 74-77, 79
Sand and oolite shoal: III; 97, 98
Sand, mineral resource: V; 104-106
Sand, physical properties: II; 84-86, 88, 91, 94
Sand sheet with strong relict grain of base-leveled dunes: I; 47, 50, 63, 69-76, 79
Sand shoal with some oolites: I; 46, 62, 68, 69
Sandflats and/or coppice sand-dune fields, active: I; 45, 54, 57, 69
Sandflats, wind-tidal, algal mats: III; 95-97, 99, 100

Serpulid reef, some calcite-cemented sand beachrock locally, sandy and shelly interreef areas: V; 104-106
Serpulid reefs: I; 46, 61, 66
Serpulid reefs and related shell-rich sand and beachrock: I; 46, 66
Serpulid reefs (relict) and interreef shoals: III; 95, 97, 98
Shelf mud and sand with shell: I; 45, 53-55, 57, 58
Shelf, open marine: III; 95, 97, 98
Shoreface, lower, and shelf, active properties: VI; 108, 111
Shoreface, lower, open marine: III; 95-98
Shoreface, sand and muddy sand: I, 45, 53-55, 57, 58
Shoreface, upper, shifting sand: III; 95-98
Shoreline, depositional: VI; 107-110, 122
Shoreline, erosional: VI; 107-110, 122
Shoreline in depositional-erosional equilibrium: VI; 107-110, 122
Solid-waste disposal site, sanitary landfills, and open dumps: II, IV, VII; 83-85, 93-95, 100, 102, 112
Spoil heap or mound, subaerial: I; 44, 47, 84, 86, 89
Spoil, reworked, subaerial: I; 44, 47, 62, 63, 84, 86, 89
Spoil, subaerial land resulting from dredging: IV, VII; 44, 101, 102, 111, 112, 117, 119, 120
Spoil, subaqueous: I, VII; 44, 47, 62, 84, 86, 89, 111, 112, 120
Spoil, subaqueous and subaerial: III; 44, 97, 98
Spoil, subaqueous, area of active reworking and redistribution by waves and currents within lagoon: VI; 108, 111
Stabilized blowout dune complex, sand, grass-covered: I; 46, 55, 56, 69, 117, 119
Stream discharge data: VIII; 114
Stream, headward-eroding, ephemeral: I; 21, 45, 48, 51, 52
Stream, natural drainage, ephemeral: VII; 112, 113
Subaerial environments and assemblages: III; 96, 97, 99, 100
Subaqueous environments and assemblages: III; 95-98, 100
Subaqueous sandflat, hypersaline, barren to sparse grass: III; 97, 98
Surf or breaker zone, normal, active processes: VI; 108, 111
Surface wind direction, percentage frequency of, 1951-1960, Kingsville Naval Air Station: VI; 26-29, 110

Topography: IX; 115, 116
Transitional wind-tidal flat and eolian sand sheet, physical properties: II; 83, 85, 87, 89, 94
Transitional zone, wind-tidal flat to eolian sand sheet: I, IV; 46, 62-64, 101-103

Utility line or cable, major power transmission line: V; 104, 105

Vegetated barrier flat, foredune ridge, and stabilized blowouts: III; 96, 97, 99, 100

Washover channel, fan, and wind-deflation trough and storm runnel: III; 97, 99
Washover channel, hurricane, site of active or potential: VI; 107, 108
Washover channel, sand, active: I; 46, 54-56
Washover fan, sand, subaerial, active: I; 46, 54-57
Water bodies, fresh to saline: III; 96-98, 100
Water systems: VII; 112, 113
Wave energy, moderate to high, area of: VI; 108, 111
Well-stabilized dune sands, dense live-oak mottes and scrub: I; 47, 69-76, 79, 80
Wind accretion ridges, rincons and potreros: I; 47, 63, 64, 69, 80, 81
Wind-deflation and wind-tidal activity, intense, erosion of sand sheet: III; 96, 97, 99, 100
Wind deflation, occasional wind-tidal flooding, and extensive clay-dune accretion, intensive, area of: VI; 108, 110
Wind-deflation trough and storm runnel on barrier flat: I; 46, 54, 57
Wind-tidal flat, mud and sand, algal-bound mud, gypsiferous, firm: I; 46, 60, 62, 63
Wind-tidal flat, mud and sand, extensive algal mats, depressed relief, wet and soft: I; 46, 60, 62, 63
Wind-tidal flat, physical properties: II; 83, 84, 86, 89, 94
Wind-tidal flat, sand and mud, extensive algal mats, alternately emergent-submergent: I; 46, 55, 60, 62
Wind-tidal flat, sand and mud, firm: I; 46, 52, 55, 60, 62, 63
Wind-tidal flat, sand, loose: I; 46, 60, 62
Wind-tidal flats: VII; 112, 113
Wind-tidal flooding, area of: VI; 107, 108, 110

Table 2. Environmental subject index, Kingsville 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

Abandoned river channels, mud-filled: I; 45, 48, 50
Acidity of substrate: II; 82-90
Aerial photographic lineations—
  relation to active or potential surface faulting: II; 91-93
  relation to banner dune distribution: I, II, IX; 73, 78, 91, 93
Agricultural products, potential sources: III, IV; 97, 99, 101, 102
Airfields and highways: I, II, III, IV, V, VI, VII, VIII, IX; 101, 102, 112
Ancient (Pleistocene) barrier-strandplain system: I; 15, 18, 23, 44, 45, 50, 51
Ancient (Pleistocene) fluvial-deltaic system: I; 14, 15, 17-19, 23, 44, 45, 48-50
Aquifers: II; 14, 90-94, 104
Artificial passes, effect of construction and maintenance on bay systems: I, VI, VII; 14, 82, 108, 111, 121, 122

Banner dune complexes—
  factors controlling morphology: 72, 78
  principal elements of: I; 47, 73, 78
  relationship to aerial photographic lineations: I, II, IX; 73, 78, 91, 93
  relationship to South Texas eolian system: I; 47, 69-77
Barrier island development, suitability: II, III, VI; 33-35, 82-90, 96, 97, 99, 100, 107-111, 115, 117-122
Barrier island, hurricane-washover areas: I, VI; 33, 34, 46, 54-57, 107, 108
Barrier-strandplain origin: I; 14, 15, 18, 19, 22, 23
Barrier-strandplain system, ancient (Pleistocene): I; 15, 18, 23, 44, 45, 50, 51
Barrier system, Modern-Holocene: I; 14, 15, 22, 24, 44-46, 52-57
Base material sources, road construction: II, V; 83-85, 104-106, 117
Bay and estuary environments—
  depth variations: I, IX; 13, 14, 22, 23, 59-69, 115, 116
  hypersalinity: I, III, VIII; 14, 22-25, 46, 59, 62, 66, 67, 69, 97, 98, 100, 113, 114
  wind-tidal effects: I, VI; 22-24, 32, 45, 46, 60, 62, 63, 117, 119
Bays and estuaries, drilling and production platforms, suitability: I, III, V, VI, VII; 29, 33-35, 46, 59-69, 95, 97, 98, 100, 104, 105, 107, 108, 111-113
Bays, estuaries, and lagoons: I, III, VI, VII, VIII, IX; 19-24, 46, 59-69, 95-100, 106-117
  oil and gas fields within: V; 104, 105
  salinity, ranges of: III, VIII; 22-24, 32, 33, 66, 67, 97, 98, 100, 114, 115
Bay-estuarine environments, human impaction: I, III, IV, V, VI, VII; 14, 24, 25, 46, 47, 59-69, 97, 98, 100-105, 111, 112, 115, 117-123
Bay-estuary—
  areas, square miles: 13, 46, 112, 116
  bottom configuration I, IX; 13, 14, 22, 23, 59-69, 115, 116
  salinity stations, Texas Parks and Wildlife Department: VIII; 114
  surface salinity, variation with rainfall and discharge: VIII; 114, 115
Bay-estuary-lagoon system, Modern-Holocene: I; 13, 14, 20-24, 46, 59-69
Beach characteristics, variation within the Kingsville area: I, VI; 29-31, 45, 53, 54, 107-110
  description of Big Shell Beach and Little Shell Beach: VI; 31, 53
Beach, impact of human activities on: I, II, III, IV; 45, 53, 54, 84-86, 88, 97, 98, 100-103, 117, 119, 121, 122
Big Shell and Little Shell Beaches, description of variation in beach characteristics: VI; 31, 53
Boundary problems, State and private ownership: I, III, IV, VI; vii, 53, 96, 97, 99-104, 107-110
Buried cables and pipes, suitability: II, 83-85

Canals and channels, suitability: II, III, VI, VII; 83-85, 97-99, 106-115, 117, 118, 120, 121
Channelization, problems as a result of: 120, 121
Clay-sand dunes, accretion: I, II, III, VI; 23, 45, 48-50, 52, 63, 64, 69-71, 85, 87, 89, 90, 93, 94, 96, 97, 99, 108, 110
Climatic characteristics of the Kingsville map area: VI, VIII; 25-35, 107-110, 114, 115
Coastal activities—
  and environmental impact: II, III, IV, V, VI; vii, 1, 2, 14, 24, 25, 83-85, 89-95, 100, 101, 104, 106, 111, 117-123
  possible problem areas: II, IV, VI; 83-85, 90-95, 100, 101, 106, 107, 115, 117-123
Coastal development and hurricane flooding potential: IV, VI, IX; 33-35, 100-104, 107, 108, 115, 116
Coastal substrate, permeability of: II; 82-95
Coastal vacation-home development, suitability: II, III, IV, VI; 33-35, 83-86, 88, 93-97, 99-103, 107-111, 117, 118, 121
Coastal Zone, general description: I; vii, 1, 2, 11-14
Compressibility of substrate: II; 82-90
Construction and shoreline erosion or deposition: IV, VI, VII; 100-104, 106-113, 117, 121
Constructional raw materials, availability in Coastal Zone: II, IV, V; 82-90, 100-106
Corrosivity of substrate: II; 84, 85
County land use patterns, relationship to environmental geology: I, IV; 44-82, 100-104

Dam structures and land inundation, suitability: II, III, IV, V, VI; 33-35, 82-90, 97, 99-110
Data sources relative to the Coastal Zone: I, II, III, IV, V, VI, VII, VIII, IX; vii, 2-11, 123-126
Depositional processes, effect on shorelines: VI; 107-110
Depth variations, bay aand estuary environments: I, IX; 13, 14, 22, 23, 59-69, 115, 116
Devegetation of coastal areas and resulting problems: II, III, VI; 83-90, 95-97, 99, 100, 107-110, 117, 119, 121
Discharge data, Water Resources Division of the U. S. Geological Survey: VIII; 114
Drainage capacity of substrate: II; 82-95
Drainage systems, natural, ephemeral: I, VI, VII, VIII; 13, 32, 33, 45, 51, 52, 107, 112-115
Drilling and production platforms in bays and estuaries, suitability: I, III, V, VI, VII; 29, 33-35, 46, 59-69, 95, 97, 98, 100, 104, 105, 107, 108, 111-113
Dunes, active eolian sand: I, II, III, VI, IX; 12, 21, 22, 24, 47, 69-81, 85, 87, 90, 97, 99, 100, 107, 108, 110, 115-117
  biologic assemblages: I, III; 47, 69-81, 97, 99, 100
  constraints on use: I, II, III, IV, VI; 47, 69-81, 85, 87, 90, 97, 99-103, 108, 110, 117
  physical properties: I, II; 47, 69-81, 85, 87, 90
  wind influence: I, VI; 21, 22, 24, 26-32, 69-81

Earthen structures, road construction: II, III, V; 83-90, 97, 99, 100, 104-106

Electrical power, transmission of: V; 104, 105
Elevation above sea level, all land areas: I, IX; 115, 116
Environmental Geologic Atlas of the Texas Coastal Zone, use of: I; vii, 1-6, 35-44
Environmental geologic units underlying areas of varied land use: I, IV, VII; 44-81, 100-104, 111-113
Environmental geology—
relationship of resource distribution to: I, III, V; 44-81, 96-100, 104-106
relationship to county land-use patterns: I, IV; 44-82, 100-104
relationship to management and planning: I; vii, 1, 2, 44-81, 115, 117-123
Eolian environments—
description: I; 47, 77-81
on barrier islands: I; 45, 46, 54-57
within the South Texas Eolian system: I; 21, 22, 24, 47, 69-81
Eolian processes and sand transport: I, VI; 21, 22, 24, 26-32, 69-81, 108, 110
Eolian system, Modern-Holocene: I; 47, 69-81
Estuaries, bays, and lagoons: I, III, VI, VII, VIII, IX; 19-24, 46, 59-69, 95-100, 106-117
oil and gas fields in: V; 104, 105
salinity, ranges of: III, VIII; 22-24, 32, 33, 66, 67, 97, 98, 100, 114, 115
Excavation potential of coastal substrate: II; 82-90, 117

Fault patterns, Coastal Zone: II, VII; 87, 91, 112
Faults, active or potential, and pipelines: II, IV, V, VII; 82-91, 100-102, 104, 105, 111-113, 123
Headward-eroding streams, sediment supply to bays: I, VII, IX; 21, 44, 51, 52, 112, 113, 115, 116
Feedlot development, suitability: II, III, IV, VI; 82-90, 93, 94, 97, 99-104, 107, 108, 115, 117-120
Fill material sources, general: II, V; 82-90, 104-106
Floral assemblages, land areas: III; 95-97, 99, 100
Fluvial areas, water-tolerant trees in: I, III; 44, 51, 52, 97, 99
Fluvial-deltaic system, ancient (Pleistocene): I; 14, 15, 17-19, 23, 44, 45, 48-50
Fluvial system, Modern-Holocene: I; 44, 51, 52
Fore-island dune ridge—
importance to construction activities: 55
relationship to climatic variables: I, VI; 26, 44, 54, 55
Foundation suitability, heavy construction or light construction: II; 82-90, 117, 119
Fresh-water ponds and reservoirs affected by hurricane flooding: III, VI, VII; 33-35, 97, 98, 100, 107, 108, 112-114

Gaging stations—
rainfall, U. S. Weather Service: VIII; 114
stream discharge, U. S. Geological Survey, Water Resources Division: VIII; 114
Gas and petroleum products, transmission of: IV, V, VII: 100-105, 111-113
Geologic units, physical properties of: I, II; 44-95
Grade material sources, road construction: II, V; 83-85, 104-106, 117
Ground water—
relation of occurrence to distribution of banner dunes: I, II; 69-78, 91-93
relation of withdrawal to land-surface subsidence and fault activation: II; 90-93
sources and usage: II, IV; 14, 90-94, 104
withdrawal versus recharge: II; 104
Herbicides, pesticides, and insecticides, use of: II, III, IV, VI; 82-90, 96, 97, 99-104, 107, 108, 111, 117
Highway construction and route planning: I, II, III, IV, V, VI, IX; 82-93, 97, 99, 100-111, 115-117
Highways and airfields: I, II, III, IV, V, VI, VII, VIII, IX; 101, 102, 112
Historical monitoring—
coastal activities and effects in coastal environments: IV, VI; 4, 5, 100-104, 107-111, 117-123
natural environments: I, III; 4, 5, 97-99
shorelines and shoreline processes: VI; 107-110, 122
Human activities, impact on beaches: I, II, III, IV; 45, 53, 54, 84-86, 88, 97, 98, 100-103, 117, 119, 121, 122
Human impact on bay-estuarine environments: I, III, IV, V, VI, VII; 14, 24, 25, 46, 47, 59-69, 97, 98, 100-105, 111, 112, 115, 117-123
Hurricane flooding: VI; 33-35, 107, 108, 122
and biologic assemblages: III, VI; 33-35, 96-100, 107, 108, 122
and current land use: IV, VI; 33-35, 100-104, 107, 108, 111-113, 122
and effect on bay waters: I, VI, VIII, IX; 33-35, 64-69, 107, 108, 114-116, 122
and relationship to topography: I, VI, IX; 33-35, 107, 108, 115, 116, 122
municipal areas affected by: IV, VI, VII; 33-35, 100-103, 107, 108, 111-113, 122
of coastal oil and gas fields: V, VI; 33-35, 104-106, 107, 108, 122
of power transmission lines: IV, V, VI; 33-35, 100-102, 104-108, 122
Hurricane tidal-flooding, depth and areal extent: VI, IX; 33-35, 107, 108, 115, 116
Hurricane-washover areas, barrier island: I, VI; 33, 34, 46, 54-57, 107, 108
Hypersalinity in bay and estuary environments: I, III, VIII; 14, 22-25, 46, 59, 62, 66, 67, 69, 97, 98, 100, 113, 114

Industrial sites—
distribution: IV, VII; 14, 100-103, 111, 112
proximity to resources: IV, V; 100-106
suitability: II, III, IV, VI, VII; 82-113
Industrial waste disposal planning: II, III, IV, VI, VII; 82-90, 93-95, 97, 99, 100-103, 107-113
Ingleside barrier: I; 18, 23, 45, 51
Insecticides, herbicides, and pesticides, use of: II, III, IV, VI; 82-90, 96, 97, 99-104, 107, 108, 111, 117

Jetties and piers, location and suitability: III, VI, VII; 97, 98, 107-110, 112, 113, 121, 122

Lagoons, bays, and estuaries: I, III, VI, VII, VIII, IX; 19-24, 46, 59-69, 95-100, 106-117
oil and gas fields in: V; 104, 105
salinity, ranges of: III, VIII; 22-24, 32, 33, 66, 67, 97, 98, 100, 114, 115
Land capability units: I, II, III, IV, VI; 44-59, 69-90, 93, 94-104, 107, 108, 110, 115, 117-120
Land inundation and dam structures, suitability: II, III, IV, V, VI; 33-35, 82-90, 97, 99-110
Land relief, local: I, IX; 115, 116
Land shaping, suitability: II; 82-90
Land-surface configuration, regional: I, IX; 12-14, 115, 116
Land-surface subsidence: II; 90-93, 123
Land use—
and capabilities, Coastal Zone resource units: I, II, III, IV, VI, VII, 44-90, 93, 94-104, 107, 108, 110-113, 115, 117-120
and shoreline processes: IV, VI, VII; 100-104, 106-113
current, and hurricane flooding: IV, VI, VII; 33-35, 100-104, 107, 108, 111-113, 122
or resource planning: I, II, III, IV, V, VI, VII, IX; 100-104, 115, 117-120
relationship to municipal areas: IV, VII; 100-104, 111-113
Land and water resource units—
definition: 115, 118
relationship to capability units: 115, 117-120
utility in land management: 117, 118
Liquid-waste disposal, requirements for: II; 83-85, 93, 94
Living assemblages, bay and estuary bottom: I, III; 64-69, 95-98, 100
Loess—
effect on construction planning: I, II; 69-71, 76, 77, 80, 85, 87, 90
origin and distribution: I, II, III; 13, 21, 22, 69-71, 76, 77, 80, 85, 87, 90, 97, 99, 100
Longshore and onshore sand transport: I, VI; 22, 26, 28-32, 107-111
Longshore drift, zone of convergence: 28-31

Man-made substrate, subaerial and subaqueous: I, II, III, IV, VI, VII; 13, 24, 25, 47, 62, 63, 81, 82, 84, 86, 89, 94, 97, 98, 100-103, 108, 111, 112, 117, 119-121
Map interpretation, general guidelines: 35-44
Mapped areas, statistics of: 45-47, 86, 98, 99, 102, 105, 108, 112, 116

Map units, square miles of all: 45-47, 86, 98, 99, 102, 105, 108, 112, 116
Marine processes, role in geologic history: 18-24
Marsh system, Modern-Holocene: I; 12, 46, 58, 59
Migratory waterfowl habitat, marsh and associated areas: I, III; 12, 46, 58, 59, 96, 97, 99
Miles (linear)—
  active or potentially active faults: II; 87
  bay, estuary, lagoon shoreline; VI, VII; 108, 112
  Gulf shoreline: VI, VII; 108, 112
  navigable streams: VII; 112
Mineral production sites: II, IV, V; 14, 83-90, 101-106
Mineral resource areas, physical properties of: II, V; 82-90, 104-106
Mineral resource areas—
  proximity to major land or water transportation routes: I, IV, VII; 100-106, 111-113
  proximity to pipelines and electric-transmission systems: IV, V; 100-106
  relationship to biologic assemblages: III, V; 95-100, 104-106
Modern-Holocene—
  barrier system: I; 14, 15, 22, 24, 44-46, 52-57
  bay-estuary-lagoon system: I; 13, 14, 20-24, 46, 59-69
  eolian system: I; 12, 13, 47, 69-81
  fluvial system: I; 44, 51, 52
  marsh system: I; 12, 46, 58, 59
  offshore system: I; 45, 52, 54, 55, 57, 58
Municipal areas affected by hurricane flooding: IV, VI, VII; 33-35, 100-103, 107, 108, 111-113, 122
Municipal areas and relationship to land use: IV, VII; 100-104, 111-113
Municipal development, suitability: II, III, IV, V, VI, VII; 82-113

Natural and man-made ponds and lakes: I, IV, VII; 100-104, 111-114
Natural drainage systems, ephemeral: I, VI, VII, VIII; 13, 32, 33, 45, 51, 52, 107, 112-115
Natural environments and historical monitoring: I, III; 4, 5, 97-99
Natural systems—
  ancient (Pleistocene): I; 14-19, 44-51
  Modern-Holocene: I; 14-16, 19-23, 44-47, 51-82
Navigation planning and bay-estuarine conditions: I, III, VI, VII; 97, 98, 100, 107-114
Number of—
  airfields: 102, 112
  education sites: 102
  offshore petroleum production platform: 102, 112
  pits and quarries: 87, 102
  waste disposal sites and sludge pits: 87, 102, 112

Offshore system, Modern-Holocene: I; 45, 52, 54, 55, 57, 58
Oil and gas fields in bays, estuaries, and lagoons: V; 104, 105
Oil and gas production areas: IV, V; 14, 100-105
  trends of and controls on distribution: V; 104, 105
Onshore and longshore sand transport: I, VI; 22, 26, 28-32, 107-111
Open Gulf bottom configuration: I, IX; 115, 116

Park and recreational lands: IV; 102, 103
Permeability of coastal substrates: II; 82-95
Pesticides, herbicides, and insecticides, use of: II, III, IV, VI; 82-90, 96, 97, 99-104, 107, 108, 111, 117
Physical properties—
  groups: II; 82-95
  of geologic units: I, II; 44-95
  of mineral resource areas: II, V; 82-90, 104-106
  of substrate in relation to soil types: II; 82-90
  of substrate supporting various biologic assemblages: II, III; 82-90, 95-100
  of substrate underlying areas of varied land use: II, IV, VII; 82-90, 100-104, 111-113
Piers and jetties, location and suitability: III, VI, VII; 97, 98, 107-110, 112, 113, 121, 122
Pipelines and active or potential faults: II, IV, V, VII; 82-91, 100-102, 104, 105, 111-113, 123
Planning and management, relationship to environmental geology: I; vii, 1, 2, 44-81, 115, 117-123
Plasticity of substrate: II; 84-90

Pleistocene systems (see also ancient systems): I; 14, 15, 17-19, 23, 44, 45, 48-51
Pleistocene-Holocene entrenched fluvial system: I; 18-20
Pollution: vii, 1, 2, 83-90, 117, 121
Ponds and lakes, natural and man-made: I, IV, VII; 100-104, 111-114
Ponds and reservoirs, suitability: II, III, VII; 84, 85, 97, 98, 111-114
Potreros and rincons, origin and development: I; 46, 69-71, 80, 81
Prairie lands: III, IV; 12, 13, 96, 97, 99-104
Public beaches, relationship to land use: I, III, IV, VI, VII; vii, 45, 53, 54, 96, 97, 99-103, 107-114

Quantifying physical properties units: II; 83

Rainfall gaging stations, U. S. Weather Service: VIII; 114
Rangeland, suitability: II, III, IV; 83-90, 97, 99-103
Recreational and park lands: IV; 102, 103
Recreational site, suitability: III, IV, V, VI; 96-111
Reefs—
  as sources of mineral resources: V; 105, 106
  history of growth and current condition: I, III; 66, 97, 98
  orientation with respect to bay and estuary water movement: I, VI; 61, 66
Relationship of topographic relief to underlying geologic units: I, IX; 44-82, 115, 116
Residential waste disposal planning: II, III, IV, VI, VII; 82-90, 93-95, 97, 99, 100-103, 107-113
Resource capability units and classes: I, II, III, V, VI; 115, 117-120
Resource distribution, relationship to environmental geology: I, III, V; 44-81, 96-100, 104-106
Resource potential: II, IV, V, VII; 82-90, 100-113
Rincons and potreros, origin and development: I; 46, 69-71, 80, 81
Road construction—
  base material sources: II, V; 83-85, 104-106, 117
  earthen structures: II, III, V; 83-90, 97, 99, 100, 104-106
  grade material sources: II, V; 83-85, 104-106, 117

Salinity ranges in bays and estuaries: III, VIII; 22-24, 32, 33, 66, 67, 97, 98, 100, 114, 115
Salinity stations, bay-estuary, Texas Parks and Wildlife Department: VIII; 114
Sand dunes, active eolian: I, II, III, VI, IX; 12, 21, 22, 24, 47, 69-81, 85, 87, 90, 97, 99, 100, 107, 108, 110, 115-117
Sand transport—
  eolian processes: I, VI; 21, 22, 24, 26-32, 69-81, 108, 110
  longshore and onshore: I, VI; 22, 26, 28-32, 107-111
Sea-level changes, historical significance in the Coastal Zone: 15-24
Seawalls, effects of construction on shoreline conditions: VI, VII; 107-114, 121
Sediment supply to bays, headward-eroding streams: I, VII, IX; 21, 44, 51, 52, 112, 113, 115, 116
Sedimentation, relative subaqueous rates: VI; 108, 111
Septic systems, suitability: II, IV, VI, VII, IX; 82-90, 93, 94, 100-103, 107-118, 121, 122
Shear or load-bearing strength of substrate: II; 84, 85, 86, 87
Shell, production and occurrence: V; 61, 66, 105, 106
Serpulid reefs: I, III, V, VI; 46, 47, 61, 66, 97, 98, 105, 106, 108, 111, 117
Shoreline—
  bay, miles (linear) of: VI, VII; 108, 112
  erosion or deposition, and construction: IV, VI, VII; 100-104, 106-113, 117, 121
  erosion or deposition, and land use: IV, VI, VII; 100-104, 106-113
  Gulf, miles (linear) of: VI, VII; 108, 112
Shorelines, effect of wave energy: I, II, III, VI; 29-35, 53, 54, 83-90, 95-100, 106-110
Shrink-swell potential of substrate: II; 84, 85, 86, 87
Slope stability: I, II, IX; 82-90, 115-117
Sludge pit and waste disposal sites, suitability: II, IV, VI, VII; 82-90, 93, 94, 100-103, 107-114, 117, 119, 121
Soil types, relationship to physical properties of substrate: II; 82-90
Solid-waste disposal, suitability and requirements for: II, III, VI; 82-90, 93, 94, 97-100, 107-114, 117, 119, 121

South Texas eolian system—
and banner dune complexes: I; 47, 69-77
areal extent: I; 12, 13, 47, 69-77
individual environments: I; 21, 22, 24, 47, 69-81
origin and development: 21, 22, 24, 69-81
principal elements: I; 69-77
Spoil dumping areas: I, II, III, VII; 47, 81, 82, 86, 89, 97, 98, 111, 112
Square miles—
of all map units: 45-47, 86, 98, 99, 102, 105, 108, 112, 116
of bay-estuary areas: 13, 46, 112, 116
Stabilization of shores by vegetation or structures: I, II, III, VI, VII; 26-35, 51, 52, 82-90, 96, 97, 99, 107-114, 117, 121, 122
State and private ownership boundary, problems: I, III, IV, VI; vii, 53, 96, 97, 99-104, 107-110
Statistics of mapped areas: 45-47, 86, 98, 99, 102, 105, 108, 112, 116
Subsidence, land-surface: II; 90-93, 123
Substrate—
acidity: II; 82-90
coastal, permeability of: II; 82-95
compressibility of: II; 82-90
corrosivity of II; 84, 85
dominantly mud and/or sand: II, V; 83-88, 105, 106
drainage capacity: II; 82-95
excavation potential: II; 82-90, 117
man-made, subaerial and subaqueous: I, II, III, VII: 13, 24, 25, 47, 62, 63, 81, 82, 84, 86, 89, 94, 97, 98, 100-103, 108, 111, 112, 117, 119-121
physical properties, general: I, II; 82-90
plasticity of: II; 84-90
shear or load-bearing strength of: II; 84, 85, 86, 87
shrink-swell potential of: II; 84, 85, 86, 87
supporting various biologic assemblages, physical properties of: II, III; 82-90, 95-100
underlying areas of varied land use, physical properties of: II, IV, VII; 82-90, 100-104, 111-113
water-holding capacity of: II; 84-87, 93, 94
Surface disposal sites affected by hurricane flooding: II, IV, VI, VII; 84-87, 93, 94, 100-104, 107-113, 117, 121, 122
Surface salinity, water depth, bottom sediments, and biologic assemblages: I, III, VIII, IX; 59-69, 95-100, 114-116
Surface salinity in bay-estuary, variation with rainfall and discharge: VIII; 114, 115

Texas Parks and Wildlife Department, bay-estuary salinity stations: VIII; 114, 115
Tidal-affected bay and estuary environments: I, III, VI, VIII; 23, 46, 97, 98, 108, 111, 114, 115, 117
Timber, potential sources: III, IV; 12, 96, 97, 99-103
Topography, relationship to hurricane flooding: I, VI, IX; 33-35, 107, 108, 115, 116, 122
Topography, relationship with underlying geologic units: I, IX; 44-82, 115, 116
Topsoil sources, fill material: II, V; 82-90, 104-106
Transitional areas, processes affecting: I, VI; 62-64
Transmission—
electric power: V; 104, 105
gas and petroleum products: IV, V, VII; 100-105, 111-113
Trees (water-tolerant) in fluvial areas: I, III; 44, 51, 52, 97, 99

Underground structures, suitability: II; 84, 85, 117
U. S. Geological Survey, Water Resources Division, discharge data: VIII; 114
U. S. Weather Service, rainfall gaging stations: VIII; 114
Urban areas and potential loss of resources to urbanization: IV, V, VII; 100-113
Urban expansion and effect on rural land use patterns: IV, VII; 100-104, 111-113
Urban growth and its impact on biologic assemblages: III, IV, VII; 95-103, 111-113
Use of Environmental Geologic Atlas of the Texas Coastal Zone: I; vii, 1-6, 35-44
Use of herbicides, insecticides, and pesticides: II, III, IV, VI; 82-90, 96, 97, 99-104, 107, 108, 111, 117

Vacation-home development (coastal), suitability: II, III, IV, VI; 33-35, 83-86, 88, 93-97, 99-103, 107-111, 117, 118, 121
Vehicle traversing off highways and roads, effect on vegetation: III, IV; 96, 97, 99-104, 117, 121

Waste disposal planning—
industrial: II, III, IV, VI, VII; 82-90, 93-95, 97, 99, 100-103, 107-113
residential: II, III, IV, VI, VII; 82-90, 93-95, 97, 99, 100-103, 107-113
Waste disposal sites and sludge pits, number: II, IV, VI, VII; 87, 102, 112
Water-based transportation systems: VII; vii, 1, 13, 14, 111-114
Water capability units: I, III, VIII; 44-47, 59-69, 95-98, 100, 114, 115, 117-120
Water depth, surface salinity, bottom configuration, and biologic assemblages: I, III, VIII, IX; 59-69, 95-100, 114-116
Water-holding capacity of substrate: II; 84-87, 93, 94
Water table, proximity to land surface: II; 14, 84, 85, 91-93
Water-tolerant trees in fluvial areas: I, III; 44, 51, 52, 97, 99
Wave energy, effect on shorelines: I, II, III, VI; 29-35, 53, 54, 83-90, 95-100, 106-110
Wetlands, nature, location, and distribution: I, II, III, IV, VI; 12, 13, 46, 58, 59, 84, 86, 88, 96, 97, 99, 101, 102, 107, 108, 117, 119
Wildlife habitats: I, III, IV; 12-14, 44-90, 95-103
Wildlife refuge, potential sites: I, III, IV, VI; 44-90, 95-103, 107-111, 119
Wind regimes and eolian processes: VI; 26-32, 108, 110
Wind-tidal effects in bay and estuary environments: I, VI; 22-24, 32, 45, 46, 60, 62, 63, 117, 119
Wind-tidal flats—
general characteristics: I, II, III, VI; 12, 13, 29, 32, 46, 60, 62-64, 84, 86, 89, 96, 97, 99, 108, 110, 117, 119
origin and development: I, VI; 22-24, 29, 32
relationship to salt-water marshes: 12, 13

Zone of convergence, longshore drift: 28-31

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 Kingsville area (table 6). In this manner, the areas of low permeability can be located on the *Physical Properties Map*. Reference to the text and table 7 provides additional description and elevation of landfill suitability. In addition, if the user wants to know the percentage of improperly located solid-waste disposal sites within the Kingsville 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.

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 both 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 subaerial units such as salt marsh, fresh-water marsh, swamp, upland woodlands, as well as some subaqueous or submerged units, where biologic activity and productivity are dominant features in potential use or environmental maintenance; (3) active-process units, such as storm channels, tidal passes, wind-tidal flats, and beaches, where specific active or potentially active physical processes are of first-order consideration; and (4) man-made features, such as spoil heaps, spoil wash, dredged channels, and made or reclaimed land, where 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 Kingsville area of the Texas Coastal Zone. These include: (1) natural units that are products of active processes and Modern 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 areas and systems classed as *Pleistocene* on the *Environmental Geology Map*, forming chiefly the coastal uplands of the northern part of the Kingsville area, are relict substrates formed in previously active but currently inactive coastal environments. These Pleistocene substrates also underlie the veneer of Modern-Holocene eolian deposits throughout the remainder of the mainland in the Kingsville area.

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 Kingsville area were deposited during interglacial periods prior to the beginning of the last glacial episode (Wisconsin) about 100,000 years B. P. Units classed herein as *Modern-Holocene* on the *Environmental Geology Map* include: (1) deposits and landforms developed during the last rise in sea level, about 18,000 to 4,500 years B. P. (Holocene); and (2) deposits and landforms developed during the past 4,500 years, during which time sea level has been approximately at its present position (Modern).

On the *Environmental Geology Map* of this Atlas, natural mapped units are further grouped into large-scale *natural systems*. Such grouping reflects the natural association and origin of specific mapped environmental categories. The origin of various natural units in the Coastal Zone is basic to considerations of resource evaluation and use since it determines the main features, composition, and character. Natural systems delineated in the Kingsville area (fig. 4) include: (1) fluvial-deltaic system, a series of Pleistocene substrates formed by older deltas and several small Modern fluvial systems; (2) barrier-strandplain system, a suite of Pleistocene substrates and Modern environments and substrates formed at the interface of the land and Gulf; (3) marsh system, including small areas of occasionally wet, grassed lands of the low-lying coastal area and hummocky, interior eolian plains; (4) offshore system, embracing various units of the Modern barrier island shoreface and inner continental shelf developed seaward of Gulf beaches; (5) bay-estuary-lagoon system, consisting of Modern, restricted, subaqueous or submerged estuarine environments (Baffin Bay-Laguna Madre) occurring landward of the barrier island and connected with the Gulf via Aransas Pass (north) and Mansfield Pass (south); and (6) environments produced and dominated by eolian or wind processes that occupy most of the land surface within the Kingsville map area. Certain specific environments or mapped units may occur in more than one natural system. 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 Kingsville area (fig. 4). These include a fluvial-deltaic system and a barrier-strandplain system formed during various interglacial stages (fig. 5). These older deposits of the Coastal Zone form the coastal uplands generally situated at elevations greater than 10 feet above present sea level. Pleistocene substrates are exposed north of Baffin Bay; south of the bay, a veneer of Modern-Holocene eolian sediments covers the relict deposits. Individual units within 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

Within the Kingsville area, three principal units within the Pleistocene fluvial-deltaic system are exposed north of Baffin Bay. These include distributary channel sands and silts, associated interdistributary muds of ancient delta plains, and marine deltaic sands (fig. 4). Pleistocene deltaic units (distributary channels and interdistributary mud) and barrier-strandplain units are commonly termed Beaumont Formation or, in part, Prairie Formation by various workers (Bernard and LeBlanc, 1965). Pleistocene meanderbelt sands and

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

		ENVIRONMENTAL GEOLOGIC MAP UNITS	Brooks County°	Kenedy County°	Kleberg County°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Kingsville map area (excluding offshore area)	Percentage of Kingsville map area covered by map unit (excluding offshore area)
PLEISTOCENE SYSTEMS	FLUVIAL-DELTAIC SYSTEM	Distributary and fluvial sands and silts, including levee and crevasse splay deposits	0	0	61	–	61	2.6
		Interdistributary mud, including bay and floodbasin deposits	0	0	77	–	77	3.3
		Delta-front mud and sand, may be reworked, veneered by thin marsh-lacustrine mud or loess, locally calichified	0	0	48	–	48	2.1
		Delta-front mud and sand, may be reworked, lacustrine mud or loess veneer removed by erosion, locally calichified	0	0	10	–	10	0.4
		Marsh, fresh-water, and poorly drained depressions, mud and sand substrate, distribution varies with climatic cycle (Modern)	0	0	*	–	*	*
		Abandoned channel and course, mud-filled (Pleistocene and Holocene-Modern)	0	0	0.3	–	0.3	0.01
		Coastal lake or pond, mud-filled (Pleistocene and Holocene-Modern)	0	0	5	–	5	0.2
		Clay-sand dunes, accretionary, active, locally sparse grass, wind-tidal flat or playa source common (Modern)	*	*	*	–	*	*
		Clay-sand dune complexes, inactive, grass or brush covered (Holocene and Modern)	*	*	*	–	*	*
		Loess sheet, thin, stippled where discontinuous, silty, overlies calichified Pleistocene fluvial sand (Holocene-Modern), brush and grass covered	*	0	*	–	*	*
	BARRIER-STRANDPLAIN SYSTEM	Loess sheet, thin, discontinuous, silty, overlies Pleistocene deltaic mud and calichified sand (Modern), brush and grass covered	0	*	*	–	*	*
		Barrier-strandplain sand, grass-covered, local sparse scrub	0	0	5.5	–	5.5	0.3
		Marsh, fresh-water, and poorly drained swales, mud and sand substrate, distribution varies with climatic cycle (Modern)	0	0	0.8	–	0.8	0.03
	FLUVIAL SYSTEM	Small ephemeral stream, alluvium or erosional, sand, silt, mud, commonly barren, sparse vegetation inland, headward-eroding	0.3	0.2	10	–	10.5	0.5
		Wind-tidal flat, sand and mud, firm, occurs locally in lower stream valley, transitional between bay and stream	0	*	*	–	*	*

Table 3 (continued)—

MODERN-HOLOCENE SYSTEMS	BARRIER AND OFFSHORE SYSTEMS	Shelf mud and sand with shell, mottled	–	–	–	–	–	–
		Shoreface, sand and muddy sand, burrowed	–	–	–	46	–	–
		Beach, sand and shell	0	1.4	0.3	–	1.7	0.07
		Fore-island dune ridge, sand	0	2.2	0.8	–	3	0.12
		Sandflats and/or coppice sand-dune fields, wind-shadow dunes common, active	0	1.2	0	–	1.2	0.05
		Barrier flat, sand and shell, grass-covered, local ponds and marsh	0	10	7	–	17	0.7
		Barrier flat, sand and shell, very sparse grass	0	1.2	0	–	1.2	0.05
		Stabilized blowout dune complex, sand, grass-covered, hummocky, ramp-like	0	3.8	2.3	–	6.1	0.3
		Wind deflation trough and storm runnel on barrier flat, sand, some seasonal fresh-water marsh and grass, algal mats	0	2.2	0	–	2.2	0.1
		Washover channel, sand, active	0	2.4	0.3	–	2.7	0.1
		Washover fan, sand, subaerial, unvegetated, active	0	1.9	0.2	–	2.1	0.09
		Back-island dune field and fore-island blowout dune, sand, longitudinal dune types common, active	0	21	12	–	33	1.4
		Back-island sandflats with small migrating dunes, unvegetated	0	4.6	0	–	4.6	0.2
	MARSH SYSTEM	Marsh, fresh-water, and poorly drained depressions, distribution varies with climatic cycle	0	0	11.4	–	11.4	0.5
	BAY-ESTUARY-LAGOON SYSTEM	Bay- or lagoon-margin sand or shell berms, accretionary, subaerial, relict depositional grain, vegetated	0	1.4	0.8	–	2.2	0.1
		Bay- or lagoon-margin sand, locally with shell and mud, subaqueous sheet or bar; occasionally subaerial near Rincon de San Jose	0	1.4	1.4	–	2.8	0.1
		Bay-margin oolites and quartz sand, sparse grass locally	0	0	1	–	1	0.04
		Bay-margin quartz sand and calcite-coated grains, sparse grass locally, Pleistocene locally exposed	0	1.2	11	–	12.2	0.5
		Sand shoal with some oolites, slight bathymetric relief	0	0.5	0	–	0.5	0.02
		Grass flat, muddy sand with shell, hypersaline	0	10	18	–	28	1.2
		Bay and lagoon sand, muddy, locally sparse grass, Pleistocene locally exposed in Baffin Bay	0	38	26	–	64	2.8
		Bay and lagoon mud, mottled, some mixed shell	0	11.5	3	–	14.5	0.6
		Bay mud, laminated, rare shell below 6 feet, some sand and shell with locally exposed Pleistocene above 6 feet	0	19.5	18	–	37.5	1.6
		Serpulid reefs and related shell-rich sand and beach rock, known reefs shown by solid circles	0	5.5	5	–	10.5	0.5
		Wind-tidal flat, sand, loose, rarely flooded	0	23	0	–	23	1
		Wind-tidal flat, sand and mud, firm	0	51	27	–	78	3.4
		Wind-tidal flat, sand and mud, extensive algal mats, alternately emergent-submergent	0	29	1	–	30	1.3
		Wind-tidal flat, mud and sand, algal-bound mud, gypsiferous, firm	0	40	0	–	40	1.7
		Wind-tidal flat, mud and sand, extensive algal mats, depressed relief, wet and soft	0	13	0	–	13	0.6
		Eolian accretionary bars and ridges, sand and clay, on wind-tidal flat (rincons, potreros)	0	7	0	–	7	0.3
		Marginal residual sand apron on windward side of rincons and potreros, wind deflation lag deposit	0	0.7	0	–	0.7	0.03
		Transitional zone, wind-tidal flat to eolian sand sheet, wind deflation, concentrated clay dunes, sand	0	65	0.5	–	65.5	2.8

Table 3 (continued)—

EOLIAN SYSTEM	Active dune complex, sand, commonly banner dunes, locally barchan dunes	0.05	52	0.2	–	52.25	2.3
	Active dune blowout areas, sand, local depressed relief, eolian grain prominent, hummocky, locally fresh-water marsh in wet seasons	0.3	74	0	–	74.3	3.2
	Sand sheet with strong relict grain of base-leveled dunes, sparse grass	2.6	208	14	–	224.6	9.7
	Sand and loess (silt) sheet with no relict grain, sparse grass	2.6	298	0.4	–	301	13
	Moderately stabilized dunes, sand and loess (silt) sheet, brush-covered	1.35	150	21	–	172.35	7.5
	Well-stabilized dune sands, dense live-oak mottes and scrub	0.8	191	0	–	191.8	8.3
	Sand and loess (silt) sheet deflation area, active, grass, high water table, occasionally flooded, poorly drained	2.6	142	1.6	–	146.2	6.3
	Clay-sand dunes, accretionary, active, locally sparse grass, wind-tidal flat or playa source common	0.3	11	5	–	16.3	0.7
	Clay-sand dune complexes, inactive, grass or brush-covered (Holocene and Modern), local sediment source	0.3	1.7	26	–	28	1.2
	Loess sheet, thin, stippled where discontinuous, silty, overlies calichified Pleistocene fluvial sand (Holocene and Modern), brush and grass-covered	1.5	0	156[30] ⊕	–	157.5[30] ⊕	6.8[1.3] ⊕
	Loess sheet, thin, discontinuous, silty, overlies Pleistocene deltaic mud and calichified sand (Holocene and Modern), brush and grass-covered	0	54	110	–	164	7.1
OTHER MAP UNITS	Barchan dune orientation in banner dune complexes	–	–	–	–	–	–
	Longitudinal dune orientation in back-island dune field	–	–	–	–	–	–
	Beach ridges, accretionary, relict (barrier-strandplain)	–	–	–	–	–	–
	Wind accretion ridges, rincons and potreros	–	–	–	–	–	–
	Serpulid reefs; approximate distribution, others unmapped	–	–	–	–	–	–
	Spoil heap or mound, subaerial	0	1.2	0.2	–	1.4	0.06
	Reworked spoil, subaerial	0	12	0.3	–	12.3	0.5
	Spoil, subaqueous	0	2.6	1.5	–	4.1	0.2
	Made land	0	0.005	0.1	–	0.105	0.004
TOTAL	Total land area+	12.7	1468.7	645.2	–	2126.6	91.5
	Total land and water area, excluding offshore area+	13	1574.8	736.4	–	2324.2	100
	Total water area (natural and artificial) excluding bay, lagoon, and open ocean	0.3	7.5	5.5	–	13.3	0.6
	Total bay and lagoon area	0	98.6	85.7	–	184.3	7.9

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

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

muds, which are commonly termed Lissie Formation (or Montgomery and Bently Formations by some workers), underlie thin loess (eolian silt) deposits and thicker eolian sand deposits west of U. S. Highway 77.

Meanderbelt sands and floodplain muds (not shown on map).—These deposits are covered by eolian sediments in the Kingsville map area (fig. 4). Meanderbelt sands are composed of channel and point-bar sands deposited within Pleistocene meandering streams. Some Pleistocene mud or clayey sediments of floodbasin origin may occur within the predominantly sandy deposits. Most of the Kingsville map area west of U. S. 77 is underlain by these Pleistocene fluvial sands and localized muds. The meanderbelt sands, covered by a thin loess deposit, support low-relief ridges that trend east-west in the region west of U. S. Highway 77 and north of Olmos Creek. South of Olmos Creek, thicker eolian sands mask the poorly defined topographic ridges, but the distribution of thick sands beneath the eolian sediments may coincide generally with large areas where wind deflation has reached a shallow water table. Eolian activity in the Kingsville area has totally destroyed any evidence of depositional grain (point-bar accretion and channel abandonment); only east-west topographic grain and the distribution of deflation areas give some hint of this depositional system.

Beneath the Modern-Holocene loess and sand veneer, the buried Pleistocene meanderbelt sands serve as relatively thin, shallow aquifers. Pleistocene floodbasin deposits are probably composed of clayey sediments with thin intercalated crevasse splay sands. Where these floodbasin sediments underlie the blanket of eolian sediments, shallow ground-water supplies should be limited. In turn, wind deflation of the compact clayey Pleistocene substrate should be negligible.

Meanderbelt sands and floodbasin muds both exhibit calichification, but maximum precipitation of calcium carbonate occurs in the upper part of the moderate to highly permeable meanderbelt sand bodies. Here, ground-water circulation continually renews the supply of the bicarbonate ion required for the calichification process.

Distributary and fluvial sands and silts.—The coastal uplands of the Kingsville area north and northwest of Baffin Bay are characterized by narrow, elongate sand bodies totaling about 61 square miles (fig. 11). These sand bodies were deposited as distributary channels, flanking levees, and crevasse splays on late Pleistocene delta plains. The principal sand body,

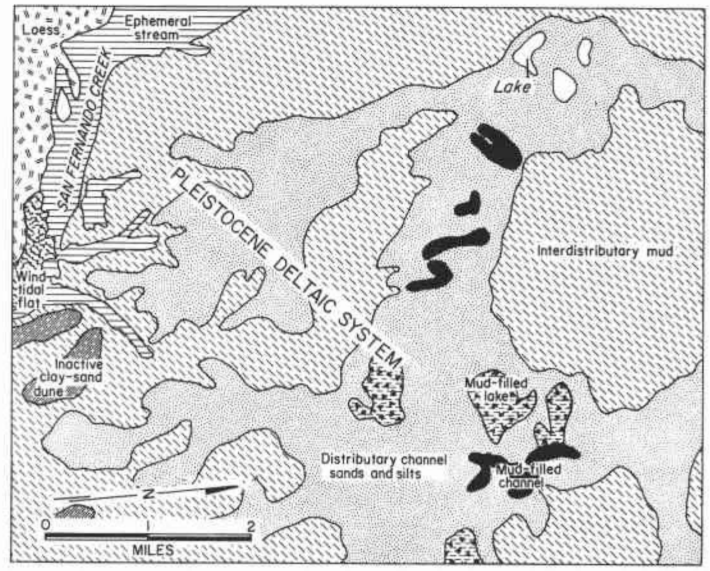


Figure 11. Pleistocene fluvial-deltaic system, coastal uplands northwest of Baffin Bay, Kingsville area. Distributary channel facies are part of a southeastern lobe of the Pleistocene Nueces fluvial-delta system.

which trends approximately normal to the present shoreline, extends for about 20 miles across the northernmost part of the Kingsville area. The sand body ranges in width from 0.5 mile to 2.0 miles and may be more than 50 feet thick; other sand bodies as much as 7 miles long branch from the main body. These elongate bodies are composed of fine-grained sands with admixtures of silt and clay. Areas underlain by the channel sands are slightly higher than surrounding areas on the coastal uplands. The sand and silt bodies exhibit a distributary or branching pattern. A few abandoned channel loops and courses can be recognized; the channels were abandoned during the late Pleistocene, though infilling continues to the present. Abandoned channels are largely mud filled in contrast to the sands on which they are superimposed. Irregular, mud-filled ponds and lakes from 0.1 to 1 mile wide occur on the distributary sands; lakes may contain both late Pleistocene and Modern-Holocene mud deposits. Mud-filled relict lakes trap some of the limited rainfall and hold it as soil moisture, permitting the growth of plants with greater than average moisture requirements. The unit is generally associated with certain Clareville, Willacy, Orelia, and Banquete soils.

The absence or limited occurrence in the Kingsville area of features such as pimple mounds, pockmarks, and abandoned channel loops may, in part, result from the dry, wind-dominated climate. Calichification and wind deflation of these sand and silt deposits are probably accelerated by lower water tables and low soil moisture.

These factors may have been responsible for obliterating evidence of channel cutoffs and may destroy or prevent development of pimple mounds.

Distributary sand bodies in the Kingsville map area originate in the Corpus Christi map area and trend coastward from the north to the vicinity of Alazan Bay and Cayo del Grullo. Erosion of the distal, gulfward parts of the distributary sands during the late Pleistocene and Modern-Holocene may account for the abrupt termination north of Baffin Bay. How much farther they extended gulfward is not presently clear, but to the north in the Corpus Christi map area, the distributary sands apparently extend gulfward beneath the Pleistocene Ingleside barrier-strandplain sand (Wilkinson, 1973; Wilkinson and others, 1975). Coring will be necessary to solve this problem. Large, inactive conical clay-sand dune complexes northeast of Alazan Bay at the terminus of the distributary deposits may represent eolian accretion on nuclei composed of erosional remnants of the distributary sands (fig. 12).

Distributary sands in the vicinity of Kingsville extend southeastward beneath the thin eolian silt (loess) blanket east of U. S. Highway 77. How far the deltaic sediments extend southward beneath the eolian sand sheet is uncertain (fig. 4). Largely inactive conical dunes west of Cayo del Grullo may be composed of sand and clay derived locally from the Pleistocene delta system beneath the loess veneer.

Interdistributary muds.—Almost 80 square miles of the coastal uplands north and northwest of Baffin Bay are underlain by broad, flat areas of mud and clay substrates and associated Victoria soils (fig. 11). These fine-grained muddy and clayey sediments represent floodbasin or overbank deposition on the Pleistocene delta plain. Several low, poorly drained interdistributary depressions extend into the Kingsville map area from the Corpus Christi area. These subtle depressions probably represent filled lakes and marshes that are remnants of late Pleistocene floodbasins. At lower elevations, such as at Madero Lake, ephemeral fresh-

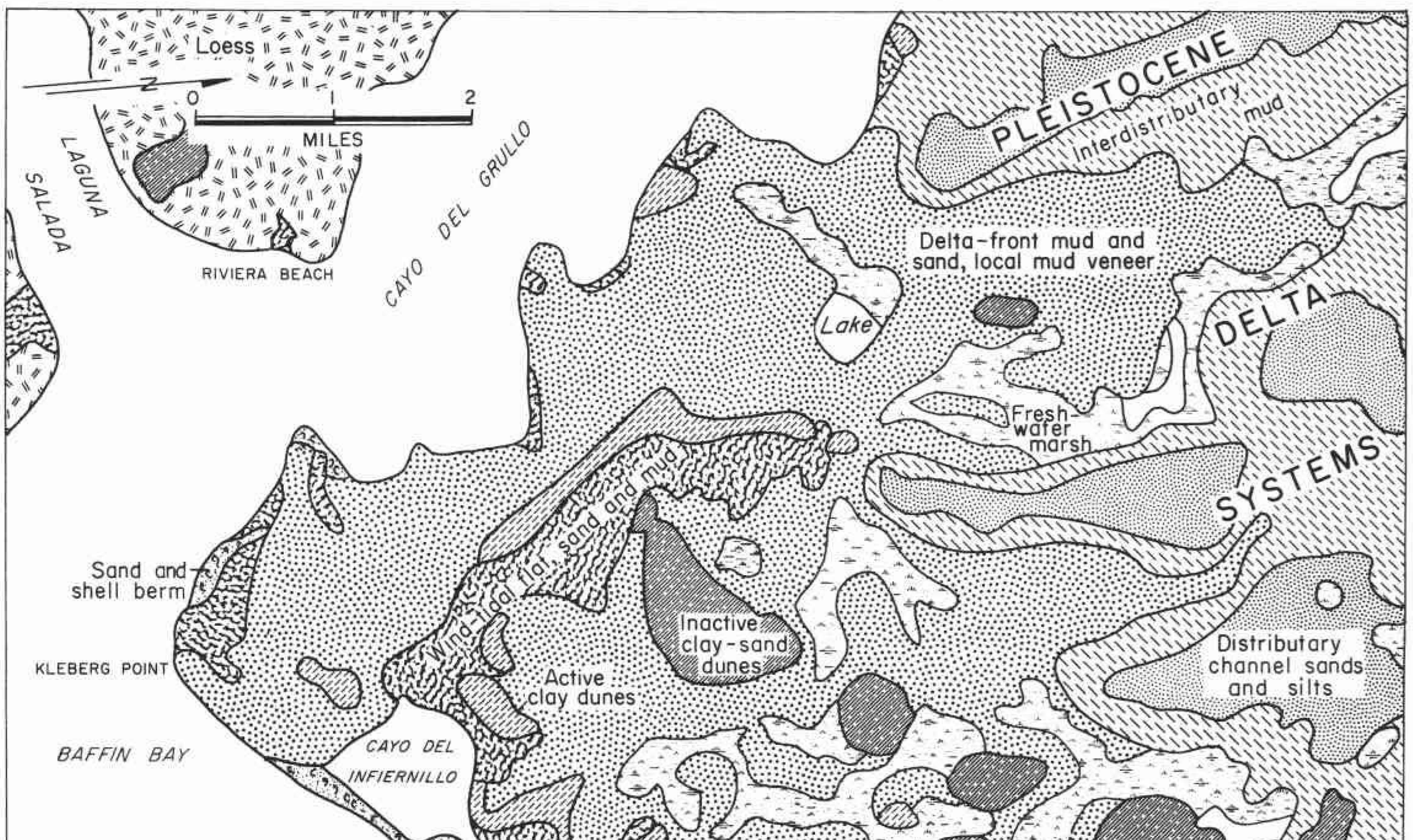


Figure 12. Distributary sand and silt, interdistributary mud, and associated delta-front sand, mud, and silt, Pleistocene delta system, north side of Baffin Bay, Kingsville area. Delta-front facies veneered by windblown silt (loess), lacustrine-lagoonal mud, and active-inactive clay-sand dunes.

water marsh or other high-moisture plants may develop in the depressions during wet periods in climatic cycles. Interdistributary bay muds were covered gradually by overbank muds as the delta system built slowly gulfward.

Soils developed on these interdistributary and floodbasin clays are dark and fertile Victoria Clays, but they are rarely cultivated in the map area because of low rainfall and the presence of large ranching interests in Kleberg County. Farming of these rich soils is abruptly terminated at the Nueces-Kleberg county line, which separates the large ranch tracts to the south from small, individually owned farms to the north.

Marine deltaic mud and sand.—Between the northwestern shore of Alazan Bay and the gulfward termination of the Pleistocene distributary sand and silt deposits is a 5-mile-wide strip of mixed sandy and muddy deltaic sediments (fig. 12). The unit lies below an elevation of about 15 feet and borders the erosional northeastern shore of Cayo del Grullo and the northwestern shore of Alazan Bay and its subsidiaries—Cayo del Infiernillo, Cayo de Hinoso, and Cayo del Mazon. These deposits are extensively veneered by thin, calichified marsh-lacustrine mud and loess (Lomalta soils); headward erosion of gulleys from the cayos has removed the mud veneer in some areas. During wet periods in the climatic cycle, depressions on the surface of this unit may support ephemeral fresh-water marsh or other high-moisture plants.

These deltaic mud, sand, and silt deposits occupy 60 square miles of the area below the 15-foot elevation between Cayo del Grullo and Laguna Larga (Corpus Christi map area). Apparently they were deposited within delta-front environments where the late Pleistocene distributary channels introduced sediment into a coastal embayment. Marine currents redistributed some of the sediment, and after the delta was abandoned, marine waves and currents continued to rework the sand, silt, and mud into sheetlike deposits. The Ingleside barrier strandplain appears to rest upon these distal deltaic deposits south of Laguna Larga in the Corpus Christi map area and in the northeastern corner of the Kingsville map area (fig. 13).

The thin veneer of mud of probable marsh and lacustrine origin covers large areas of deltaic sediment and may represent late Pleistocene (perhaps Peorian; fig. 5B) sedimentation in lakes and brackish lagoons landward of the Ingleside barrier strandplain. Regional uplift of less than 10 to 15 feet (or a similar drop in

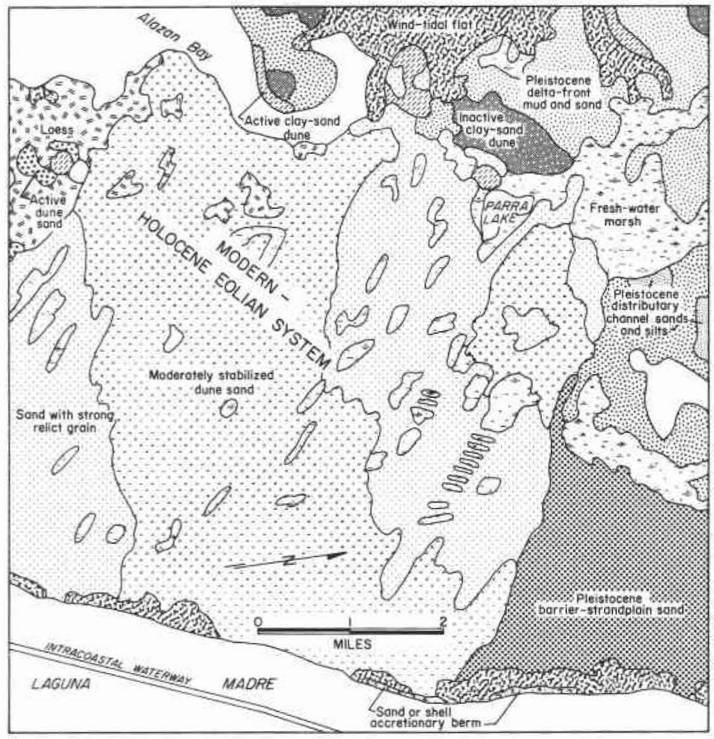


Figure 13. Pleistocene (Ingleside-Encinal) barrier-strandplain system, modified by eolian deflation north of Baffin Bay, Kingsville area. Poorly drained area landward of barrier-strandplain occupied by ephemeral fresh-water marsh or hydrophytic plants.

absolute sea level) would be required to account for its present position. It is also possible that the thin muddy sediment was deposited 5 to 15 feet above present sea level in Modern lakes and lagoons which formed several thousand years ago when sea level reached its approximate present level. Similar relationships occur in the Port Bay area of the Corpus Christi map area. The mud veneer has been extensively eroded by Modern gully erosion and sheetwash.

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 dunes, 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 sands may be strandplain deposits formed along ancient shorelines by redeposition of sands eroded from deltas. Strandplains are similar to barrier islands except that the strandplain develops along the mainland shoreline rather than offshore. Although local lagoons and lakes may be associated with a strandplain, extensive lagoons, such as Laguna Madre, do not occur landward of a strandplain system.

In the northernmost part of the Kingsville area, a portion of this ancient barrier-strandplain system is well preserved. Extending southward from the Corpus Christi map area, the sandy deposit supports a ridge (called Flour Bluff or Encinal) about 2 to 3 miles wide and 10 to 25 feet in relief. It extends along the mainland shoreline of northern Laguna Madre and is essentially parallel to the Modern Gulf shoreline (fig. 13). In the Coastal Bend region, the Pleistocene barrier strandplain is called Ingleside due to its occurrence in the town of Ingleside near Corpus Christi (Price, 1933, 1958).

The Ingleside sand rests on an erosional terrace (Ingleside terrace) that was eroded into Pleistocene delta sediments. The terrace is exposed along the northwestern side of Cayo del Grullo at about 10 feet above sea level; the terrace underlies Laguna Larga (Corpus Christi map area). The grass-covered sand body extends southward to Point of Rocks at the mouth of Baffin Bay. For almost 8 miles north of Point of Rocks, Ingleside sand has been extensively deflated by the southeasterly winds. Wind sculptured the sparsely vegetated deposit into strong elongate sand ridges and deflation troughs (fig. 13); brushy vegetation now partially stabilizes parts of the hummocky dune ridges. Deflation troughs pond water and support some freshwater marsh during wet cycles. North of Baffin Bay, approximately 15 square miles have been affected by wind deflation and dune development. Large volumes of sand derived from this Pleistocene deposit have been blown northwestward into a series of large eolian lobes (Parra Lake eolian lobe) located between Alazan Bay and Laguna Larga (Corpus Christi map area). Erosion of the mainland at Point of Rocks has resulted in exposure of aragonite-cemented beach rock, with locally concentrated shells, from the Ingleside barrier-strandplain system.

The original extent of the Ingleside sand body south of Baffin Bay can only be estimated because of the extensive eolian modification of the relict shoreline. South of Point Penascal for 6 miles along the mainland shore of Laguna Madre, a low, elongate ridge that separates the Laguna from Rocky Slough may represent an exhumed Ingleside beach ridge. Further to the south, the various potreros that were formed by wind accretion of clay and sand (especially Potrero Cortada, Potrero Grande, and Potrero de los Caballos) may have formed around nuclei composed of eroded remnants of Pleistocene beach ridges. It can be speculated that much of the sand of the Sarita eolian lobe was derived from the Ingleside sand body south of Baffin Bay.

Ingleside barrier.—Strandplain sands commonly overlie and are bounded both seaward and landward by impermeable Pleistocene muds and clays (Wilkinson and others, 1975). The sands are well-sorted marine deposits less than 50 feet thick. Relict beach ridges have been obliterated by eolian activity except for possible accretionary grain near the shore of Laguna Madre. Calcium carbonate, derived from shells within the Ingleside shoreface and beach deposits, has cemented the sands into hard beach rock which is exposed along the erosional mainland shoreline of Laguna Madre. Ingleside sands form local, shallow aquifers, commonly with perched water tables. In the Kingsville map area, the Ingleside barrier-strandplain sand body apparently rests upon muddy, silty, and locally, sandy deltaic sediment. Modern lagoonal muds and lagoon-margin sands overlap the sand along its gulfward side. Modern-Holocene lacustrine, bay, or lagoonal muds and sands may underlie some of the Parra Lake thin eolian sands between Alazan Bay and Laguna Larga (fig. 13).

MODERN-HOLOCENE SYSTEMS

Four major and two minor natural systems are currently active in the Kingsville area; for the most part, they have existed during the past 2,500-2,800 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 barrier system, offshore system, bay-estuary-lagoon system, and eolian system; minor systems include fluvial system and marsh system. In addition, several man-made units occur within the Kingsville area. Forty-eight distinct and separate environments are delineated and mapped within these systems (see *Environmental Geology Map*). Specific environments are recognized by floral and faunal assemblages, geomorphic expression, depositional grain and morphology, sediment composition, and dominant active processes.

Fluvial System

Modern-Holocene fluvial systems are of minor importance within the Kingsville map area; no large rivers exist within the area. Small, headward-eroding streams are restricted to the northern one-third of the map area. Drainage systems have been unable to develop in the arid, southern two-thirds of the map area where recent and current eolian activity has developed a hummocky, poorly drained sand plain. Integration of drainage has been impossible within the sand sheet during Holocene and Modern times because of the dynamic, shifting character of eolian erosion and deposition.

Several small ephemeral stream systems in the northern part of the Kingsville area are eroding headwardly into either exposed or loess-covered Pleistocene uplands (fig. 14). These streams, which cover about 10 square miles, are not in adjustment and are actively eroding, at least in the upper reaches of the drainage basins. Examples include Olmos, Santa Gertrudis, San Fernando, Tunas, and Petronila Creeks (see Corpus Christi map area) and minor tributaries. These streams have a limited number of lesser tributaries because integration of a drainage net has been restricted by recent eolian deposits and, locally, by caliche karst development, which diverts surface drainage into shallow Pleistocene aquifer sands. Little tree vegetation occurs along stream courses, and streams flow within erosional channels containing very little alluvium. Storage of water in channel fill or bank alluvium is limited, so that subsurface irrigation of plants along streams within the Kingsville area is very limited.

The erosional character of these headward-eroding systems diminishes significantly along the lowermost reaches of the streams where the gradient decreases and the streams flow onto the wind-tidal flats of Laguna de los Olmos, upper Cayo del Grullo (fig. 14), Cayo del Mazon, and Cayo de Hinoso. These tidal flats are developed on sandy, valley-filled river sediment deposited in the upper parts of the Baffin Bay estuary during late Holocene and Modern times. Sandy sediment that is flushed through the headward-eroding system during brief periods of high discharge, generally associated with tropical storms or hurricanes, is carried across the tidal flats by complexly braided channels. During periods of peak flow, the streams discharge sufficient volumes of water to produce temporarily fresh to brackish salinities in associated estuaries.

Deposition of high bedload sediments in the shallow, freshened bay system takes place by a combination of fan-delta processes (McGowen, 1970) and lacustrine delta processes (homopycnal or Gilbert delta;

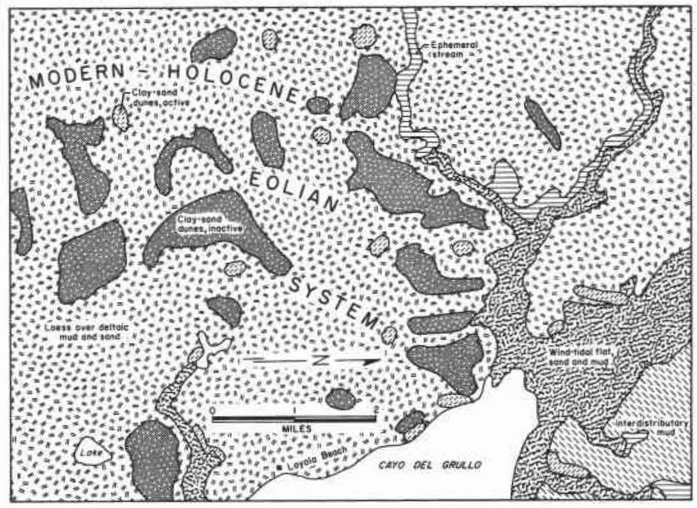


Figure 14. Modern headward-eroding stream system (San Fernando Creek) near Kingsville, Texas. Streams are ephemeral and grade bayward into wind-tidal flats. Pleistocene deltaic deposits are veneered with loess and local clay-sand dunes.

Fisher and others, 1969). Braided channels debouch the sandy bedload into the shallow bay as a series of thin, progradational, low-angle foreset or fan-fringe beds; topset or fan-plain beds are composed of aggradational braided channel sand bars and associated deposits. Suspended clays constituting the pro-fan or bottomset deposits are widely distributed within the bay. As the flood level drops, the principal braided channels erode the topset deposits. Since sea level reached its approximate present level, the bayhead fan or lacustrine deltas at the mouth of the ephemeral streams have been slowly filling the upper ends of the estuary. The topset or fan-plain deposits are building slowly bayward over the very thin foreset or fan-fringe deposits. Eventually, Laguna Salado, Cayo del Grullo, and Alazan Bay will be filled.

During the long periods between floods, southeasterly and northerly winds deflate and redistribute much of the topset or fan-plain sediment to produce low dunes and sand sheets. Wind-generated tides also flood the flats periodically, depositing thin lamina composed of suspended mud and algal mats over the surface of the bayhead delta (fig. 14). When tidal water retreats from the flats, the thin clay-algal mat lamina is desiccated, cracked, and disintegrated into silt- and sand-sized pellets that are blown to adjacent Pleistocene valley walls where they are deposited as clay dunes. The bayhead deltas of Baffin Bay, therefore, undergo short periods of rapid deposition or construction followed by long periods of eolian and wind-tidal modification and destruction.

Barrier and Offshore Systems

An important natural system within the Kingsville area is the Modern barrier-island system. The suite of environments that compose this system forms at the interface of land and ocean. Padre Island, which constitutes the barrier system in the southern part of the Texas Coastal Zone, is a continuous strip of sand from 0.5 mile to 2.5 miles wide that extends along the entire Gulf shoreline of the Kingsville area. The island covers approximately 70 square miles. No natural passes break up Padre Island. Yarborough Pass, an artificial pass located a few miles north of Middle Ground, has been open for only a few months since it was first dredged in 1941; it was last open for a few days in 1952. Throughout most of its length, Padre Island is separated from the mainland by Laguna Madre, a broad, shallow lagoon from 2 to 10 miles in width (fig. 4). Between approximately latitude 26°45′ N and 27°00′ N, the island is joined to the mainland by the broad wind-tidal flats of the Land-Cut Area.

These tidal flats are developed upon sediments transported into Laguna Madre by wind and storm surge in the area of net longshore drift convergence (fig. 8A). The northern two-thirds of Padre Island within the Kingsville map area exhibit a relatively high, generally continuous fore-island dune ridge. Southward, the dune ridge becomes discontinuous and the number of washover channels that breach the island becomes more numerous. Back-island dune fields are common along much of Padre Island, but they are absent in the area between Middle Ground and the Land-Cut Area. Shelly beaches are typical of much of Padre Island within the map area. The density of vegetation and, consequently, the resistance to water erosion or wind deflation decrease southward along Padre Island.

Padre Island is composed of 12 units within the Kingsville area. Extending landward from the Gulf shoreline, the main components of the barrier system are beach, fore-island dune ridge, fore-island blowout dunes, stabilized blowout sand dunes, barrier flat, and back-island dune fields. A variety of other environmental geologic units along the Padre Island barrier system include washover channels, washover fans, wind deflation troughs and storm runnels, sandflats and coppice sand dune fields, barrier flats with sparse vegetation, and back-island sandflats. The island is veneered principally by Mustang soils.

The offshore system of the Kingsville area includes the inner continental shelf that is floored in most of the area by a thin veneer of Modern-Holocene muddy deposits that overlie relict Pleistocene mud and sand. Exceptions are areas where buried valleys beneath the Modern shelf are filled with thick Holocene sediments (fig. 6). The shoreface environment of Padre Island is developed on relict Pleistocene sediments seaward of the beach and extends to a depth of about 30 feet where it grades into the shelf environment. Probably the single most important process affecting Padre Island is longshore drift. Currents moving parallel to shore, combined with onshore wave and swash action, transport and deposit sediment that builds or maintains the shoreface and beach environments. Periodic hurricanes contribute large volumes of sediment to the longshore system by onshore storm transport of relict shelf sediments. Fisk (1959) presented subsurface cross sections of the Modern-Holocene barrier island and associated offshore deposits (fig. 15).

Barrier System

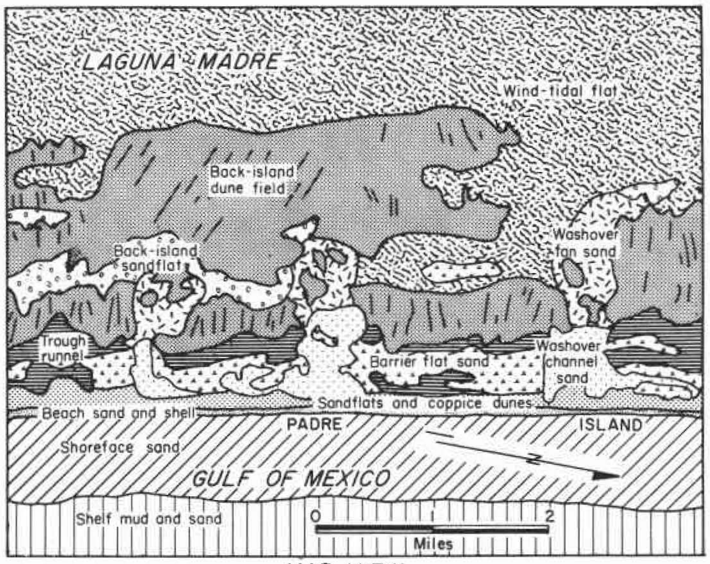
Beach.—Almost 2 square miles of Gulf beach occur between low tide and the first inland line of vegetation (figs. 15, 16). North of the Land-Cut Area, the vegetation line on Padre Island coincides approximately with the gulfward side of the fore-island dune ridge. Southward along Padre Island, the vegetation line becomes so discontinuous that in the southernmost part of the map area, the beach grades imperceptibly into broad sandflats and coppice dune fields. Padre Island beaches have developed across the mouth of washover channels; the beach is eroded repeatedly at these points by hurricane-tidal surge. Beaches become shelly southward along the coast. Little Shell Beach, which is about 10 miles in length, occurs immediately north of Yarborough Pass; Big Shell Beach extends south of the Pass into the Brownsville-Harlingen area. Little Shell Beach is characterized by *Donax*, a small clam; Big Shell Beach contains abundant large clams: *Eontia*, *Mercenaria*, and *Echinochama*. Watson (1971, 1972) has suggested that there may be a direct relationship between a high, well-developed fore-island dune ridge and abundant shell on adjacent beaches. According to Watson, shell is trapped on the beach, whereas sand is capable of being moved across the island by wind, thus concentrating the shells (lag deposit) on the beaches by a sorting process.

Padre Island beaches exhibit two distinct zones: *forebeach*, the seaward-sloping smooth part of the beach that is affected daily by swash, and *backbeach*, which is normally separated from the forebeach by a berm. The backbeach slopes very gently seaward or locally may slope away from the sea to produce a shallow backbeach trough or runnel. Beach cusps are common on the forebeach, especially north of the shelly beaches. Lamina composed of dark heavy minerals, principally magnetite, are common on the forebeach sands where swash has concentrated the high density particles.

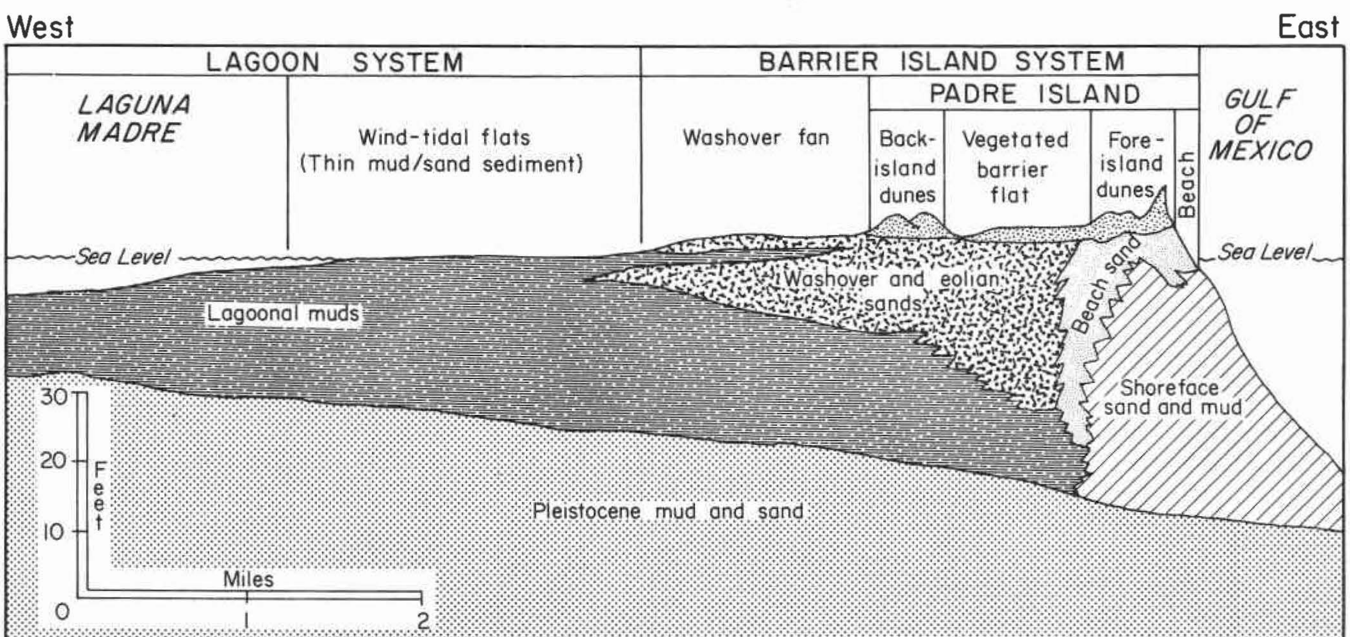
Beaches on Padre Island in the Kingsville map area exhibited long-term equilibrium or slight accretion during the past 120 years as evidenced by vintage navigation charts and, since 1930, by aerial photographs (Brown and others, 1974). Short-term erosion, however, is common along Big Shell Beach, where shoreline profiles have not yet reached equilibrium following the combined impact of Hurricanes *Carla* in 1961 and *Beulah* in 1967. Beach processes are locally still eroding high shelly berms; forebeaches are reaching a normal profile but backbeach areas are still the site of excess shell and sand. Abnormally high tides may still erode the berms, producing low escarpments between the forebeach swash zone and the backbeach. In the section describing the *Active Processes Map*, additional aspects of beach processes are considered.

Fore-island dune ridge.—The greatest relief on Padre Island occurs along the narrow ridges of moderately to poorly stabilized sand dunes, which parallel the beach along much of the northern half of Padre Island (figs. 15, 16). North of the Land-Cut Area, the dune ridge is relatively continuous; along the southern half of the island, the ridge breaks up into short, discontinuous segments. Approximately 3 square miles of fore-island dunes exist in the Kingsville area.

The fore-island dunes rise from an elevation of about 5 feet in the backbeach area to as much as 30 to 35 feet on the highest ridges. The dune ridge is the product of sands that are blown from the backbeach



MAP VIEW



GENERALIZED CROSS SECTION

Figure 15. Modern barrier island system, Padre Island, near Land-Cut Area, Kingsville area. Cross section after Fisk (1959). Eolian processes are important along this arid part of the Texas Coast.

and stabilized by a sparse to moderate cover of salt-tolerant grasses and vines. This important environment occurs principally on Mustang and northern Padre Islands and is best developed where there is a delicate balance between persistent onshore, dry winds to deflate backbeach sands and sufficient precipitation to stabilize and stack up the eolian deposits. North of Mustang Island, in the more humid part of the coast, fore-island dune ridges are low and poorly developed where dense vegetation and moist, onshore winds preclude significant vertical growth. South of central Padre Island, the very low rainfall and persistent, dry Gulf winds prevent stabilization of dune sands sufficient to produce the high ridges. In this southern area, sandflats and coppice dune fields occupy the fore-island area.

Internally, the dune ridge is composed of well-sorted sand arranged in steeply dipping eolian crossbeds displaying a complex history of deflation and deposition. High storm or hurricane tides may erode the dune ridge back many yards. Sands blown from the beach will slowly accrete the ridge gulfward; many years may be necessary to heal or return the ridge to its prestorm position. The fore-island sand ridge protects the barrier island from the full impact of the hurricane-tidal surge.

Because preservation of the fore-island dune ridge is so delicately balanced, long-term climatic cycles may modify significantly its height and rate of accretion or state of equilibrium. Any activity that reduces the vegetation cover may initiate a period of erosion. For example, 19th and early 20th century ranching on the island reduced the vegetation cover, and in turn, may have led to development of extensive fore-island blowouts and growth of the large back-island dune fields.

Fore-island blowout dunes.—These sand dunes develop at point sources by wind deflation of the fore-island dune ridge, either by natural or man-induced devegetation. Once the salt-tolerant grasses and vines have been destroyed, dry, onshore winds slowly move exposed sand into sheets and dunes that migrate slowly across the vegetated barrier flat (fig. 16). Various types of dunes may develop in the blowout field; small barchans are common but elongate dunes subparallel to southeasterly winds are prevalent in larger blowout fields. Where the blowout becomes partly stabilized along its margin, parabolic dunes may develop. Two or three square miles of blowout sands occur in the area.

Blowout dunes may become alternately active and inactive, depending upon climatic variations. They may become permanently fixed (stabilized blowout dunes) or eventually coalesce with the back-island dune field. Immediately south of Yarborough Pass, a large blowout complex occupies the entire island from beach to tidal flat. Near the gulfside of the barrier island, small shells may be mixed with well-sorted sand in the blowout dunes.

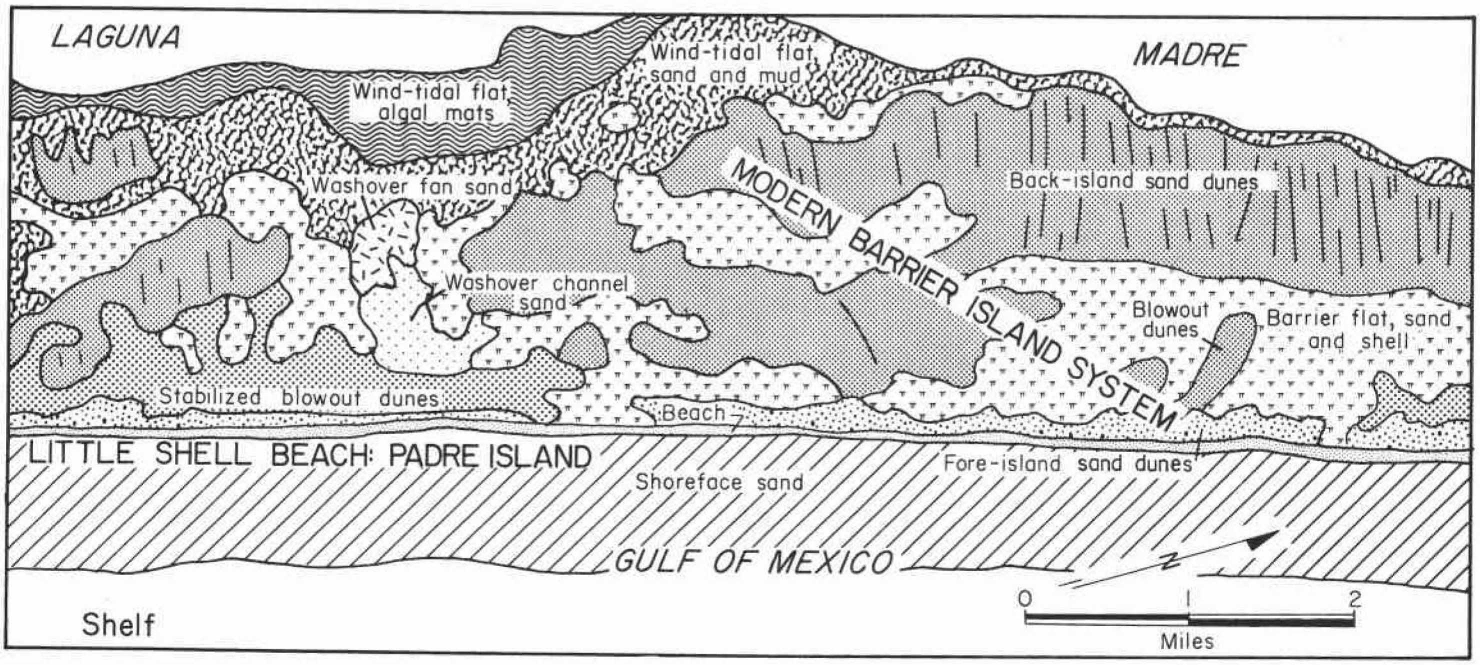


Figure 16. Barrier island facies along the northern part of Little Shell Beach, Padre Island, Kingsville area.

Blowout dunes are common along the northern part of Padre Island where the fore-island dune ridge is relatively continuous. South of latitude 27°00′ N, sand eroded from the discontinuous fore-island dunes is blown into vast sandflats and coppice dune fields where it remains until it is washed across the island through one of many washover channels. Extensive back-island dune fields on central and south Padre Island are supplied with sand by washover channels, rather than by the blowout dunes typical of northern Padre Island.

Stabilized blowout sand dunes.—Landward-sloping complexes of stabilized blowout dunes are common along Padre Island for almost 25 miles south of Baffin Bay (fig. 16). Six square miles of stabilized blowout dunes occur within the Kingsville map area.

These hummocky, ramplike sand dune fields were derived from the fore-island dune ridge but are now stabilized by grasses. The sandy ramp slopes lagoonward from an elevation of about 15 feet near the fore-island ridge to about 5 feet where it normally terminates at the barrier flat. Locally, the stabilized dunes terminate into large back-island dune fields. The stabilized blowout dunes exhibit very irregular topography resulting from a complex history of deflation and dune development. The original arcuate or parabolic dune shape (convex downwind) is preserved. Any natural factor or human activity that reduces the vegetation cover will undoubtedly lead to reactivation of the dunes.

Barrier flat.—This environment, which is composed of low, relatively flat, grass-covered sands, constitutes a principal environment on barrier islands (fig. 16). The barrier flats slope gently lagoonward from an elevation of about 5 feet near the fore-island dune ridge or stabilized blowout dunes to sea level on the landward side of the barrier.

Linear beach ridges, which are prominently associated with barrier flats north of central St. Joseph Island (see Corpus Christi map area) have been obscured by wind deflation on Mustang and Padre Islands. On central St. Joseph Island, blowout dunes cut across and destroy the beach ridge topography. The absence of the accretionary ridges on Mustang and Padre Islands is not, therefore, evidence that significant accretion has not occurred on Padre Island.

In the Kingsville area, approximately 17 square miles of Padre Island are occupied by barrier flats. Local depressions and shallow, elongate wind deflation troughs may be occupied by ephemeral fresh-water marsh. Salt-tolerant grasses hold the sand in place even during hurricane-tidal flooding. The flat is supplied with sand from the beach and fore-island dunes by blowouts and storm-washover channels. The barrier flat is breached by numerous washover channels along central and southern Padre Island (fig. 15).

Back-island dune fields.—Padre Island is characterized by large eolian dune fields concentrated principally on the landward side of the island. Dune axes in these back-island fields are generally aligned in an east-west direction. The areal extent and distribution of these large fields of bare, shifting sand dunes change continuously. Approximately 30 square miles were present in the Kingsville area when the aerial photographs used in this report were made (fig. 3). Back-island dune fields are supplied with sand by either hurricane-washover channels (fig. 15) or by fore-island blowout dunes (fig. 16).

Recent studies by Hunter and others (1972b) indicate that the back-island dune fields are composed of a variety of dune types. The principal and most permanent dune type is oriented approximately parallel to the predominant southeast wind regime (figs. 8, 9). These elongate dunes have been called "longitudinal dunes," although Hunter and others (1972a) call them "oblique dunes" because they are oriented almost east-west as a result of alternating southeasterly and northerly winds. Price (1958) reaches somewhat similar conclusions about dune origin. Smaller and shorter lived barchan dunes and transverse dunes develop quickly during the period of dry, persistent southeasterly winds. Internally, the back-island dunes exhibit a variety of large-scale eolian crossbeds that generally exhibit dip to the northwest quadrant.

Back-island dunes may migrate eventually into Laguna Madre (fig. 16) where lagoonal currents redistribute the sand into subaqueous bars along the lagoon margin. In other areas, the dunes migrate onto wind-tidal flats where they gradually break up into smaller dunes and sand sheets that are blown across the tidal flat (fig. 15). Hurricane-tidal surge passing through washover channels may erode and redeposit much of the eolian sand as sandy lamina intercalated with thin algal-bound clay lamina.

Washover channels and fans.—During hurricanes, storm-surge tides breach Padre Island in many places. Storm-generated currents erode channels through the barrier island and carry sand to the bayside of the barrier where it is deposited as a washover fan (fig. 15). At least 13 washover channels that occupy almost 3 square miles have been mapped on Padre Island within the Kingsville map area. Between storms, sand transported by longshore currents temporarily fills the washover channels along the gulfside of the barrier island.

The channel is floored by sand that moves through the breach during storms as subaqueous sand waves. The washover channel not only carries the storm-surge tide from the Gulf into the lagoon, but when the hurricane passes, water from the lagoon returns through the channel to the Gulf. This ebb flow, which is caused by the excessively high tides in the bays and lagoon, returns some sediment to the Gulf. When the channel is inactive, suspended clay may be deposited in the channel, but the finer sediment is eroded during subsequent storms.

A number of washover channels on Padre Island have been healed and are blocked from the Gulf by fore-island dunes. These relict channels have the potential to be reactivated during an unusually severe hurricane, especially if the fore-island dune ridge is weakened by devegetation and wind deflation. The large lobe of sediment in Laguna Madre that constitutes the Middle Ground area was probably deposited by a series of washover fans. Although only one washover channel is currently active in the area, the morphology of the barrier indicates that several relict channels may have supplied sediment to the Middle Ground area.

A washover fan is a low, unvegetated sandy lobe deposited at a point where the constricted hurricane channel opens onto the submerged wind-tidal flats. Between storms, wind processes erode and redistribute some of the sands of the washover fans, thus nourishing the back-island dune fields. Because of eolian modification, large, well-defined washover fans, common on barrier islands to the northeast, have not developed on Padre Island. Instead, the washover fans of Padre Island are thin, localized features (totaling 2 square miles). The fans have provided most of the sediment that has filled Laguna Madre and produced the extensive wind-tidal flats.

Wind-deflation troughs and storm runnels.—This environment is unique to Padre Island and it results from wind deflation and landward migration of the back-island dune field. As the dune field migrates, normally as a result of extended drought conditions, an irregular, elongate deflation trough is produced. The troughs are oriented parallel to subparallel with the shoreline (fig. 15). Called a "deflation flat" by Hunter (1972) and Hunter and others (1972a), the features occur on northern Padre Island; they are best developed on the central and southern part of the island where there is insufficient vegetation to heal and stabilize the deflation area. The environment, which covers 2.2 square miles, has been independently mapped in the southern part of the area where it is well defined. In the northern part of the map area where marsh and barrier flat vegetation tends to heal the deflation scar, the environment has been included with the barrier flat (fig. 16).

Along central and southern Padre Island, some of the storm-tidal surge is diverted from the washover channels (fig. 15) into the deflation troughs. Periodically, the troughs serve as storm channels or runnels. Following passage of the hurricane, elevated bay waters discharge gulfward through the washover channels and storm runnels. Receding floodwater may be ponded within the runnel channels.

Wind-deflation troughs and storm runnels are floored with interbedded sand and clay-algal mat lamina. Sands display small-scale ripple and trough-filled crossbeds that indicate flow along the trough axes. Following storm flooding, suspended clay is deposited within the troughs from ponded water, and algae flourish until the water evaporates. Locally, some patches of fresh-water marsh may thrive during wet climatic cycles.

Sandflats and coppice sand dune fields.—Southward along central and southern Padre Island, the fore-island dunes become progressively discontinuous and are replaced by 1.2 square miles of low coppice (wind-shadow) sand dunes and broad sandflats (fig. 15). Where some vegetation occurs, the wind builds the low coppice or wind-shadow dunes. If rainfall becomes sufficient, it is possible for coppice dunes to accrete eventually into fore-island dunes. In the absence of vegetation, the sand is blown into extensive sheets or flats. The environment contains well-sorted beach sand mixed with shell fragments.

Coinciding with the southward diminution of barrier island vegetation, which is required to stabilize fore-island dunes, is an increase in available beach sand due to longshore convergence (fig. 8). Storm surge and persistent southeasterly winds move the beach sand landward; the excess sand is temporarily stored in broad sandy flats, rather than in fore-island dunes. The ready availability of this unstabilized sand has played an important role in filling central Laguna Madre.

Sparsely vegetated barrier flat.—The barrier flat adjacent to the Middle Ground wind-tidal flats is sparsely vegetated. Stabilizing grasses have not fully developed, but the 1-square-mile tidal flat area appears to be slowly evolving into a barrier flat environment.

Back-island sandflats.—Several areas on the landward side of back-island dune fields and the barrier flat are occupied by small, shifting dunes and sandflats. The environment covered almost 5 square miles when aerial photographs used in this Atlas (fig. 3A) were taken, but the size and distribution of the dunes and sandflats change rapidly. The environment is transitional between back-island dunes and wind-tidal flats. As the larger dunes move onto the tidal flats, they gradually break up into smaller dunes and sand sheets.

Offshore System

The area gulfward of the present beach is included on the *Environmental Geology Map* as part of the offshore system. Environments include the shoreface of Padre Island and the innermost part of the continental shelf (fig. 4).

The inner part of the *continental shelf* extends seaward from just above the 30-foot or 5-fathom line. Offshore from Padre Island, limited deposition occurs, and the area is floored principally by relict Pleistocene and Holocene sand and mud. Modern sediments are thin and discontinuous where present. Biologic activity is the dominant process.

The *shoreface* is the gulfward extension of Padre Island that extends seaward from the break in slope of the beach to about the 5-fathom line or the boundary with the inner continental shelf (figs. 15, 16). Along Padre Island, the shoreface is slightly less than 1 mile wide and rests on Pleistocene deltaic sediments. The shoreface is a zone of high physical energy, especially in the upper part where waves break. 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 time that of water depth. Normal wind-driven waves are 2 to 4 feet in height and break on the upper part of the shoreface. Only during storms when wave heights are great do waves break on the lower part of the shoreface. The absence of breaking waves, except during storms, and the slow rate of sedimentation on the lower shoreface result in the accumulation of finer grained sediment in the lower shoreface zone; accordingly, biologic activity dominates, and the lower shoreface consists largely of extensively burrowed or mottled mud and muddy silts.

The middle portion of the shoreface (between water depths of 12 and 30 feet) is less muddy than the lower shoreface but is burrowed extensively. The middle shoreface is also little affected by currents generated by normal wind waves. The upper shoreface, extending from mean sea level to a depth of about 12 feet, is, by contrast, the zone where normal wind-driven waves feel bottom and break. Several lines of breakers or spilling waves may be observed on the upper shoreface. These result in the formation of breaker bars which form 3 or 4 zones of shifting en echelon bars that are elongate parallel to the shoreline.

Marsh System

Marshes and swamps, which are important and areally extensive environments in the central and northeastern part of the Coastal Zone, are of minor significance along the arid South Texas coast. Swamps are nonexistent and marshes are limited in variety, stability, and areal distribution.

Four general types of marsh occur in the Kingsville map area: (1) a narrow, discontinuous band of salt-water marsh fringing the land side of Laguna Madre and Baffin Bay; (2) locally distributed, very small patches of fresh- to brackish-water marsh seasonally occurring in narrow swales landward of bay- or lagoon-margin sand and shell berms and within isolated depressions associated with clay dunes on the landward margin of wind-tidal flats; (3) localized areas of seasonal fresh-water marsh within deflation swales on barrier islands and in the blowout areas within eolian sand sheet; and (4) areas of fresh-water marsh and other hydrophytes associated with shallow depressions occupying relict lake or lagoonal areas at the southern end of Laguna Larga and depressions within Pleistocene interdistributary floodbasin and bay deposits northwest of Alazan Bay (figs. 12, 13). Only the last category exhibits sufficient definition and scale to permit mapping. The diminution of significant fresh-water marsh environments in the region results principally from a gradual southward decrease in effective rainfall. Fresh-water marshes decline substantially in areal distribution southward across the Corpus Christi map area; the southernmost swamp environment exists within the valley of the Nueces River near Corpus Christi.

Salt-water and fresh- to brackish-water marshes are replaced south of Corpus Christi Bay by broad wind-tidal flats. Except for narrow salt marshes fringing relatively steep, erosional shorelines along the landward side of Laguna Madre and Baffin Bay, all broad, low-lying areas near sea level are occupied by wind-tidal flats. The alternately emergent-submergent wind-tidal flats preclude development of extensive salt-water marsh. Wind-tidal flats covered with algal mats occupy the environmental niche filled by salt marsh north of Padre Island.

Salt-water marshes, fresh- to brackish-water marshes, and local fresh-water marshes are too small, indistinct, or short lived to depict at the scale of the Environmental Geologic Atlas maps.

The *fresh-water marsh* mapped on the Kingsville sheet is seasonal in nature. Much of the 11 square miles of ephemeral marsh delineated is occupied during dry parts of climatic cycles by hydrophytes and other nonmarsh plants with high moisture requirements. Following excessively wet years, and especially after tropical storms and hurricanes, marshes thrive. They are, nevertheless, so delicately balanced in regard to moisture requirements that they can best be characterized as marginal wetlands.

As long as Laguna Larga is filled, the adjacent marshes (fig. 13) survive reasonably well; when the lake dries up, however, the marshes consequently diminish. The Laguna Larga marshes occupy broad, poorly drained depressions that were once occupied by a larger, ancestral lake or lagoon.

Similar ephemeral fresh-water marshes and hydrophytes occupy poorly drained depressions, such as near Madero Lake (fig. 12), where compaction of Pleistocene deltaic mud has formed low areas that pond water during wet seasons and following tropical storms. These depressions are generally interconnected by poorly developed drainage. Some marsh areas south of Cayo de Hinosa occupy depressions between large, partially stabilized clay-sand dunes. A number of mud-filled ponds and lakes that occur on the Pleistocene delta system near the northern map boundary were probably occupied by similar marshes before the depressions were filled (fig. 11).

Bay-Estuary-Lagoon System

An extensive network of shallow-water bays, lagoons, and estuaries characterizes the Texas Coastal Zone and comprises a major natural system in the Kingsville area (fig. 4). 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 Gulf is normally limited to natural and artificial tidal passes through the barrier islands. During storms, Gulf waters also enter the bay through washovers and breaches eroded across 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 was formed during the Holocene when rising sea level inundated and flooded river valleys. General morphology or outline of the bay margins locally reflects relict erosional topography. Arcuate shorelines, especially those along the west margin of Baffin Bay, may be relict incised meanders eroded during late Pleistocene and early Holocene.

In the Kingsville region, subaqueous depositional systems include Laguna Madre, a narrow, elongate lagoonal system landward of Padre Island, and Baffin Bay, a bay-estuary system that extends inland some 18 to 20 miles from its entrance to Laguna Madre. Excluding wind-tidal flats, Baffin Bay and Laguna Madre occupy 185 square miles of the Kingsville map area. *Laguna Madre* is 2 to 4 miles wide and is divided into northern and southern parts by the wind-tidal flats of the Land-Cut Area. South of a narrow restriction at Middle Ground is The Hole, a highly restricted portion of northern Laguna Madre. The northern and southern parts of Laguna Madre are now linked by the Intracoastal Waterway. The lagoon is generally less than 3 feet deep, although along its axis it deepens to 6 feet.

The Pleistocene valley eroded by the Olmos - Santa Gertrudis - San Fernando - Petronila drainage system is now occupied by *Baffin Bay*, an elongate estuary. The principal part of the bay system is 1.5 to 3.5 miles wide and extends inland for 20 miles; lesser arms of the bay include Alazan Bay, Cayo del Grullo, Laguna Salada, and Laguna de los Olmos. The elongate, east-west-trending central part of the bay ranges from 6 to 11 feet in depth; a narrow shelf less than 3 feet deep extends along the bay margin. The smaller arms of Baffin Bay are less than 6 feet deep.

Northern Laguna Madre communicates with the Gulf of Mexico via Corpus Christi Bay (Aransas Pass and Fish Pass) and southern Laguna Madre connects with the Gulf to the south through Mansfield Pass and Brazos Santiago Pass. Yarborough Pass connected with the Gulf for brief periods in the early 1940's and again in 1952. No tidal passes or channels between the lagoon and the Gulf are currently open within the Kingsville map area. Baffin Bay, which connects with Laguna Madre through a narrow entrance at Point Penascal, is even further restricted from the influence of the Gulf of Mexico. The salinity of Laguna Madre and Baffin Bay is variable, but generally the system is hypersaline; hypersalinity develops and is maintained by extensive evaporation of waters within the restricted bays and lagoon. Immediately following hurricane-aftermath rainfall, however, the system may become temporarily freshened.

Because of the hypersaline environments of Laguna Madre and Baffin Bay, the biologic assemblages and sediments are distinctive for the Texas Coastal Zone. Oyster reefs are currently absent, but serpulid reefs have thrived intermittently. High salinities, coupled with intense wave energy, have generated calcium carbonate deposition in shallow waters along the mainland shore of Laguna Madre and along much of the shoreline of Baffin Bay. The restricted center of Baffin Bay, on the other hand, is a low-energy, stagnant environment with very little biologic activity.

Breuer (1957), Behrens (1963, 1964, 1966), Dalrymple (1964), Scott and others (1964), and Alaniz and Goodwin (1974) have provided a variety of data and insight about the Baffin Bay system. Rusnak (1960), Simmons (1957), Parker (1959), Hedgpeth (1947), and Collier and Hedgpeth (1950) reported on various aspects of Laguna Madre, and to some extent, on Baffin Bay. Price (1933, 1958) and Fisk (1959) provided a basic understanding of the extensive wind-tidal flats associated with the central part of Laguna Madre. All of these studies have contributed significantly to the interpretation of bay-estuary-lagoon environments mapped in the Coastal Atlas program; the following description of the bay-estuary-lagoon system draws heavily from these and other sources of information.

Bay-Estuary-Lagoon Environments

The various environments composing the bay-estuary-lagoon system in the Kingsville area form two broad categories—bay-margin environments and bay-center environments. Environments of the central part of the bay-lagoon are exclusively subaqueous, though certain of the serpulid reefs may shoal and even break water. Bay-lagoon margin environments include both shallow subaqueous and subaerial environments developed as part of the shoreline complex. Waves and currents are critical factors controlling bay-lagoon margin environments (fig. 9). Various environments of the bay-estuary-lagoon system shown on the *Environmental Geology Map* are defined by dominant physical or biologic processes and composition and nature of the bay-lagoon substrate.

Subaerial bay-lagoon margin environments.—The principal subaerial bay-lagoon margin environments include local mainland beaches, relict berms and accretionary bay-lagoon margin deposits, occasionally flooded wind-tidal flats, and marginal eolian and transitional environments. *Mainland beaches* are poorly developed along the margin of Laguna Madre, Baffin Bay, and associated bays. Most of the mainland shoreline is bounded either by low erosional escarpments cut into Pleistocene sediments or by narrow and discontinuous shelly and rocky beaches resting on Pleistocene deposits. Wind-tidal flats are developed at the heads of bays and small cayos. Extensive wind-tidal flats that border the landward side of Padre Island and the Land-Cut Area do not exhibit beaches.

Thin, discontinuous, high-energy, rocky beaches occur along the shore of Baffin Bay for 4 to 6 miles west of Point Penascal and Point of Rocks, respectively, where the Pleistocene Ingleside barrier-strandplain sand is exposed. Other poorly developed beaches occur along the high-energy shoreline west of Black Bluff, near Kleberg Point, and near Riviera Beach; Pleistocene deltaic deposits are exposed in these areas of thin shelly and rocky beaches. Locally thin, poorly developed beaches also occur along the erosional mainland shore of both northern and southern Laguna Madre.

Mainland beaches are too small and discontinuous to map at the scale of the Environmental Geologic Atlas. Most of these beaches are erosional, and deposits are principally related to storm deposition of beach rock, shell debris, and some sand eroded from Pleistocene bluffs.

About 2 square miles along the margin of the Baffin Bay system and the mainland shore of Laguna Madre are occupied by *bay- or lagoon-margin sand and shell berms* (figs. 12, 13). These thin narrow berms may occur up to 2 or 3 feet above mean sea level; some are relict and most are actively accreted only during principal storms. Some evidence of depositional grain can be observed from aerial photographs. The berms developed along those segments of erosional shorelines are subjected to high-energy waves generated by the northern or southeastern wind regimes (fig. 9). Price and Kornicker (1961) have reached similar conclusions concerning the origin of shell berms in Laguna Madre. At several points southwest of Point of Rocks and along the southern shoreline of Baffin Bay, berms have built across the mouths of small bays occupied by wind-tidal flats. These berms accumulated during storms when abnormally high waves and currents carried sand, shell, and beach rock onshore from adjacent erosional areas. Successive building of storm berms gradually accreted or extended the shoreline in local areas. Small areas of salt- and fresh- to brackish-water marsh may occur behind and within swales between bay- and lagoon-margin berms.

A spitlike berm complex has accreted extensively at Starvation Point (fig. 17) and at Kleberg Point (fig. 12). An extensive berm composing Rincon de San Jose (fig. 18) built northward along the northwestern shoreline of southern Laguna Madre by combined subaqueous spit accretion and storm berm deposition. Near Rocky Slough west of Middle Ground, a similar berm has developed in northern Laguna Madre; this berm complex may have accreted upon relict beach ridges of the Pleistocene Ingleside barrier strandplain which underlies Penascal Rincon.

Dominantly subaerial *wind-tidal flats* occupy approximately 185 square miles of the Kingsville map area. These environments are characterized generally by flat, barren, relatively featureless terrane less than 3 feet above mean sea level. They principally occur on the surface of sediments transported into Laguna Madre from Padre Island by wind and storm-surge tides (fig. 15). Other tidal flats occur along the mainland margin where southeasterly winds have deflated older eolian deposits, as well as Pleistocene barrier-strandplain and deltaic deposits. The upper ends of various arms of Baffin Bay, including numerous small cayos along the bay margin, are occupied by wind-tidal flats. Ephemeral streams supply the sediment to upper bay areas on which the wind-tidal flats have developed. Studies by Price (1958) and Fisk (1959) have provided much insight into the nature of these environments.

Wind-tidal flats are flooded rapidly, generally by northers or the prevailing southeasterly wind regime (fig. 9). Prior to dredging of the Intracoastal Waterway in 1949, the flats in the Land-Cut Area, called "Saltillo flats" by Price (1933), were unbroken between Padre Island and the mainland, permitting free movement of tidal water and wind-transported sand and clay. The waterway has significantly blocked normal sediment transport in the region. The western flats that lie landward of the waterway are now experiencing a deficit of sediment supply which will ultimately lead to changes in the natural processes and character of the tidal flats.

A spectrum of wind-tidal environments that occur within the Kingsville area (fig. 18) ranges from the high, sandy flats to the low, depressed, muddy flats and includes: (1) rarely flooded, elevated loose sand; (2) occasionally submerged, firm sand and clay; (3) alternately emergent-submergent sand and thin clay lamina containing algal mats; (4) repeatedly submerged or ponded firm, gypsiferous, algal-bound clay and sand; and (5) perenially soft and wet, algal-bound clay and sand in depressed areas.

High, sandy, wind-tidal flats occur adjacent to Padre Island in the Land-Cut Area where storm-surge and wind-transported sand are introduced into the lagoonal system (fig. 15). These flats are rarely submerged and are composed of well-sorted sand beds with some thin clay lamina. More extensive, firm, wind-tidal flats fringe much of Laguna Madre and are composed of mixed sand, clay, and rare algal lamina; similar flats occur along the margin of Baffin Bay. These flats are only occasionally submerged.

Wind-tidal flats containing extensive algal mats occur principally to the west of the Intracoastal Waterway. Several exceptions include very low-lying to depressed areas east of the Intracoastal Waterway which are flooded repeatedly by Laguna Madre. These tidal flats (fig. 18) contain abundant clay lamina as well as sand; thicker and more numerous algal lamina are also common. West of the waterway, the flats are generally depressed and wind-tidal flow is more restricted, so that algal-bound, gypsiferous clay and sand comprise the tidal flat deposits. In locally depressed basins, the flats may remain wet and soft most of the time. Because the tidal water is ponded within these depressed areas of the flat, the abundant, relatively thick clay lamina are deposited from suspension. These clay lamina are interbedded with abundant algal mats. Hydrogen sulfide bubbles generated by decaying algae are commonly trapped below the impervious algal mats. Evaporite minerals (gypsum, halite, dolomite) are precipitated from brines that saturate the sediment beneath the tidal flat depressions. Desiccation of clay lamina produces clay chips that are abraded and transported landward by dry, southeastern winds. The clay pellets provide the

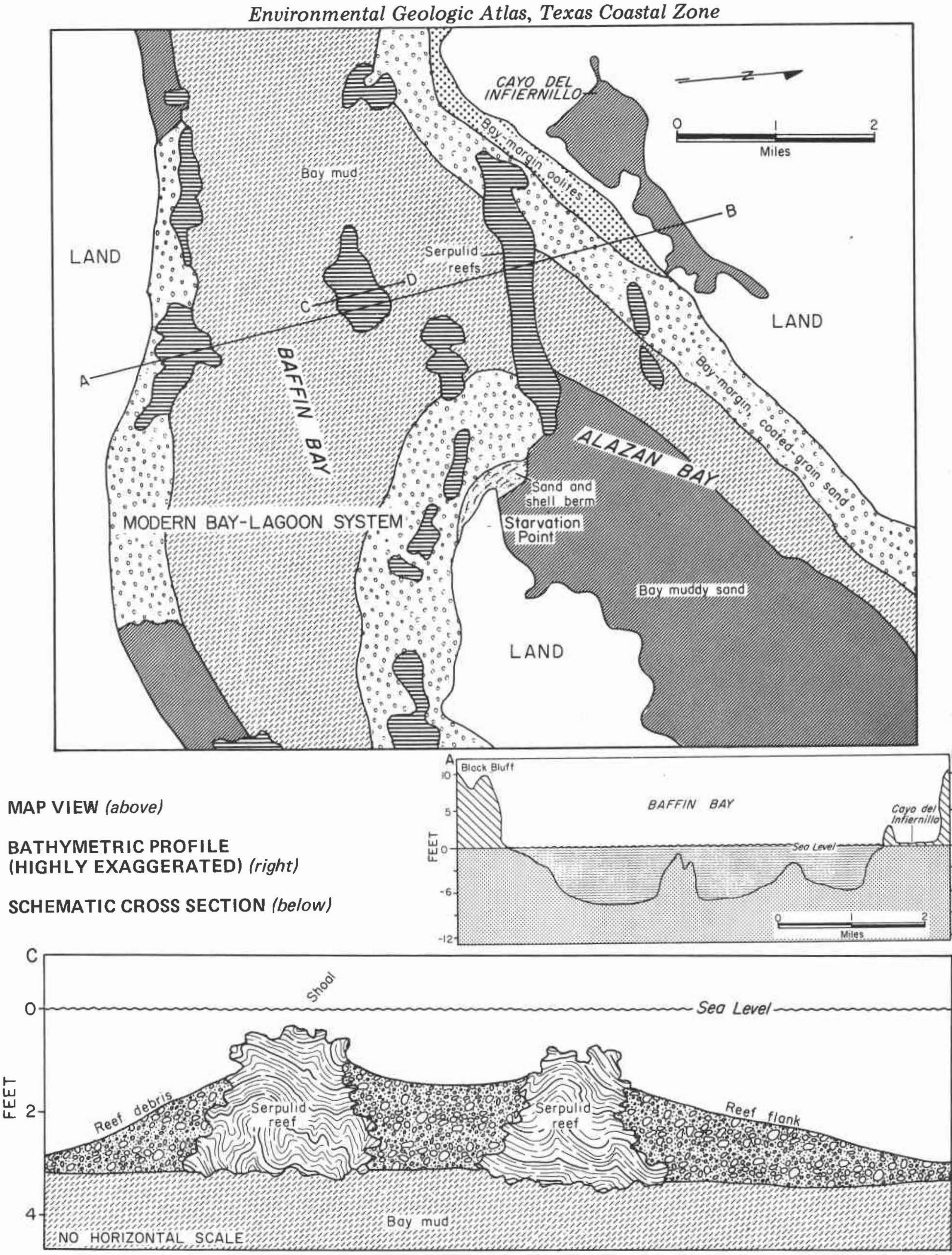


Figure 17. Modern bay-estuary facies within Baffin Bay. Bathymetric profile illustrates the effect of serpulid reefs on bay-bottom configuration; nature of the reefs and flanking reef debris is shown in the schematic cross section.

principal source of sediment for wind-accretion deposits such as rincons, potreros, and the abundant small clay dunes that fringe the landward edge of the wind-tidal flats.

Unique to the Kingsville and Brownsville-Harlingen map areas, *marginal eolian and transitional environments* are closely associated with and genetically related to the extensive wind-tidal flats of the South Texas coastal region. They are considered part of the bay-estuary-lagoon system because their origin is closely tied to wind-tidal processes. These units (figs. 19, 20) include eolian accretionary bars and ridges (rincons and potreros), marginal residual sand aprons on the windward side of eolian accretionary elements, and a transitional zone between wind-tidal flats and the South Texas eolian system. The areal extent of these environments totals about 70 square miles, principally along the western side of the Land-Cut Area.

With the exception of the Intracoastal Waterway and its associated dredge-spoil mounds, the *eolian accretionary bars and ridges* (potreros and rincons) are the most prominent features on the broad wind-tidal flats (figs. 19, 20). The *potreros* are unique, elongate, islandlike depositional features occupying about 7 square miles on the wind-tidal flats near the margin of the eolian system immediately west of The Hole. The origin of potreros (meaning "pasture or corral") was first suggested by Price (1958). Sand-sized pellets of salty clay produced by the desiccation and disintegration of tidal-flat clays are blown across the flats, where

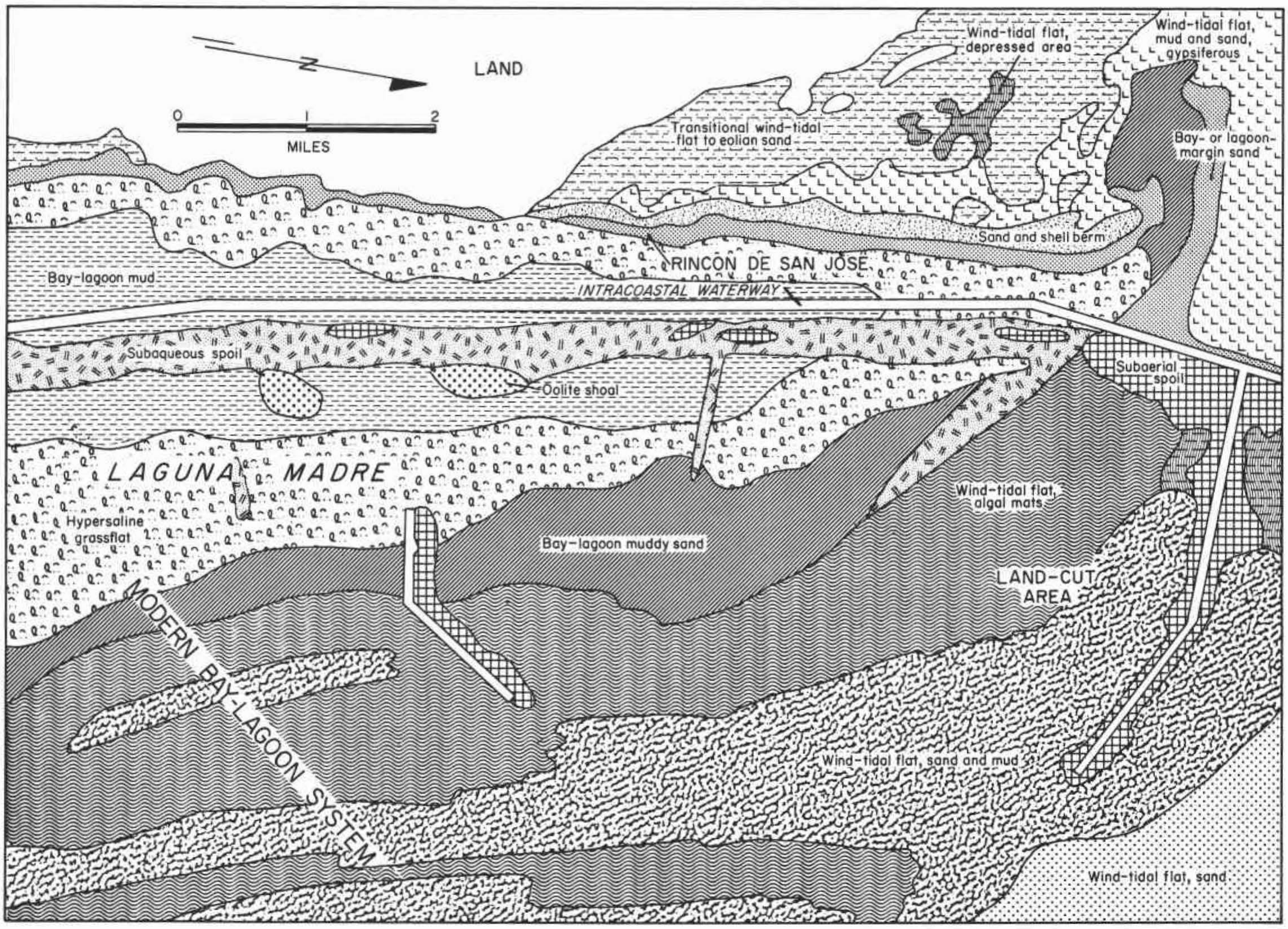


Figure 18. Wind-tidal flats and adjacent subtidal lagoonal facies, Laguna Madre, Kingsville area. Broad wind-tidal flats are flooded during extended periods of southeast winds and during hurricanes.

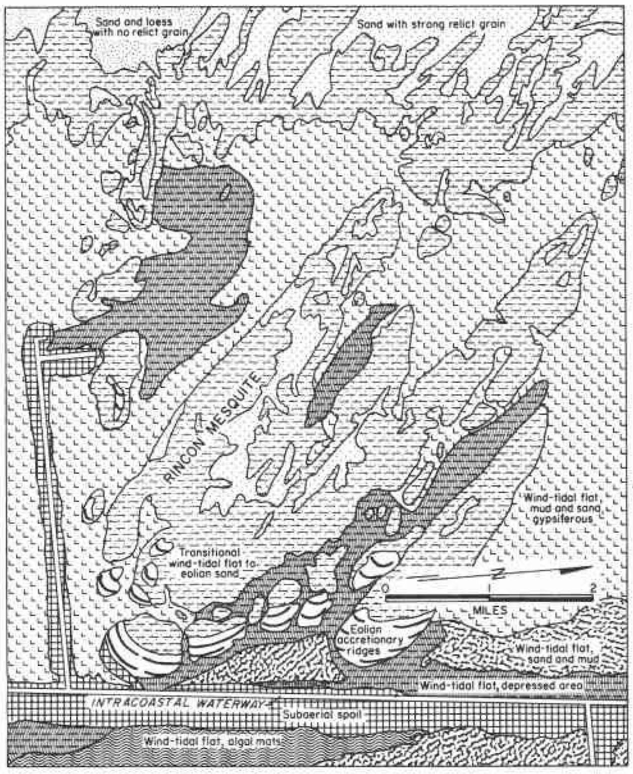


Figure 19. Relict eolian blowouts (rincons) preserved on broad wind-tidal flats, Kingsville area. Rincons in the Land-Cut Area of Laguna Madre are protected from continued excessive deflation by windward-accreting eolian ridges.

they accumulate on the windward side of a berm, spit, levee, or other obstruction. The clay pellets are swept upward and deposited against the obstruction, resulting in a gradual windward accretion of clay and fine sand ridges. Fine particles of halite, associated with the clay deposit, absorb moisture from the atmosphere, which stabilizes the clay pellets. The potreros are characterized by strong accretionary grain, prominently shown on topographic maps and aerial photographs (fig. 20); Price (1958) called these kinds of eolian features "stepped-back eolian ridges."

Fisk (1959) suggested that the nuclei of the potreros (Potrero Cortado, Potrero Grande, Potrero de los Caballos, Potrero de las Canelas, Potrero Farias, and Potrero Lopeno) may be berms and spits similar to Rincon de San Jose that fringed an earlier shoreline of Laguna Madre. As Laguna Madre was filled, the relict potreros became isolated from the lagoon by wind-tidal flats and served as obstructions against which eolian clay ridges were accreted. The nuclei of at least some of the potreros may also be remnants of Ingleside (Pleistocene) beach ridges because exhumed Pleistocene barrier-strandplain beach ridges do extend southward from Point Penascal toward Rocky Slough and the potreros.

In the Kingsville map area, other unique eolian clay-dune ridges called *rincons* (meaning "hidden corner" or "isolated area") have developed by accretion of clay pellets onto the windward margins of "islands" composed of relict sand sheet deposits. Isolated on the wind-tidal flats, these remnants of the sand sheet represent interblowout areas remaining after extensive wind deflation (fig. 19). Rincon Mesquite, El Toro Island, Tres Marias Islands, and the Calabasas Islands all exhibit distinctive eolian accretionary ridges that are convex in an upwind direction. The wind deflation or blowout origin of these features can best be shown by comparing the shape of Rincon Mesquite to the large banner dune blowout areas on the adjacent eolian sand sheet. For example, there is a strong similarity between Rincon Mesquite and the eolian blowout area 1 to 3 miles north of Calabasas Islands; many other areas composed of interblowout remnants occur throughout the transitional zone between wind-tidal flats and the South Texas eolian system (fig. 20).

Less than 1 square mile of *marginal residual sand aprons* lies on the upwind or lagoonal side of eolian accretionary bars or ridges. These wind-deflation lag deposits develop at the toe of clay accretion deposits and are composed of particles too large to be transported up the inclined or windward flank of the potrero or rincon (figs. 19, 20).

A *transitional zone* that separates the wind-tidal flats from the South Texas sand sheet covers 65 square miles of the landward margin of extensive wind-tidal flats of the Land-Cut Area (figs. 4, 20). This zone is composed of wind-tidal flats containing many small remnants of the deflated margin of the sand sheet, numerous clay dunes accreted windward of these relict erosional features, and large landward-trending blowout depressions intermittently flooded by wind tides. These mixed wind-tidal and eolian elements were mapped together because the individual elements are generally too small to be mapped as separate units. Southward in the Brownsville-Harlingen map area, the individual elements in the transitional zone are larger and have been mapped as independent elements.

The transitional zone is periodically flooded by wind-driven tides, but during much of the year the zone is the site of wind deflation, winnowing of airborne sediment, and windward accretion of small eolian clay dunes. The highly serrate landward margin of the zone is

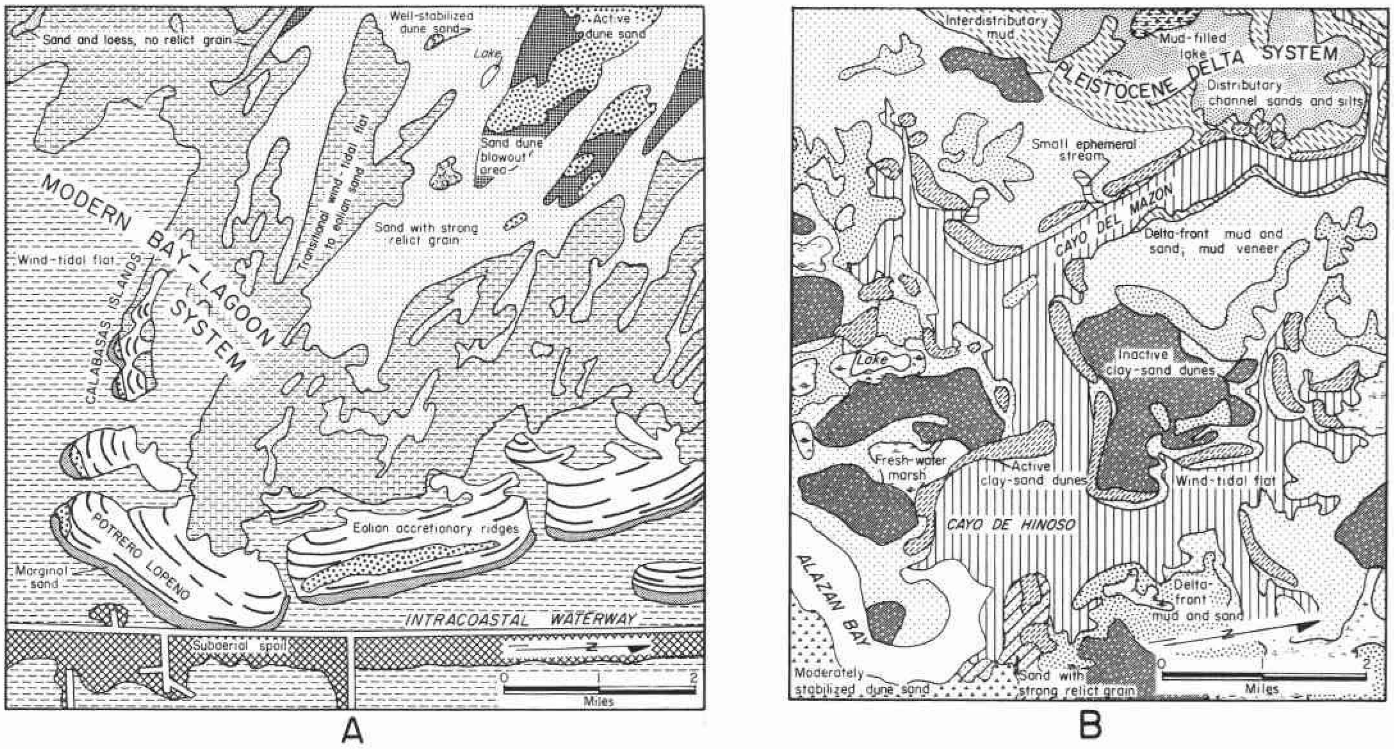


Figure 20. Eolian accretionary deposits associated with wind-tidal flats, Kingsville area. (A) Potreros in the Land-Cut Area of Laguna Madre accrete windward from earlier shoreline composed of Pleistocene (Ingleside) beach ridges. (B) Active and inactive clay dunes along margin of wind-tidal flats, Cayo del Mazon and Cayo de Hinoso, Baffin Bay.

the result of wind-tidal flooding and wind deflation of banner dune complexes.

Subaqueous bay- or lagoon-margin environments.— The submerged margin of Baffin Bay and Laguna Madre is characterized by about 120 square miles of various marginal shoal-water environments and broad areas of low-energy, shallow grassflats and flats of muddy sand. Narrow, marginal shoal water and shallow submerged areas include: bay- or lagoon-margin sand and shell; bay-margin oolites and quartz sand; bay-margin quartz sand and aragonite-coated sand; and serpulid reefs and related interreef areas. Broad, lower energy areas include bay and lagoon muddy sand with sparse to absent grass and marine grassflats. All of these submerged bay and lagoon environments occur in less than 3 feet of water; some serpulid reefs occur on isolated bathymetric highs surrounded by the deeper bay-lagoon center environments.

The *bay- or lagoon-margin sands* occupy a narrow fringe along the landward side of Laguna Madre and near the entrance to Baffin Bay at Point Penascal and Point of Rocks. This shallow (1 to 3 feet) environment occupies almost 3 square miles of the map area and is composed of moderately sorted quartz sand, shell fragments, and locally some oolites or aragonite-coated grains. Near the mouth of Baffin Bay, calcite-cemented beach rock, eroded from the Pleistocene Ingleside barrier bar, is concentrated within the high-energy environment. Bay- and lagoon-margin sands are derived principally from eroded Pleistocene deposits along the mainland shore. Longshore transport along the lagoon shoreline (fig. 9) continually redistributes the winnowed sediment. Onshore waves generated by southeasterly winds move the sand landward into shallow subaqueous bars and berms. Shoaling of these bars locally generates calcium carbonate deposition in the form of oolites and aragonite-coated sand grains. Toward the lagoon, the sandy, high-energy environment grades into the broad, shallow, low-energy grassflats underlain by sand, muddy sand, and shell.

Because of radically fluctuating wind tides in the northern end of southern Laguna Madre near Rincon de San Jose, the lagoon-margin sand is periodically emergent (fig. 18). Submerged berms and bars can be observed on large-scale aerial photographs. Migrating subaqueous bars are concentrated north of Point of Rocks and south of Rincon de San Jose. The environment near Point of Rocks and between Point Penascal (meaning "rocky place") and Rocky Slough is characterized by beach rock, shell, and fragments of relict serpulid reefs.

Clams, such as *Anomalocardia*, *Tellina*, and *Mulinia*, and snails, such as *Cerithium*, flourish within local patches of shoalgrass (*Diplanthera*), widgeongrass (*Ruppia*), and turtlegrass (*Thalassia*); the blue-green alga (*Acetabularium*) is also common.

About 1 square mile of the high-energy shoreline along Baffin Bay is occupied by *bay-margin oolites and quartz sand* (fig. 17). The environment is restricted to water depths of less than 3 feet where breaking waves continually agitate the bay bottom before striking the erosional shoreline. Flanking Kleberg Point near the mouth of Alazan Bay, this environment is subjected to the highest wave energy in Baffin Bay (fig. 9). Southeasterly winds gain maximum fetch across 5 miles of open bay and strike the bay shoreline near Kleberg Point and Cayo del Infiernillo (fig. 17). The high wave energy, combined with hypersalinity (about 70°/₀₀) that persists within this part of the bay system, leads to development of oolites and calcium carbonate-coated quartz grains. Oolites are spherical to subspherical grains of aragonite (calcium carbonate) that were deposited in thin concentric layers; coated grains are quartz particles encased by layers of aragonite. Most oolites developed by repeated precipitation of the aragonite around a nucleus of quartz or shell. Aspects of the petrography and geochemistry of the oolites are described by Freeman (1962), Behrens (1964), and Frishman (1969).

Abundant shell fragments are composed principally of the pelecypod (clam) genera *Mulinia* and *Anomalocardia*; some foraminifer tests also occur within the environment. Marine grass is absent, although floating grasses derived from Laguna Madre are washed ashore and concentrated along the bay margin. The oolitic sediment is a thin veneer overlying eroded Pleistocene sediments. Pleistocene deltaic sandy mud deposits are exposed locally within the high-energy environment.

Along the margins of Baffin Bay, *bay-margin quartz sand and aragonite-coated sand* deposits occupy 12 square miles of high-energy environments. The environment is principally restricted to the narrow, shallow shelf that surrounds the deeper bay center; water depths are generally less than 4 feet. This environment is transitional with and lies bayward of the oolitic facies near Kleberg Point and the northwestern shore of Alazan Bay (fig. 17). In the legend of the *Environmental Geology Map*, the composition of the coated grains that characterize the environment is incorrectly described. The mineral composition of calcium carbonate coatings is aragonite and not calcite.

The environment is well developed along the high-energy shoreline between Point of Rocks and Starvation Point, opposite Kleberg Point at the mouth of Alazan Bay, and along the southern shoreline of the bay west of Black Bluff. Extensive development of the environment on the north and northwest shorelines of Baffin Bay is caused by the persistent southeasterly winds that generate waves across 3 miles of open bay. On the south side of the bay, high wave energy is generated periodically by north winds. The environment grades laterally along the bay shoreline into lower energy environments characterized by muddy sand. Bayward, the environment grades abruptly into the bay-center facies composed of laminated mud facies. This gradation occurs in about 3 feet of water, except along the northern shoreline between Point of Rocks and Starvation Point where strong currents transport sand and coated grains bayward into water depths of 6 to 8 feet. Locally, small areas of Pleistocene deposits are exposed on the bay bottom. Wave energy is periodically high, but the persistence and intensity of wave action on the bay bottom in this environment is less than within the area of extensive oolite precipitation. Most precipitation of aragonite is in concentric layers around quartz sand grains, hence the term "coated grains." Shell fragments of the clams *Mulinia* and *Anomalocardia* are common; a few living species have been reported by investigators.

Numerous *serpulid reefs and related interreef areas* comprise over 10 square miles of Baffin Bay and northern Laguna Madre near the mouth of the bay (fig. 17). This shoal-water environment occurs along the shallow margin of the bay and lagoon, as well as on prominent bathymetric highs within the bay and across bay mouths. The location of individual reefs and interreef areas shown on the *Environmental Geology Map* was compiled from Andrews (1964), Breuer (1957), and Rusnak (1960) and interpreted from latest navigational charts (fig. 3). The accuracy and completeness of these data are limited by the quality and scale of source maps and navigational charts. High-turbidity waters in the area prevent mapping of individual reefs with conventional aerial photographs. Andrews (1964) provided the most comprehensive picture of serpulid reefs, especially their geometry and internal structure.

Serpulid (or annelid worm) reefs in Baffin Bay and Laguna Madre are currently dormant structures; no living annelids have been observed on or within the reefs. Annelids are sessile, marine worms that secrete calcium carbonate tubes to produce rigid, wave-resistant reef rocks. Along the Texas coast, annelid reefs are restricted to the Baffin Bay-Laguna Madre hypersaline bay-lagoon system.

Andrews (1964) recognized two distinctive occurrences of annelid reefs in the bay-lagoon system: patch reefs and reef fields. *Patch reefs* are small, isolated reefs that are common along the western margin of northern Laguna Madre near the mouth of Baffin Bay (see *Environmental Geology Map*). Patch reefs vary from small circular structures 25 feet in diameter to atoll-like and ellipsoidal forms 130 feet long. There is some evidence that these reefs are oriented generally normal to persistent currents that supplied nutrients to the filter-feeding worms. Some reefs appear to have built southeastward into the prevailing wind which generated currents that nourished the reefs. Water depths around patch reefs are generally 2 to 3 feet; the reefs commonly shoal and may be exposed during low tides. Reefs apparently developed on sandy or shelly bathymetric prominences.

More common within Baffin Bay are *reef fields*. Andrews (1964) reported broad areas composed of scattered reef rock protruding 1 or 2 feet from the bottom. The water depths over the scattered reefs and reef rock debris are generally about 2 feet. Reef fields occur southwest of Starvation Point and in Laguna de los Olmos; bathymetric maps of Baffin Bay (fig. 3) indicate that many of the occurrences within the bay are of this variety or are composed of patch reefs within extensive reef (or interreef) fields. Individual reefs within the reef fields exhibit randomly oriented annelid tubes, as well as a relatively abundant fauna and flora: the alga *Acetabularia*, the clam *Brachiodontes*, and the stone crab *Menippes*. Andrews (1964) observed a few oysters (*Crassostrea*) attached to a reef; this is the only reported occurrence of oysters in the bay-lagoon system of the Kingsville map area. W. Armstrong Price (*in* Breuer, 1957) reported the presence of large mounds of oyster shells at Indian campsites along the bay margin suggesting normal marine salinities during prehistoric times.

Serpulid reefs contribute a significant amount of reef rock debris to the flanking and interreef areas as a result of wave erosion. In addition, the windward side of reef structures baffles wave energy and permits lower energy mud sedimentation to occur in leeward areas. Andrews (1964) has suggested that the serpulid organisms thrived under normal salinities and that hypersalinity conditions eliminated the marine worms. Likewise, he suggests that the changeable, more adverse environments in the upper part of Baffin Bay control the development of reef fields rather than patch reefs.

In addition to marginal high-energy environments, two associated environments are typified by lower wave and current energy. Environments underlain by bay and lagoon muddy sand and marine grassflats occupy narrow belts exposed to moderate wave energy along the margin of Baffin Bay and Laguna Madre, respectively. These environments also occupy broad, shallow subaqueous flats that are subject to very low wave energy; however, grassflats do not occur within Baffin Bay.

The *bay and lagoon muddy sand substrates* underlie extensive areas (64 square miles) in Baffin Bay and Laguna Madre. Although this is locally a bay-margin environment in Baffin Bay, it is restricted to areas of lower wave and current energy. For example, it occurs along the main bay shoreline between Point Penascal and Black Bluff and south (across the bay) of Kleberg Point; both lower wave energy areas are not subject to southeasterly winds and are partly shielded from north winds. This environment occurs also in Alazan Bay on the northwest side of the peninsula separating Baffin Bay and Alazan Bay (fig. 17), where the bay is protected from southeasterly winds, and in the upper reaches of Alazan Bay, Laguna Salada, and Cayo del Grullo.

The environment grades bayward into the bay-center environment; water depths are generally less than 4 feet. Small areas of Pleistocene deposits are exposed locally where wave erosion is intense. Marine grass has not been reported within the environment in Baffin Bay.

Within northern Laguna Madre, a highly restricted, shallow inlet called The Hole is underlain by muddy sand substrate with sparse marine grasses reported in some areas. The salinity and temperature of the shallow waters of The Hole increase significantly during summer months. When combined with depleted dissolved oxygen content, the severe salinity and temperature may lead to occasional fish "kills" in which large numbers of fish suddenly die. North of The Hole and south of the mouth of Baffin Bay, the environment is generally restricted to less than 3 feet of water. Near the mouth of Baffin Bay, the shallow-water environment grades transitionally northward into broad marine grassflats that occupy the sandy, shallow-water substrates in most of northern Laguna Madre.

In southern Laguna Madre, bay and lagoon muddy sand occurs in shallow, marginal areas. This environment grades into wind-tidal flats along the lagoonward side of Padre Island and into hypersaline grassflats within the lagoon.

The sedimentary substrate within this environment is variable, but it is composed principally of muddy sand deposits with clam shell fragments. In Baffin Bay, some living *Anomalocardia* and *Mulinia* have been reported (Parker, 1959). In Laguna Madre, these living clams are also associated with the clam *Tellina* and the snail *Cerithium*, along with other less common molluscs. Although marine grass has not been reported within this environment in the Baffin Bay system, some sparse to locally dense grass occurs within the environment in Laguna Madre, where it is transitional with grassflats.

The *grassflats* are composed of dense, subaqueous marine plant life and underlie 28 square miles of northern and southern Laguna Madre (fig. 18). These shallow (less than 3 feet deep) environments occupy broad subaqueous flats within Laguna Madre north of the mouth of Baffin Bay and south of the Land-Cut Area and exhibit generally low levels of wave and current energy (fig. 18). Substrates to which the grasses are attached vary from sand to muddy sand. The density of the marine grasses (spermatophytes) in northern Laguna Madre diminishes south of the mouth of Baffin Bay. Near Middle Ground and within The Hole, marine grasses occur locally, but the subaqueous meadows are poorly developed. The total absence of living marine grasses within Baffin Bay has been reported by various workers (for example, Breuer, 1957), but shoalgrass is washed ashore within the bay, probably from sources in Laguna Madre.

The principal grass within the environment is *Diplanthera (Halodule) wrightii* (shoalgrass) which can tolerate salinities between 3 and 70°/₀₀ with optimum salinity at 44°/₀₀. Small areas of *Ruppia maritima* (widgeongrass) that can successfully tolerate salinities as high as 40°/₀₀ occur mixed with *Diplanthera* communities. *Thalassia testudinum* (turtlegrass) may occur sparsely in deeper water (more than 3 feet) where salinity is not excessive. Some *Cymodocea manatorium* (manateegrass) may occur in the Kingsville map area, especially in southern Laguna Madre where salinity does not range as high as north of the Land-Cut Area. In northern Laguna Madre, *Diplanthera* thrives in the shallowest flats; the species is generally absent below a depth of 3 feet. Sufficient light for photosynthesis is the critical factor controlling the distribution of spermatophytes in the bay-lagoon system because salinities have not been sufficiently high to eliminate *Diplanthera* since construction of the Intracoastal Waterway. Turbidity in Baffin Bay, as well as in parts of Laguna Madre, limits light penetration and, therefore, limits the growth of these marine plants. *Ruppia* is generally restricted to slightly deeper water with firmer substrates such as those that exist along the high-energy mainland shore of Laguna Madre from 2 to 5 miles north of Point of Rocks. *Diplanthera (Halodule) wrightii* communities also compose the attached grassflat flora in southern Laguna Madre, although substrates are commonly finer grained silty muds.

The grassflat environment is the habitat of a large number of molluscs, such as small gastropods (snails) and burrowing pelecypods (clams). Leafy, calcareous algae (*Acetabularia*) thrive within some of the grassflats. A variety of fish and invertebrates, especially arthropods, spawn within the grassflat environment where there is food and protection for larvae and fingerlings.

McMahan and others (1965-67) have indicated general salinity limits for various marine grass species. Sample transects across Laguna Madre indicate the occurrence of locally dense communities within widespread areas inhabited by less dense vegetation. Variations in the density of marine grass communities occur seasonally; maximum growth occurs during spring and summer months, while growth is essentially static during fall and winter. The extreme dominance of the shoalgrass (*Diplanthera (Halodule) wrightii*) in this part of Laguna Madre is unique along the Texas coast. Hypersalinity combined with high water turbidity within the lagoon exerts a control upon the grass communities by restricting the distribution of widgeongrass (*Ruppia maritima*) and turtlegrass (*Thalassia testudinum*). Even *Diplanthera* is absent in Baffin Bay where intense shoreline erosion and wave action develop excessively turbid conditions.

The grassflat environment exhibits very high biologic productivity. It is also an environment that is tenuously balanced by factors such as salinity, turbidity, and water depth. The dynamic nature of this highly productive environment along with its sensitivity to several environmental factors make it a critical area in the Kingsville region. An increase in turbidity resulting from spoil disposal or other man-induced development may be sufficient to destroy or severely restrict the grassflat environment.

Bay-lagoon-center environments.—Three environments occupy the center of Baffin Bay and Laguna

Madre, covering an area of more than 50 square miles (figs. 17, 18). These environments are characterized by distinctive substrate properties: laminated bay mud, mottled bay and lagoon mud, and sand shoal with some oolites.

The *laminated bay mud* environment underlies 37 square miles of the bay-center environment within the Baffin Bay system (fig. 17). The environment occupies deeper parts (4 to 9 feet) of the restricted, normally hypersaline bay. The substrate is composed of dark gray, soft, laminated mud with some thin, white, fine-grained calcium carbonate lamina. Except along the margin of the area where it grades abruptly into marginal environments, the bay center is the site of suspension sedimentation from the turbid bay waters. Suspended organic matter brought to the bay by streams during floods and from Laguna Madre by southeasterly winds slowly settles to the bay bottom. Burrowing has not been observed in this environment and living or relict organisms are very rare.

This bay-center environment is restricted to Baffin Bay. A sill composed of serpulid reefs resting on sandy shoals and beach rock fragments is situated across the mouth of the bay. The sill has effectively sealed the deeper part of the bay-center environment from Laguna Madre. For this reason, deeper parts of the highly restricted bay center are the sites of reducing (euxinic or oxygen-deficient) conditions that preclude the survival of a fauna. Fish inhabit the upper, oxygenated part of the bay-center area.

Deposits of *mottled bay and lagoon mud* underlie about 15 square miles of the deeper parts of northern and southern Laguna Madre (fig. 18). Within the Kingsville map area and principally within northern Laguna Madre, almost 15 square miles of the lagoon lies at depths below 3 or 4 feet and a significant part of this area lies between 6 and 9 feet. Small areas in southern Laguna Madre (adjacent to the southern map boundary) lie below a depth of 6 feet; the 6-foot contour is shown on the *Topography and Bathymetry Map*, but it is missing from the *Environmental Geology Map*. This environment is the site of mixed mud and sand deposition. The turbidity of the lagoon waters limits the growth of marine grass below 3 feet, but a relatively abundant fauna inhabits the muddy sand bottom.

Sparse widgeongrass (*Ruppia maritima*) and rare turtlegrass (*Thalassia testudinum*) may occur locally above 4 feet. Relatively abundant burrowing clams (*Anomalocardia*, *Tellina*, and *Mulinia*) and the snail *Cerithium* inhabit the bottom of this enclosed, normally hypersaline environment. The mottled nature of the muddy sand substrate results from burrowing of the sediment by the molluscan fauna. These organisms destroy sedimentary lamina as they move slowly through the substrate in search of food and protection.

Sedimentation within the environment is principally from suspension, although waves locally rework subaqueous and subaerial spoil and redeposit both sand and mud within the environment (fig. 18).

Below a depth of about 3 feet, circulation is partially inhibited within the disconnected, closed bathymetric depressions that underlie the center of the lagoon. Although not as restricted as the bay-center environment of the Baffin Bay system, the substrates beneath this deeper water environment are not subjected to significant wave and current energy except perhaps during hurricanes and severe tropical storms.

Areas of *sand shoals with some oolites* occur locally within southern Laguna Madre between the Land-Cut Area and Port Mansfield (Brownsville-Harlingen map area). Although these shoals occupy only 0.5 square mile, they are prominent features isolated within the central part of the lagoon (fig. 18). The shoals are located in water depths of about 5 to 8 feet. They display local relief of 2 to 4 feet and, therefore, the tops of the shoals are generally at a depth of 3 to 6 feet.

Considerable wave motion is generated along the axis of southern Laguna Madre by southeasterly winds. The superelevation of lagoon water against the Land-Cut Area apparently generates a deep return tidal flow that moves southward along the bottom of the lagoon toward the Port Mansfield Channel. Most of this deep return tidal flow probably moves through the Intracoastal Waterway, but the channel may be unable to carry the total ebb (wind) tidal flow. Consequently, some tidal currents probably move southward along the bottom of the deeper center of Laguna Madre. Sufficient wave and/or tidal current energy is expended in the lagoon to produce winnowed sands and some oolites on the bathymetric highs.

Although the salinity of this part of southern Laguna Madre does not reach the concentration recorded in Baffin Bay, there is sufficient hypersalinity for the precipitation of the calcium carbonate (aragonite) that composes the oolites. Oscillation ripples occur across the top of the shoals. The high-energy environment with shifting sand and oolites is not especially hospitable to benthonic organisms, but some pelecypods do inhabit the shoals. Marine grasses are sparse to absent because of the shifting substrates and turbulent water.

The origin of the shoals is uncertain but the orientation of the subaqueous mounds (Brownsville-Harlingen map area) indicates a possible relationship with Pleistocene fluvial systems which extend beneath the area. The shoals may have formed on remnants of levees associated with this relict river system.

Eolian System

Most of the land surface within the Kingsville map area is occupied by environments which have been dominated or affected to some degree by various eolian (wind-related) processes. These environments are underlain by a variety of sand and some clay deposits (fig. 4). Called the South Texas eolian system (or sand sheet), this complex of wind deposits and associated active processes covers slightly more than 1,500 square miles or two-thirds of the Kingsville map area. The eolian system, which extends southward for about 12 miles into the Brownsville-Harlingen map area, has been mapped for more than 60 miles west (inland) of the Kingsville map area (Brewton, in preparation). Much of the research and many of the fundamental ideas about the eolian system are based on the work of W. Armstrong Price, who summarized his concepts in a 1958 report. Hayes (1967) and Fisk (1959) also contributed to a better understanding of eolian processes in the region.

A dozen eolian environments compose the South Texas eolian system (table 4); two of these environments are also associated with the Modern bay-estuary-lagoon system and the Pleistocene delta system. Other eolian environments are closely associated with and are component parts of the Modern barrier island system (6 units) and the wind-tidal flats of the Modern bay-estuary-lagoon system (3 units). These nine eolian environments have been classified and described as components of the other natural systems with which they are more closely associated.

Extensive areas of the South Texas system are occupied by active sand dunes that move slowly inland (northwestward) during dry summer months under the influence of the predominant southeasterly wind regime (figs. 8, 9). The source of dune sands is variable, but

Table 4. Eolian environments and deposits, Kingsville map area, Texas. Units may be physical (sedimentary deposits and erosional features), biological (stabilized by distinctive vegetation), process (deflation, distinctive accretion), or a combination of these elements. Units denoted by (°) also associated with Pleistocene delta and Modern bay-estuary-lagoon systems.

ACTIVE AND RELICT SAND DUNE FIELDS AND ASSOCIATED BLOWOUT AREAS

Eolian System

Active banner dune complexes, local barchan dunes common
Active dune blowout areas, depressed relief, local marsh
Sand sheet with strong relict grain of base-leveled dunes
Moderately stabilized dunes, brush-covered
Well-stabilized dunes, live-oak-covered

Barrier Island System

Fore-island dune ridge
Sandflats and/or coppice sand dune fields
Stabilized blowout dune complex, grass-covered
Wind deflation trough and storm runnel on barrier flat
Back-island dune field and fore-island blowout dunes
Back-island sandflats with small migrating dunes

LOESS PLAINS WITH VARIABLE THICKNESS OF SILTY, WIND-DEPOSITED SEDIMENT

Eolian System

Loess sheet overlying Pleistocene fluvial sands
Loess sheet overlying Pleistocene deltaic sand and mud

EOLIAN PLAINS DISPLAYING VARIABLE DEGREES OF WIND DEFLATION AND DEPOSITION

Eolian System

Sand and loess sheet with no relict grain, grass-covered
Moderately stabilized sand and loess sheet, brush-covered
Sand and loess sheet deflation area, shallow water table

AREAS OF LOCALLY INTENSE WIND DEFLATION AND DUNE ACCRETION

Eolian System

°Clay-sand dunes, active
°Clay-sand dunes, presently inactive

Bay-Estuary-Lagoon System

Eolian accretionary bars and ridges, clay-sand on wind-tidal flats, potreros, and rincons
Marginal residual sand apron (lag deposit) on windward side of rincons and potreros on wind-tidal flats
Transitional zone between wind-tidal flat and eolian sand sheet

sand is derived principally from wind erosion of relict Pleistocene barrier-strandplain, meanderbelt, and distributary channel deposits (fig. 4). At the surface, the South Texas eolian system is principally of Modern age, but older, buried wind deposits are at least as old as early Holocene (Fisk, 1959). It is likely that Pleistocene eolian deposits occur in the subsurface within the region.

As a consequence of the wind erosion (or deflation), silt- and clay-sized sediments are winnowed from various deposits of Pleistocene, Holocene, and Modern age. The residual sands migrate slowly northwestward across the eolian plain as sand dunes. The finer grained sediment is removed and carried downwind (inland) and deposited as an extensive, relatively thin blanket of silt-sized quartz and clay particles. This airborne silt deposit is called "loess," a term that has been applied to similar deposits of windblown glacial sediment. Extensive areas of loess occur downwind from principal sand dune fields (fig. 4).

Other large areas of the eolian system are composed of sandy to silty plains that are covered either by sparse grasslands or by brushlands. No evidence of dune development exists in these broad eolian plains. The sandy plain is, in part, composed of a veneer of loose, highly winnowed (deflated) lag sand derived locally from subjacent Pleistocene sand deposits. Other areas within the eolian plain are mantled by a loess veneer derived locally from deflation of sandy and silty Pleistocene deposits. In areas underlain by a shallow water table, the amount of deflation is controlled by soil moisture derived from the intersected water table; during wet climatic cycles, deflation is prevented. Sparse grass communities cover most of the eolian plains, but brushlands have developed on areas of thicker sand veneer.

Locally, intensive wind deflation of dry playa lakes supplies silt-sized clay pellets which are blown leeward of the lake to produce accretionary clay-sand dunes. Relict dunes of similar origin are moderately stabilized by grass and brush vegetation. Similar accretionary deposits that occur on or adjacent to wind-tidal flats have been previously described as components of the bay-estuary-lagoon system (potreros and rincons).

Principal Elements of the Eolian System

Four principal types of elements are present within the South Texas eolian system (fig. 21): eolian sand lobes and dune trains, loess sheets, mixed sand and loess plains, and deflation complexes (table 5).

The *eolian sand lobes and dune trains* are composed of active and relict sand dune complexes that include migrating dunes, blowout areas, dunes stabilized by vegetation, and extensive sand sheets composed of base-leveled dunes (deflation depressions, low relict longitudinal dunes, stabilized lag ridges), which Price (1958) called the "stripped plains." *Loess sheets* are composed of thin, commonly discontinuous blankets of airborne silt that have been deposited downwind of eolian sand lobes and drape pre-loess topography; only localized in situ deflation occurs in this principally depositional area. *Mixed sand and loess plains*, which occupy a significant part of the eolian system, are grass and brushlands underlain by a variety of sand and loess deposits of variable thickness resulting from in situ deflation and redeposition of older substrates, mixed with airborne silt (loess) from upwind sand dune complexes. *Deflation complexes* are widespread areas where wind erosion has locally intersected substrates containing sufficient moisture to limit or prevent continued erosion. This base level may result from the presence of a shallow, fluctuating water table within subjacent Pleistocene sand bodies.

Parra Lake eolian sand lobe.—This eolian feature is located along the mainland shore of Laguna Madre northeast of Alazan Bay and has been an area of extensive wind deflation and dune migration, especially during drought cycles (figs. 13, 21). Dry southeasterly winds have eroded Pleistocene marine sands of the Ingleside barrier-strandplain system; dunes have periodically migrated northwestward into Alazan Bay, onto the wind-tidal flats of lower Cayo de Hinoso, and across the marshy, poorly drained lowlands between Laguna Larga and Alazan Bay.

The history of the eolian lobe is not well understood. It is not clear whether the small lobe had an extensive Holocene history similar to the other eolian lobes of the South Texas system, or whether it developed more recently as a result of drought and overgrazing. Price and Gunter (1943) suggested that drought and overgrazing between 1870 and 1890 had great impact on wind and water erosion in the region. The Parra Lake lobe may have experienced intense deflation during that period. During the past several decades, the Parra Lake eolian sand lobe has been moderately stabilized by grass and brushland.

North of the eolian sand lobe, sufficient rainfall and grass vegetation existed to stabilize the Ingleside

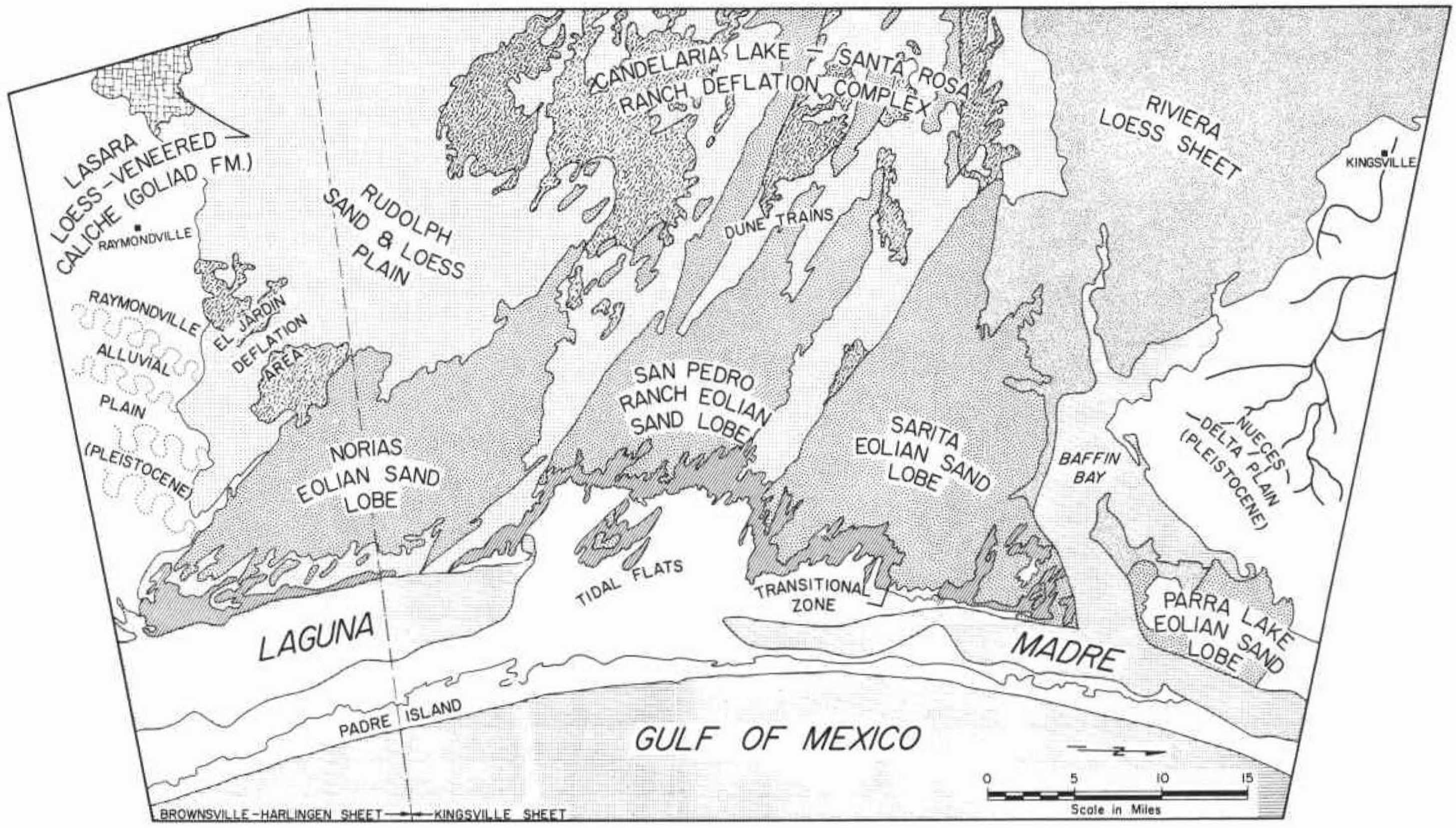


Figure 21. Principal elements within the South Texas eolian system, Kingsville and Brownsville-Harlingen areas.

barrier-strandplain sand and to prevent its erosion. Some wind deflation did occur locally along the sandy Pleistocene substrate as far north as Copano Bay as evidenced by the presence of stabilized blowouts and oriented deflation lakes.

Silt-sized sediment winnowed from the Pleistocene sand body was airborne and carried across Alazan Bay where a thin blanket of loess was deposited on the Pleistocene delta deposits (figs. 12, 14). Although this widespread loess deposit was too thin and discontinuous to map, thicker areas of loess probably supported the spread of brushlands along the low escarpments that trend between Tunas Creek and the Madero Lake area (see *Environments and Biologic Assemblages Map*).

Sarita eolian sand lobe.—This dune complex constitutes the largest eolian lobe within the South Texas system (fig. 21). It is composed of active sand dunes and blowout areas, as well as oak-covered relict (stabilized) dunes and base-leveled or stripped dune fields (fig. 22). Base-leveled dune fields display prominent textural and topographic "grain" on aerial photographs and topographic maps, respectively. This grain is produced by repeated eolian blowout, dune migration, and erosion. The unique texture and topography of the stripped plains are the "scars" of repeated dune development and eventual base-levelling by wind erosion as the dunes migrated downwind.

In the upwind or southeastern part of the lobe, wind erosion and blowouts are dominant within large areas of stripped or base-leveled plains. Active dunes are concentrated in the central part of the lobe, and the downwind or northwestern part of the lobe is composed predominantly of hummocky dunes that became stationary and were eventually stabilized by extensive oak mottes (see *Environmental Geology Map*).

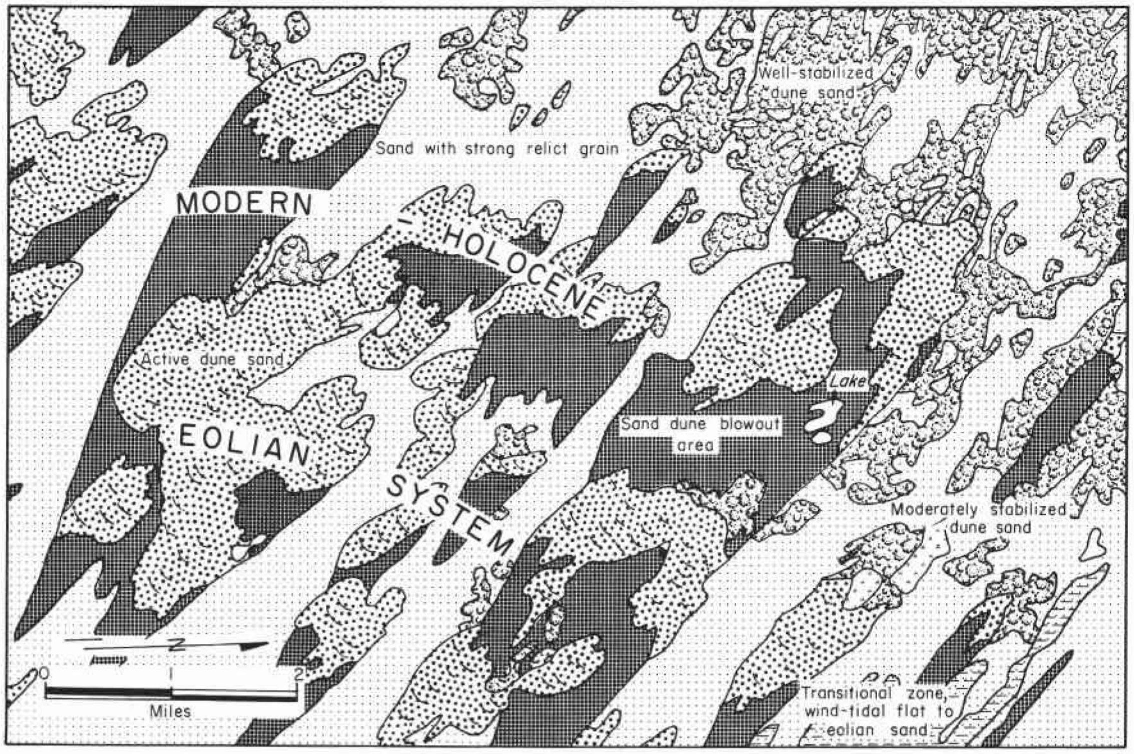
Eolian activity in the Sarita lobe was probably initiated in the early Holocene; Pleistocene eolian processes may have existed in the area, but direct evidence of this earlier history is currently unavailable. Studies by Fisk (1959) show that eolian sands now buried 15 to 40 feet below Padre Island were deposited directly on top of the eroded Pleistocene surface. Source of the sand within the Sarita lobe was originally

Table 5. Environments, principal elements, and map units within the South Texas eolian system, Kingsville and Brownsville-Harlingen map areas. Units denoted by (*) occur in more than one principal eolian element. Refer to figure 21 for general location of principal eolian elements.

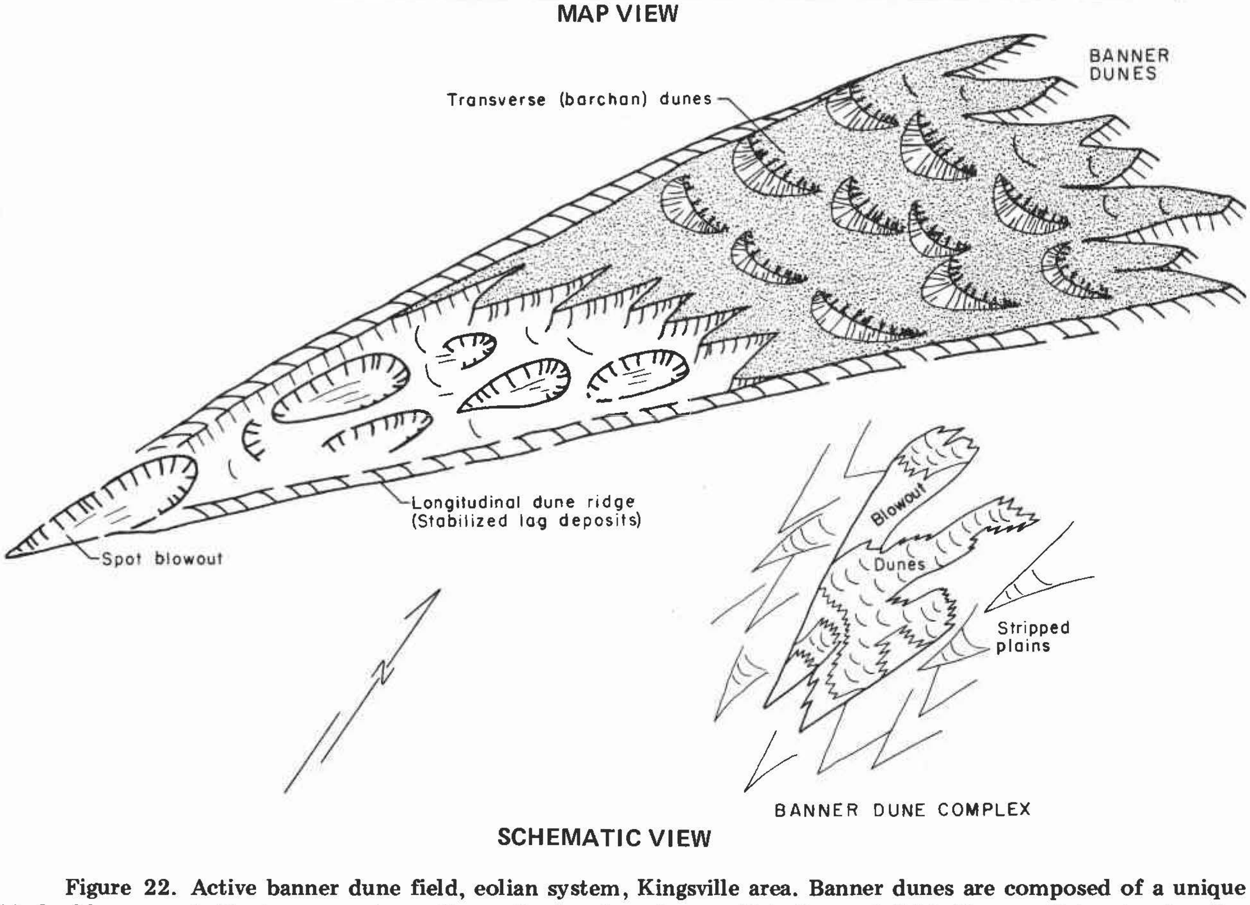
NATURE OF EOLIAN ENVIRONMENTS	PRINCIPAL ELEMENTS OF THE SOUTH TEXAS EOLIAN SYSTEM	SOUTH TEXAS EOLIAN SYSTEM: EOLIAN MAP UNITS
Eolian sand lobes and dune trains composed of active and relict sand dune fields and associated blowout areas	Parra Lake eolian lobe Sarita eolian lobe San Pedro Ranch eolian lobe Norias eolian lobe	*Active dune complex:* sand, commonly banner dunes, locally barchan dunes *Active dune blowout areas:* sand, local depressed relief, eolian grain prominent, hummocky, locally fresh-water marsh in wet seasons *Sand sheet with strong relict grain of base-leveled dunes:* sparse grass **Moderately stabilized dunes:* sand and loess (silt) sheet, brush-covered **Well-stabilized dune sands:* dense live-oak mottes and scrub
Loess sheets composed of airborne silt derived from upwind areas of wind deflation	Riviera loess sheet Lasara loess sheet	*Loess sheet:* thin, stippled where discontinuous, silty, overlies calichified Pleistocene fluvial sand, brush- and grass-covered *Loess sheet:* thin, discontinuous, silty, overlies Pleistocene deltaic mud and calichified sand, brush- and grass-covered **Clay-sand dunes, active:* accretionary, locally sparse grass, playa source common **Clay-sand dune complexes, inactive:* grass- or brush-covered, local sediment source
Sand and loess plains subjected to varying degrees of wind deflation and deposition	Rudolph sand and loess plain	*Sand and loess (silt) sheet with no relict grain:* sparse grass **Moderately stabilized dunes:* sand and loess (silt) sheet, brush-covered **Well-stabilized dune sands:* dense live-oak mottes and scrub **Clay-sand dunes, active:* accretionary, locally sparse grass, wind-tidal flat or playa source common
Large areas of wind deflation associated with fluctuating level of ground-water table	Candelaria Lake-Santa Rosa Ranch deflation complex El Jardin deflation area	*Sand and loess (silt) sheet deflation area:* active, grass, high water table, occasionally flooded, poorly drained **Clay-sand dunes, active:* accretionary, locally sparse grass, wind-tidal flat or playa source common

the southern part of the Ingleside barrier-strandplain sand of late Pleistocene age. This marine sand body, which is eroded by southeasterly winds in the Parra Lake eolian lobe, extends south of the mouth of Baffin Bay where it has been intensively deflated along the landward side of Laguna Madre. Sands eroded from the Ingleside sand body were transported inland by extensive banner dunes for more than 25 miles from Laguna Madre to the vicinity of Sarita (fig. 21). Sand within the lobe has undoubtedly passed through several cycles of wind deflation, dune transport, stabilization by vegetation, and repeated deflation. Climatic cycles may have been an important factor in recycling the sand; the extensive base-leveled or stripped plains are evidence of repeated erosional-depositional cycles.

Dunes of the Sarita lobe locally migrate into Baffin Bay along the shoreline between Black Bluff and Point Penascal. East of the town of Sarita, the eolian lobe has encroached slowly across the loess-covered delta plains (Riviera loess sheet) near Parra Ranch. Intensive wind deflation within the Sarita lobe has resulted in the winnowing of silt-sized particles, which are then transported downwind to the northwest where the particles settle out of the atmosphere to produce the Riviera loess sheet (fig. 21). The intense deflation that occurred



MAP VIEW



SCHEMATIC VIEW

Figure 22. Active banner dune field, eolian system, Kingsville area. Banner dunes are composed of a unique kind of large parabolic dune complex with smaller barchan dunes within the sand field. Strong relict grain of earlier base-leveled dunes indicates long history of dune activity. Schematic view illustrates the various features that compose an individual banner dune. After Price (1958) and Scott and others (1964).

south of Carnestolendas Ranch has provided sufficient airborne silt to mantle Pleistocene fluvial and delta deposits inland for tens of miles. At least 7 square miles of the mainland has been eroded by wind deflation in the Sarita lobe south of Carnestolendas Ranch. Although moderate deflation in the Penascal area has provided some airborne silt to the region northwest of Alazan Bay and northeast of Cayo del Grullo, the loess deposit is thin and was not separately mapped.

The distinctive map pattern displayed by the transitional zone between the wind-tidal flats of the bay-lagoon-estuary system and the South Texas eolian system (fig. 21) clearly shows the erosional effect of banner dune deflation along the margin of the mainland (fig. 20). Remnants of Ingleside beach ridges extend southward from Point Penascal to Rocky Slough; south of Rocky Slough, relict Pleistocene beach ridges may provide the nuclei of the six prominent wind accretion features called potreros.

San Pedro Ranch eolian sand lobe.—The San Pedro lobe, located in the central part of the Kingsville map area, is composed of the same fundamental environments and eolian features that characterize the Sarita and Norias lobes (see *Environmental Geology Map*). The San Pedro lobe, however, is composed of three elongate, and partly overlapping, lobes or "dune trains" (fig. 21). These narrow dune trains (2 to 4 miles wide) originate along the edge of the tidal flats that compose the Land-Cut Area and extend downwind to the northwest for tens of miles. Each dune train is composed of active dunes and blowout areas, as well as oak-covered relict dunes and extensive base-leveled or stripped plains (fig. 23). The southernmost dune train, which passes on the north side of the Armstrong Ranch headquarters, displays very few active dunes, although several blowout areas exist along the narrow eolian belt.

Elongate dune trains of the San Pedro lobe are separated by 1- to 4-mile-wide belts of mixed sand and loess prairies, deflation areas, and interlobe oak mottes. The interlobe oak mottes may mark the sites of early Holocene sand dunes. The dune trains are similarly separated from the Sarita lobe on the north and the Norias lobe on the south. The two northern dune trains coalesce southeast of Cayo Grande to form a composite lobe about 7 miles wide near San Pedro Ranch.

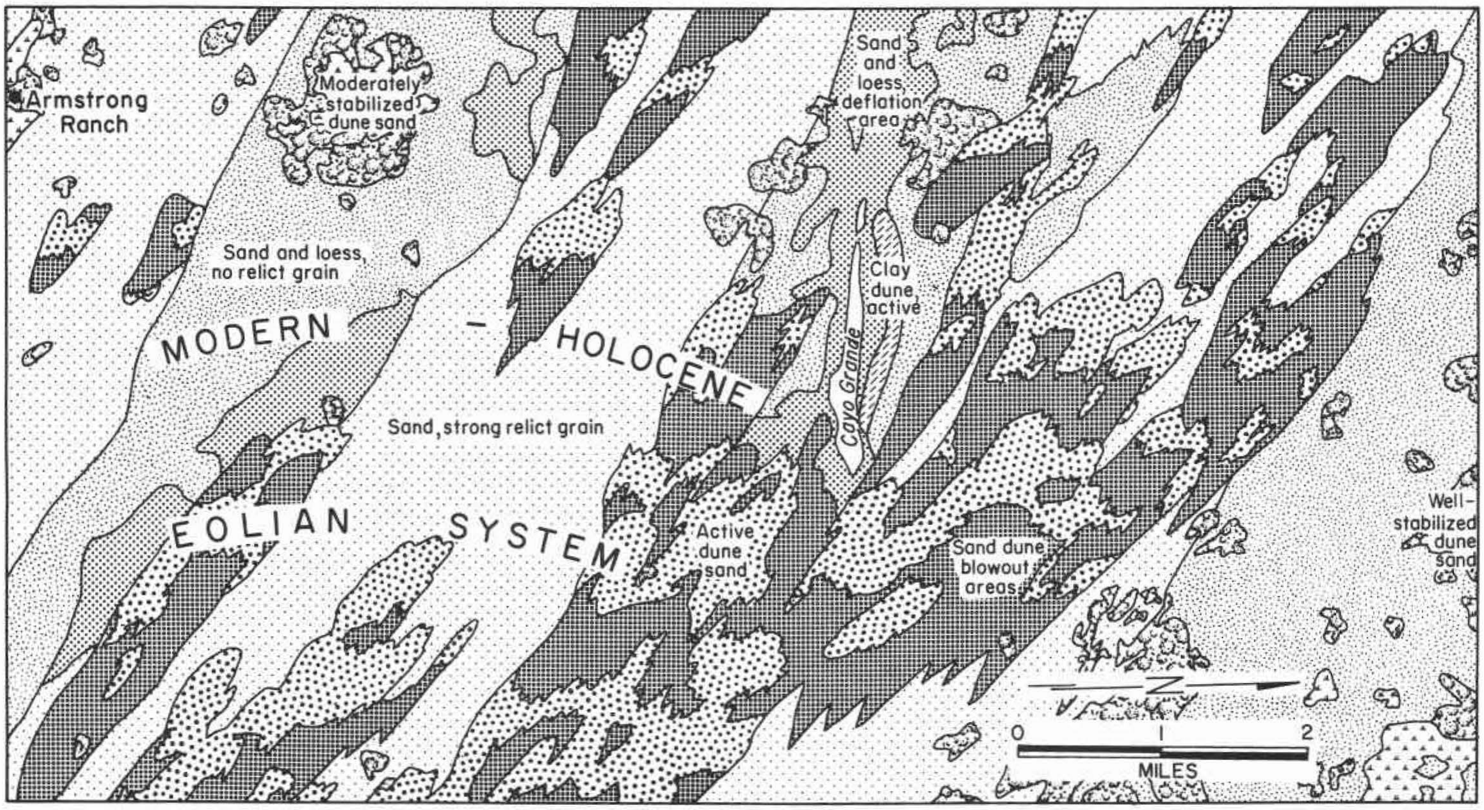


Figure 23. Facies mosaic within the South Texas eolian system, Kingsville area. Dune trains trend for many miles parallel to dry, prevailing southeasterly wind regime.

Approximately 60 square miles of the mainland have been eroded on the upwind (southeastern) side of the San Pedro Ranch lobe. Remnants of the eolian lobe lie isolated on the broad wind-tidal flats in the Rincon Mesquite area (fig. 19). Intense deflation by banner dune blowouts has allowed the wind-tidal flats of Laguna Madre to encroach northwestward from 4 to 6 miles over deflated eolian deposits. The combined factors of low rainfall, low humidity, persistently strong southeasterly winds, and sparse vegetation have been responsible for subjecting the San Pedro Ranch eolian lobe to this unusually severe wind erosion. Dune trains of the San Pedro lobe extend farther inland than either the Sarita or Norias lobes.

San Pedro Ranch eolian deposits probably originated from several sand sources. The Pleistocene Ingleside sand body apparently thins significantly south of Carnestolendas Ranch, but it may have supplied some sand to the San Pedro Ranch lobe during mid-Holocene. Recycling of this sand by repeated deflation, dune development, and deposition may have supplied sand to inland dunes. It is also probable that the individual dune trains have been locally supplied with sands where they intersect and deflate subjacent Pleistocene fluvial and deltaic sand bodies. West of Cayo Lake and Santa Rosa Ranch (fig. 24), a strong aerial photographic linear anomaly emanating from the Gyp Hill salt dome near Falfurrias (west of the Kingsville map area) defines the northwestward termination of the northern dune train of the San Pedro Ranch eolian lobe. Similarly, the southernmost dune train terminates along a distinct aerial photographic lineament west of U. S. Highway 77 (northwest of Armstrong). A relationship may exist between lineations, faults, fractures, and ground-water levels in Pleistocene fluvial aquifers that underlie the sand sheet. These structural features may serve as hydrologic barriers, which may affect the distribution of soil moistures and thus control the development of dune

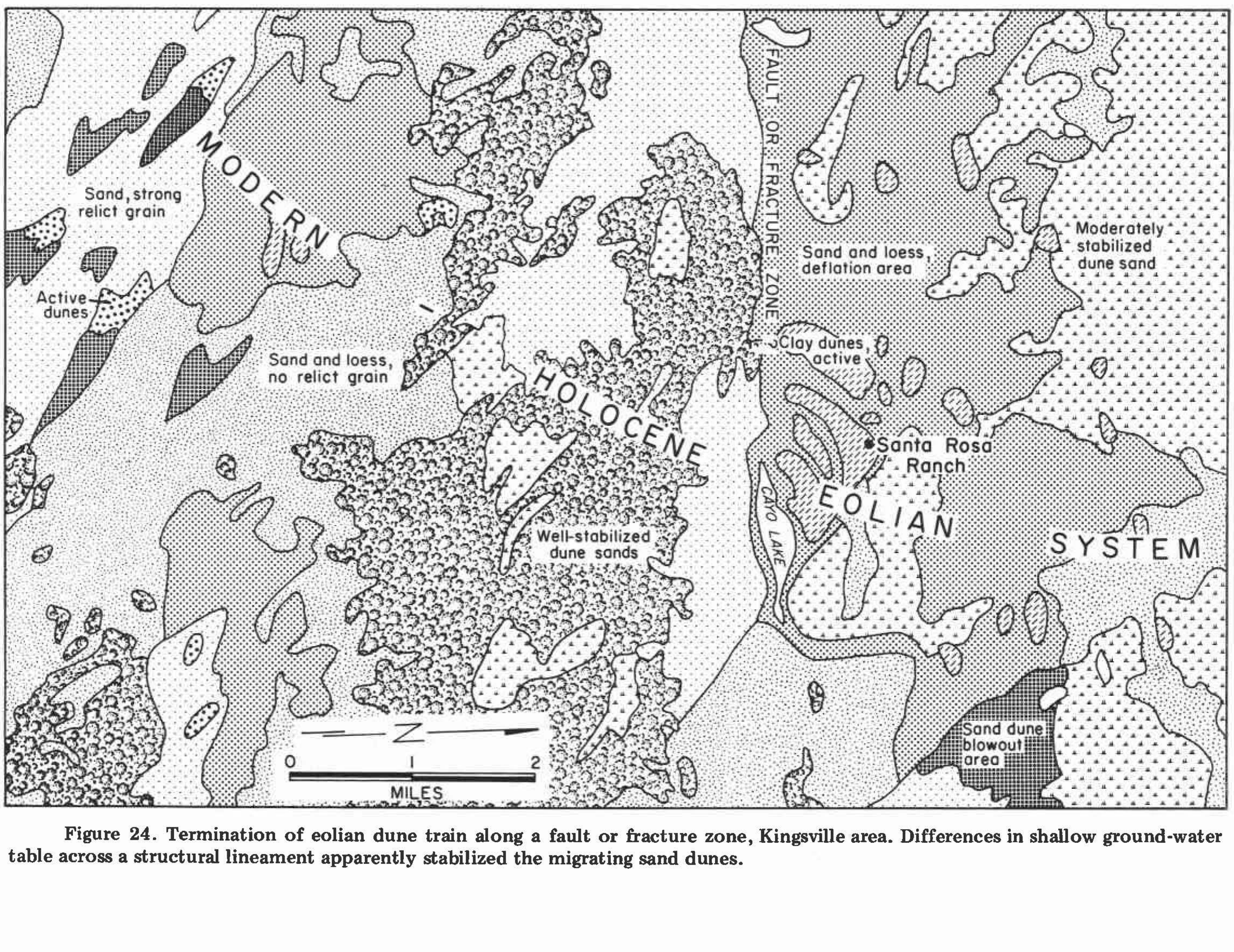


Figure 24. Termination of eolian dune train along a fault or fracture zone, Kingsville area. Differences in shallow ground-water table across a structural lineament apparently stabilized the migrating sand dunes.

trains by limiting the effectiveness of eolian (wind) processes.

Norias eolian sand lobe.—Eolian dunes of the Norias lobe (fig. 21) originate along or near the western shore of southern Laguna Madre between the Land-Cut Area and Port Mansfield (see Brownsville-Harlingen map area). The Norias lobe is composed of fewer banner dunes and smaller areas of stripped plains than exhibited by the San Pedro Ranch and Sarita eolian lobes. The inland part of Norias lobe is densely vegetated by oak mottes (fig. 25). Unlike other eolian lobes, Norias lobe is generally restricted to the area east of U. S. Highway 77; active dunes are concentrated very near the Laguna Madre shoreline. A few small blowout areas occur west of the highway between Norias and Armstrong.

On aerial photographs, the eolian texture or grain displayed by the Norias lobe is subdued, which indicates that wind deflation is now less intense than within the other eolian lobes. This observation is supported by the presence of dense oak mottes that have developed on extensive relict dunes and by brushlands that have covered many relict blowout areas (fig. 25). All evidence points to recent diminution of eolian processes in the Norias lobe with consequent development of dense vegetative cover on the relict dunes.

The Norias eolian lobe probably has been active since early Holocene. Presently exposed active and relict dunes overlie the late Pleistocene Raymondville fluvial system (fig. 21) that serves as the principal source of sand for the Norias lobe. Meanderbelts of the Raymondville system pass under the apex of the Norias lobe; relict point-bar deposits have been extensively deflated and the sand moved northwestward by prevailing winds. Earlier episodes of deflation and dune migration are indicated by relict, heavily vegetated dunes.

Silt particles winnowed from the blowouts in the Norias lobe are transported downwind and deposited in the Rudolph sand and loess plains and in the Candelaria Lake deflation area (fig. 21).

Riviera loess sheet.—Airborne silt winnowed from the Sarita eolian lobe by wind deflation is carried downwind (northwestward) and deposited to form the thin, locally discontinuous Riviera loess sheet (fig. 21). The sheet lies principally between Cayo del Grullo-Santa Gertrudis Creek and the Sarita-San Pedro Ranch eolian elements. The Riviera sheet extends beyond the western boundary of the Kingsville map area. The loess sheet thins northwestward and northward, but it was not mapped north of Cayo del Grullo and Santa Gertrudis Creek (except northwest of Kingsville). Loess deposits occur for several miles north of the mapped boundary of the loess sheet, but they are very thin and discontinuous. Most of the loess sheet was covered by brush before the area was extensively cleared for pastures and cultivation.

West of U. S. Highway 77, the thin deposits of airborne silt cover an irregular pre-loess surface that had developed on Pleistocene fluvial sands and muds (Lissie Formation). Eastward-trending topographic ridges are underlain by elongate fluvial sand bodies. East of U. S. Highway 77, the loess overlies flat Pleistocene delta-plain deposits composed principally of mud with localized elongate sand and silt bodies (Beaumont Formation). The Riviera loess sheet varies in thickness from a few inches to several feet; locally the loess is absent and Pleistocene deposits are exposed at the surface. The loess and underlying Pleistocene deposits, especially the sands, are extensively calichified.

A significant number of active and inactive clay-sand dunes occur within the Riviera loess sheet. Active dunes are principally accretionary clay dunes associated with playa lakes, especially east of U. S. Highway 77. These active dunes result from the deflation of silt-sized clay aggregates from the bottom of dry playas; the particles are generally deposited as a dune on the northwest side of the dry playa lake. Larger conical to elongate dunes that are covered by grass or brush are

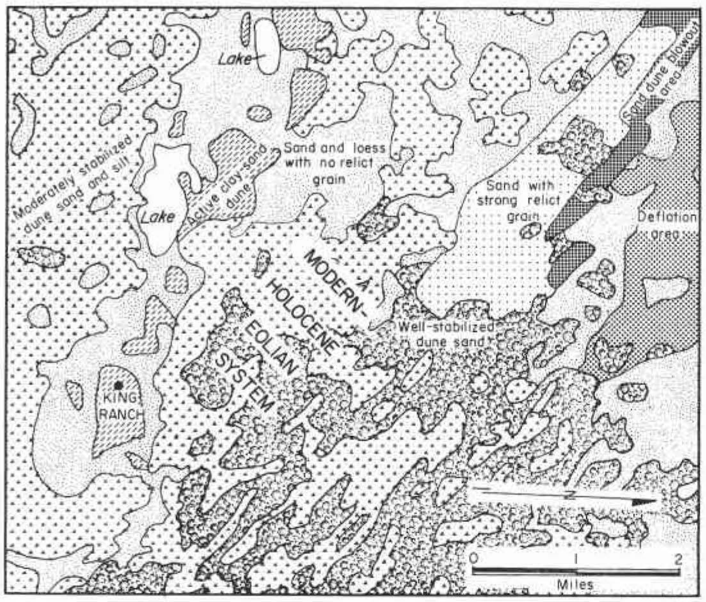


Figure 25. Inactive dune fields stabilized by live oaks and brush, South Texas eolian system, Kingsville area. Wind deflation in sand- and loess-covered interdune areas characterized by playa lakes and active clay dunes.

relict eolian features within the loess sheet. These large dunes, which are composed of sand and clay, are similar to relict dunes that occur along the northwestern shore of Alazan Bay. Field observations indicate that the relict dunes may be in situ features produced during extremely arid climatic periods by wind deflation of Pleistocene sand and silt deposits. The distribution of the large dunes indicates that the Pleistocene sand and silt sources may be elongate fluvial deposits. There is no evidence that these relict dunes migrated very far from a sand source; they were stabilized by vegetation during periods of increased rainfall.

A small part of the *Lasara loess-veneered caliche* unit occurs in the northwestern part of the Brownsville-Harlingen map area (fig. 21). The thin, discontinuous loess overlies calichified sand, conglomerate, and some mud deposits of the Goliad Formation. The loess is extensively distributed across parts of the Pleistocene Goliad Formation outcrop west of the Kingsville and Brownsville-Harlingen map areas.

Rudolph sand and loess plains.—Loose sand and loess plains occupy large areas within the South Texas eolian system (figs. 25, 26). The Rudolph sand and loess plains are composed of mixed areas of loess and locally derived in situ eolian sands (fig. 21). These grass- and brush-covered plains display no eolian grain on aerial photographs or topographic maps. Low, vegetated dunes and shallow, relict deflation depressions are scattered throughout the Rudolph plains; locally, oak mottes occur on the low, hummocky, relict dunes within the Rudolph plains. Oak mottes within the sand and loess plains occur south of San Pedro Ranch, in the Los Indios Ranch area, near Armstrong Ranch (fig. 23), south of Cayo Lake (fig. 24), and in several other localities. Most of these occurrences are associated with the dune trains of the San Pedro Ranch eolian lobe (fig. 21), and they probably represent remnants of early Holocene dune activity. Active clay dunes associated with playa lakes occur within the Rudolph sand and loess plains.

East of U. S. Highway 77, the Rudolph plains overlie principally Pleistocene deltaic muds and sands west of the highway; the sand and loess deposits generally overlie Pleistocene interfluvial (floodbasin) muds. Small in situ dunes are produced by wind deflation of these localized Pleistocene fluvial sand and silt bodies. The winnowed silt is carried downwind where the loess is normally deposited within the Rudolph plains. Consequently, this element of the South Texas eolian system was produced by widespread deposition of airborne loess and local deflation of subjacent Pleistocene sands or relict eolian deposits. The Rudolph plains are not homogeneous, but they constitute a series of mixed eolian deposits and erosional features.

The ground-water table beneath the Rudolph plains is probably deeper than beneath the eolian sand lobes as evidenced by the limited number of playa lakes, the friable nature of the sand/silt sheets, and the presence of plants with low water requirements. In areas (fig. 25) where thicker, hummocky sands occur, such as south of the King Ranch headquarters, dense brush has invaded the plains, probably representing a climax vegetation induced by the low rainfall and relatively deep or low yield ground-water system.

Candelaria Lake - Santa Rosa Ranch deflation complex.—Large areas within the South Texas eolian system underlain by shallow Pleistocene aquifers have been deflated so that the water table is intersected by the surface of the eolian plain (fig. 26). Wind deflation within the Candelaria Lake - Santa Rosa Ranch area (fig. 21), generally west of U. S. highway 77, has been stabilized by high soil moisture. A rise or fall of the ground-water table may either stabilize or permit accelerated deflation, respectively. Fluctuation of the ground-water level may have resulted in an alternation of periods of stability and wind erosion in the area.

Playa lakes are concentrated in the Candelaria Lake-Santa Rosa Ranch deflation complex (fig. 26). Similarly, a large number of perennial lakes occur within the complex where the surface intersects the aquifer. High soil moisture probably occurs throughout the area when the ground-water level is relatively high. The plants of the deflation areas differ from the typical grasses of the Rudolph sand and loess plains, probably reflecting higher soil moisture in the deflated area.

The deflation areas are poorly drained with subtle depressed topographic relief. The areas are extensively flooded by hurricane rainfall (see *Active Processes Map*); recharge of the shallow aquifer occurs through perennial lakes (Baker, 1971).

The large Candelaria Lake-Santa Rosa Ranch deflation area is probably underlain at a shallow depth by a significant number of lenticular fluvial sand bodies of the Lissie Formation; it is also possible that some sands and gravels of the Goliad Formation may directly underlie the sand sheet along the western margin of the Kingsville map area (Brewton, in preparation). Deeper

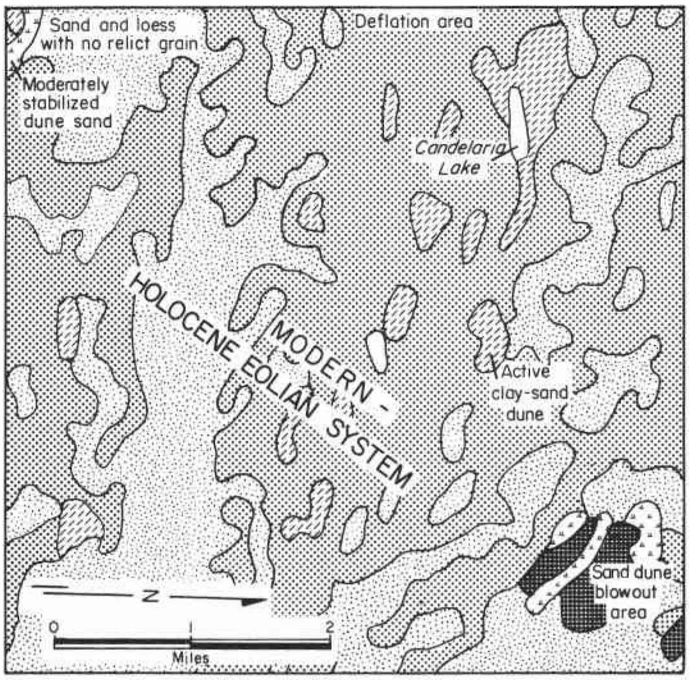


Figure 26. Interdune area where wind has apparently deflated sand and loess sheet to the top of shallow water table. About 90 percent of the inland playa lakes occur within this eolian unit. Pleistocene fluvial sands probably underlie the deflation area and constitute the local aquifer.

aquifers in the Kingsville area occur in the Goliad Formation (Shafer and Baker, 1973). The approximate contact between fluvial (Lissie Formation) and deltaic (Beaumont Formation) deposits is shown on figure 4.

The *El Jardin deflation area* in the northern part of the Brownsville-Harlingen map area (fig. 21) resembles the Candelaria Lake - Santa Rosa Ranch feature. It is similarly underlain at a shallow depth by aquifer sands of the Lissie Formation and/or the Raymondville fluvial system (upper Beaumont Formation).

Eolian Environments

Twenty-one eolian environments have been mapped on the *Environmental Geology Map* of the Kingsville area. Only 12 of the eolian environments compose the South Texas eolian system. The other 9 environments are components of the Padre Island barrier system or the Laguna Madre-Baffin Bay system (table 4) and are described elsewhere in this report.

The principal elements of the South Texas eolian system have been described (fig. 21; table 5). Following is a description of the individual map units that compose the eolian system. The substrates within the eolian system are principally well-sorted quartz sand, although loess (silt-sized particles), some pond clays and marls, and clay dunes occur within the system.

Active dune complex.—The banner dunes of South Texas are probably the most striking features within the eolian system (figs. 22, 23). The dunes cover about 50 square miles within the sand sheet area, although the precise positions and areal extent change annually as the windblown sand shifts with changing winds and climatic variations. The dunes, which are components of the Sarita, San Pedro Ranch, and Norias eolian lobes, display a net forward movement to the northwest in alignment with the prevailing southeasterly winds (fig. 9).

The term "banner dune" has been applied to the South Texas dunes (Price, 1958), which display a tattered or serrated downwind margin (fig. 22B). Individual dunes are normally large bannerlike features; numerous transverse or barchan dunes migrate downwind across the sandy surface of the banner dune complex. These transverse dunes serve as a conveyor system that moves sand from the upwind deflation areas to the downwind margin of the migrating dune complex. The banners are composed of well-sorted, principally fine-grained quartz sand.

Transverse dunes are broken into sand sheets and small coppice dunes by vegetation along the downwind margin of the banner dune. The gradual buildup of sand sheets and coppice dunes, which gradually bury the vegetation in the path of the dune complex, provides a sandy surface over which subsequent transverse dunes can move. The banner dune, therefore, is perpetuated by continual upwind erosion and downwind deposition. Banner dunes move inland until they lose momentum and eventually become stabilized by vegetation. Several factors are responsible for limiting the inland migration of barrier dunes, including diminished sand supply, diminished wind strength and persistence, increased vegetation as atmospheric salt diminishes inland, and increased elevation and topographic roughness.

As each banner dune migrates downwind, the water table may rise a foot or more beneath the dune. Eolian deflation of the upwind part of the dune erodes the sand to the top of the water table; the few inches to a foot or so of moist dune sand below the water table remain in place as the rest of the dune sand is entrained and transported downwind. Fluctuation of the shallow water table, therefore, controls the thickness and permanence of eolian deposits within the stripped plains. If the water table later drops, the dry sand above the table will again be subjected to deflation.

V-shaped pairs of longitudinal dunes, which Price (1958) called stabilized lag ridges, bound the margin of the banner dunes. These dunes form the boundary between the moving banner dune and the adjacent plains. The lag ridges, which are composed of coarse lag deposits, become stabilized by vegetation. The ridges exhibit a distinctive textural and topographic grain on aerial photographs and topographic maps, respectively. The lag ridges are a major feature of the stripped or base-leveled plains.

Active dune blowout areas.—Closely associated with the active banner dunes are localized areas where wind erosion provides the sand that initiates and nourishes dune migration. The blowouts originate at point sources called spot blowouts (fig. 22B). The blowout grows larger as the area of wind deflation migrates downwind with the banner dune complex. The blowout and the banner complex define approximately a 25° angle originating at the spot blowout; this angle may be related to the range of variation displayed by the prevailing southeasterly winds.

The blowout area is composed of a series of depressions that exhibit a hummocky topography. Progressive deflation of the blowout widens the area downwind (figs. 22, 23). Transverse ridges within the blowout depressions mark sites of transverse dunes stabilized by rising ground-water table. Ponds develop where the erosional depression intersects the shallow water table. Fringing fresh-water marsh develops around and within the ponded deflation depressions. Marly pond deposits are common within the blowouts.

The blowouts are bounded by the lag or longitudinal ridges that develop along the lateral margins of banner dunes. The blowout persists long after it is stabilized by rising water table; slowly the depression is filled by windblown and sheetwash deposits or by another banner dune complex.

About 75 square miles of the eolian system are occupied by active blowout areas. Partially or completely filled, relict blowouts underlie most of the base-leveled or stripped plains.

Sand sheet with strong relict grain.—Approximately 225 square miles of the eolian lobes (fig. 21) of the South Texas system are occupied by sandy plains composed of base-leveled dunes and blowouts that Price (1958) called the "stripped plains." These grass-covered plains (figs. 22, 23, 24) exhibit a unique texture on aerial photographs and a distinctive topographic configuration. The map unit is made up of eolian lag (longitudinal) ridges and remnant blowouts that outline the shape of numerous relict banner dune complexes. Blowout areas and lag ridges are partially preserved by rising ground water which may temporarily prevent further wind deflation and destruction. This map unit consists, therefore, of base-leveled dunes, lag ridges, and blowouts which have been stripped to the water table by wind erosion. Fluctuating ground-water table permits repeated erosion and stabilization; a similar process has been described by Stokes (1968) from ancient eolian deposits of the Colorado Plateau region.

Crosscutting relationships exhibited by successive banner dunes can be observed on aerial photographs. This indicates that the banner dunes within the eolian lobes have developed repeatedly, possibly in response to cyclic climatic (rainfall) variations. Each banner dune, hence, develops by spot blowout, downwind dune migration, and eventual stabilization of the distal part of the eolian lobe by brush and oak mottes. The path of dune migration is marked by the lag ridges, relict blowouts, and thin basal deposits of the dune. Wind erosion eventually destroys those relict deposits that lie above the water table.

Sand and loess sheet with no relict grain.—Coincident with the grass-covered part of the Rudolph sand and loess plains, this environment occupies about 300 square miles of the South Texas eolian system (fig. 21). The sheet is composed of a complex mosaic of thin sand and loess deposits produced by wind deflation (figs. 23, 24, 25). Most of the sand deposits are low, in situ dunes and sand sheets produced locally by moderate wind erosion of older eolian deposits or, perhaps, of lenticular Pleistocene sand bodies beneath the sand sheet. Silt-sized particles winnowed by wind erosion are airborne and carried downwind where loess deposits are formed. Some loess deposits within the environment are derived from intensive deflation in upwind eolian lobes. The sand and loess deposits that underlie the grass-covered plains display no eolian grain; on aerial photographs, the area is a featureless plain with no evidence of banner dune development. Topographically, the plains are relatively flat, but low grass-covered relict dunes and shallow deflation depressions mark the site of earlier, localized wind erosion.

The environment is underlain generally from a few inches to several feet by muddy Pleistocene deposits, principally of deltaic (Beaumont Formation) and interfluvial (Lissie Formation) origin. The paucity of shallow aquifers has permitted repeated episodes of wind erosion and development of low dunes. The grassy prairies grade into brushlands developed on thicker relict dunes; locally, oak mottes occupy the sites of thick eolian sand deposits.

Moderately stabilized dunes.—Approximately 170 square miles of the eolian system are covered by low brushlands (figs. 24, 25). The brush covers small, elongate blowout areas in the downwind part of the Sarita and Norias eolian lobes. Live-oak trees cover most of these relict dunes, but brush occupies those blowouts that are still active during severe droughts.

Brush has also encroached large areas of the Rudolph sand and loess plains and the Parra Lake eolian lobe. Brushland on the Rudolph plains may represent a fire-climax vegetation that has replaced the heavily grazed and frequently burned grasslands. Once the brush has invaded an area or occupied a dune field, the area is effectively stabilized against eolian processes. Only a severe drought can lead to rejuvenation of wind deflation or dune development. Man has cleared large areas of brush in the region, principally to restore grasses needed to support the large cattle industry. Similar brushlands originally occupied most of the Riviera loess sheet before the region was cleared for cultivation and grazing (see *Environments and Biologic Assemblages Map*). Brushlands within the Parra Lake eolian lobe have encroached the base-leveled plains developed on the Pleistocene Ingleside sand body (fig. 13).

The displacement of grasses by brush has been discussed by Johnson (1955). The relationship of plant ecology and eolian processes active in South Texas is still poorly understood and warrants further research.

Well-stabilized dune sands.—Oak mottes occupy about 190 square miles of the eolian system. Situated principally upon relict dunes, the dense oak trees represent a climax vegetation in the coastal dune fields (figs. 24, 25). The oak mottes are concentrated on the downwind or inland part of the Sarita and Norias eolian lobes. Dense mottes also occur on and between the dune trains of the San Pedro Ranch eolian lobe (fig. 24). The oaks apparently occupy areas of thicker eolian sands that are underlain by a shallow water table and, perhaps, by marly pond deposits. These areas have been unaffected by eolian erosion or dune activation during the many years necessary for the slow growth of the oaks. Only a long-term, severe drought can destroy the oak mottes. Locally, however, active banner dunes have been observed to migrate over and bury oaks in the path of movement (note the active dunes on the Norias lobe).

Brushlands and oak mottes provide the habitat for a variety of wild mammals and fowl. Good forage grasses are associated with the mottes, probably because of the higher water table and protection from the persistent winds.

Sand and loess sheet deflation area.—Approximately 145 square miles of the eolian system are occupied by sand and loess sheets that undergo periodic deflation controlled by fluctuations in the ground-water table. This unit is coincident with the Candelaria Lake - Santa Rosa Ranch deflation complex (fig. 21). The grass-covered deflation area is entirely surrounded by the grassy sand and loess sheet with no relict grain (fig. 26). The map unit displays a unique texture on aerial photographs probably caused by abundant clay dunes, abundant playa and perennial lakes, high soil moisture, dense stands of high-moisture-demanding plants, and subtle depressed relief.

The origin of this eolian unit is poorly understood; the following discussion is partly speculative and should be evaluated by future studies. The Pleistocene substrate that has been projected beneath the eolian area is the Lissie Formation (and perhaps upper Goliad Formation to the west), composed of elongate, lenticular sand bodies and floodbasin muds. A shallow water table within these Pleistocene deposits is indicated by the high concentration of playa and perennial lakes, as well as the occurence of distinctive plants that probably require higher soil moisture than found elsewhere in the Rudolph plains. Ponding of water that occurs in the area following hurricane rainfall (see *Active Processes Map*) indicates a subtle, depressed relief. The abundance of clay dunes associated with the playas indicates repetitive wet and dry conditions necessary to permit the deflation of silt-sized clay aggregates from the dry playas.

Northwest and downwind of the large Candelaria Lake deflation area, principally west of U. S. Highway 281 between Barrosa and Encino (not shown on map), is a large, oak-covered eolian lobe of earlier Holocene age. The sand within this relict eolian lobe was probably derived from the Candelaria Lake deflation area (Brewton, in preparation).

Studies by Baker (1971) show that water in a lake within the Candelaria deflation complex near the community of Armstrong communicates freely with ground water within a shallow aquifer. The lake apparently recharged the aquifer following the heavy post-Beulah hurricane rainfall, but the lake was, in turn, recharged later by the shallow aquifer when the lake level dropped below the water table. This relationship supports the hypothesis that the degree of deflation in the area is controlled by a fluctuating ground-water table.

Active clay-sand accretionary dunes.—About 16 square miles of the Kingsville map area are occupied by accretionary clay dunes that are rarely sandy. Clay dunes are distinctive eolian features that result from the windward accretion of silt-sized clay aggregates (see discussion of rincons and potreros in chapter, Bay-Estuary-Lagoon System). Clay dunes in the South Texas area were described by Coffey (1909) and Beck and Henderson (1928). Price (1933, 1958, 1963), Huffman and Price (1949), and Price and Kornicker (1961) have considered the processes and rates of clay-dune accretion.

In the Kingsville map area, clay dunes generally border the western and northwestern margins of wind-tidal flats and playa lakes. They are common along the margin of wind-tidal flats in the Alazan Bay area, in the transitional zone between wind-tidal flats and the eolian sand sheet, and adjacent to playas within the various sand and loess sheets of the South Texas eolian system (figs. 14, 24, 25, 26). Melton (1940) called such features "source-bordering eolian ridges"; Price (1958) refers to these as "stepped-back eolian ridges."

Clay-dune deposition involves windward accretion of sand- and silt-sized clay aggregates that are derived by eolian disintegration of clay chips on the bottom of dry playa lakes and wind-tidal flats. The salty clay pellets are blown from the lake bed or tidal flat by dry southeasterly winds. Pellets may be deposited nearby as a loessic blanket or apron that thins downwind (northwest). Commonly, the clay pellets will accrete upon a nucleus of dense plant growth and erosional remnants of levees, beach ridges, or other obstacles adjacent to the lake or tidal flat source area. Rain, heavy dew, or moisture absorbed by the contained salt tends to stabilize the clay pellets. Unlike sand dunes that are temporarily stalled by moisture, the clay dunes are permanent features constructed by repeated deposition and stabilization of loess. The dunes generally display from 5 to 20 feet of relief.

Potreros, rincons, and gavilans (see also Brownsville-Harlingen map area) display exceptionally well-developed accretionary ridges (figs. 19, 20). Clay dunes adjacent to the wind-tidal flats along Alazan Bay, for example, are generally elongate features aligned along the edge of low erosional bluffs bounding the tidal flats. Grass traps the clay that is blown westward or northwestward up the steep escarpment from the flats. Clay dunes associated with playa lakes are normally located on the northwest side of the playa; these dunes may be simple features or compound dunes exhibiting a complex geometry such as those associated with Cayo Lake (fig. 24). Clay dunes, therefore, are vertically or laterally accreted loessic structures with an adjacent source of pelletized clay particles.

Along the wind-tidal flats, quartz sand and silt may be mixed with the more abundant clay pellets. Shell fragments and artifacts may also occur in the dunes. Price (1958) has used artifacts to estimate the depositional rate of several clay dunes. The active clay dunes in the Kingsville area are Modern features.

Inactive clay-sand dune complexes.—Large relict grass- or brush-covered dunes in Kleberg County cover about 28 square miles. The dunes range up to 2 miles in length (figs. 12, 14) and exhibit 15 to 25 feet of relief. They are conical to elongate in shape, resembling haystacks; Price (1958) referred to these features as "conical dunes." Little information is available about the internal structure of the relict dunes, but sandy and sandy loam soils developed on and around the dunes suggest that the relict dunes are composed of both sand and silt. The Kleberg County dunes do not resemble the clay dunes associated with playa lakes and tidal flats. Rather, the relict dunes may be in situ features resulting from local, perhaps periodic, wind erosion of subjacent Pleistocene sand bodies controlled by cyclic changes in net rainfall. In other words, the dunes may represent repeated episodes of eolian deflation and stabilization by vegetation.

The dunes occur west of Cayo del Grullo and Santa Gertrudis Creek and within the Riviera loess sheet and rise directly from the loess plains. West of U. S. Highway 77, the dunes commonly overlie sandy ridges buried beneath the thin loess blanket. East of U. S. Highway 77 (fig. 14), the bases of dunes generally range from 20 to 30 feet above MSL and may be developed by wind deflation and in situ dune accretion. The sediment source may be Pleistocene distributary sands similar to those at this elevation north of Cayo del Grullo. The bases of relict dunes within the area northwest of Alazan Bay (fig. 12) occur at 15 feet above MSL and probably represent in situ dune deposition around nuclei composed of erosional remnants of Pleistocene deltaic deposits. Deflation of Pleistocene deltaic mud and sand exposed on the broad terrace between 5 and 10 feet above MSL provided the source of sediment required to construct the large dune complexes. The relict dunes of Kleberg County are late Holocene and Modern in age.

Loess sheets.—Two map units compose the Riviera loess sheet (fig. 21); the two units are delineated on the basis of the nature of the subjacent Pleistocene deposits. Together, these two units occupy about 350 square miles. The principal source of the loess is the Sarita eolian lobe to the southeast (fig. 21). The clay and silt particles are separated from the coarser sandy sediments during wind deflation in blowout areas associated with banner dunes. The finer particles are airborne and transported downwind to the northwest where the sediment slowly settles from the atmosphere. Locally within the loess sheet area, wind erosion and in situ dune deposition have produced a local supply of loessic sediment (see section on inactive clay-sand dune complexes).

West of U. S. Highway 77, loess deposits overlie sand and mud deposits of Pleistocene fluvial origin (Lissie Formation). The pre-loess topography west of the highway is gently rolling with eastward-trending low ridges underlain by Pleistocene sands. The loess sheet is thin and discontinuous, ranging from a few inches to several feet thick. Calichification of the loess and the subjacent Pleistocene deposits is locally severe; the caliche is locally mined for road construction material.

Except for an area south of the Kingsville Naval Air Station, the loess sheet east of U. S. Highway 77 overlies Pleistocene delta-plain muds and elongate sand-silt bodies (Beaumont Formation). The pre-loess topography east of the highway is flat, similar to the Pleistocene delta plain north of San Fernando Creek. Locally, the Pleistocene deposits are exposed where the loess thins or has been removed by sheetwash. Playa lakes and active clay dunes are common in the southern part of the area, especially south of Laguna Salada and Laguna de los Olmos. Pleistocene delta deposits are exposed along the banks of most small streams within the loess sheet and along low bluffs bordering Laguna Salada, Laguna de los Olmos, and the southern shore of Cayo del Grullo and Baffin Bay.

Artificial Units

Very little made land exists within the Kingsville map area, but subaerial and subaqueous spoil occupy a belt along the entire length of the Intracoastal Waterway. These units are shown on the *Environmental Geology Map*.

Made land.—The only made land mapped in the area occurs at Malaquite Beach Development within Padre Island National Seashore and in Laguna Salada, where oil well production platforms are constructed of landfill. Made land totals only 0.1 square mile of the map area.

Spoil.—Almost 18 square miles of spoil occur in the Kingsville map area. Most of the spoil has been derived from the original excavation and maintenance of the Intracoastal Waterway that extends from north to south across the map area along the axis of Laguna Madre (figs. 18, 19, 20). Some spoil deposits lie along smaller channels that have been dredged from the Intracoastal Waterway to oil and gas exploration-production sites within Laguna Madre or adjacent tidal flats. Small amounts of spoil remain along Yarborough Pass, which is an artificial pass between the Gulf and Laguna Madre that is now abandoned and partially filled.

Common practice is to pile dredged sediment from the channels along the margin of the cut. The natural environment is altered not only by the cut or channel but also by the discharge of disposed dredged sediments. Dredged spoil is further reworked and redistributed. On the wind-tidal flats of the Land-Cut Area, the spoil is eroded and redeposited mainly by rainfall sheetwash and, within Laguna Madre, by currents and waves. The area of wind-tidal flat and lagoon bottom that is covered by spoil is, therefore, increased markedly. Piling of spoil into mounds and ridges on the wind-tidal flats creates local artificial relief; on the lagoon bottom, it serves as a partial dam to current circulation. On the wind-tidal flats of the Land-Cut Area, the spoil heaps and reworked spoil have been eroded into gullies, and small alluvial fans have developed where the gullies discharge onto the flat. The ridge of subaerial spoil and the Intracoastal Waterway have subdivided the tidal flats into two distinctive areas: a western, slightly depressed flat that is poorly drained and an eastern flat that is well drained.

The three kinds of spoil mapped on the *Environmental Geology Map* and their areal extent are subaerial spoil heaps or mounds (1.4 square miles), subaerial reworked spoil (12.3 square miles), and subaqueous bay-bottom spoil (4.1 square miles).

Other map symbols.—A variety of symbols have been employed to portray the orientation of various environmental features. These include the orientation of transverse or barchan dunes within the banner dune fields and the position of beach ridges and wind-accretion ridges. The dune symbols illustrate only general orientation and not position of the dunes since the dunes continuously change position. Beach ridge symbols accurately depict these features as observed on aerial photographs. Serpulid reefs shown by dot symbols are compiled from various sources (*see* discussion of serpulid reefs in Subaqueous Bay- and Lagoon-Margin Environments); precise position of the symbol is limited by the accuracy of the source and the scale of the map.

SPECIAL-USE ENVIRONMENTAL MAPS

The eight *Special-Use Environmental Maps* included in this Atlas of the Texas Coastal Zone 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 that may be prepared by overlaying or combining any of the more than 150 map units of the environmental series (table 1). For example, the pipeline network of the Kingsville area can be compared directly with the distribution of active or potentially active surface faults to identify those areas where faulting might result in damage to a pipeline. Likewise, current land use can be compared to areas of hurricane flooding to determine kinds and amounts of land use affected. To facilitate direct use, certain map units are common to several of the maps. Statistical analyses of all units and features included on the *Environmental Geology Map* and the various *Special-Use Environmental Maps* are summarized in tables 3, 7, and 9-14.

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, and Group XII lands are a thin, discontinuous veneer on substrates with variable physical properties; other land groups 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 twelve major groups in the Kingsville 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 6 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 on table 6; these are by no means the only land 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 under-

Table 6. Evaluation of the natural suitability of physical properties groups for various coastal activities and land uses, Kingsville 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, abandoned channel-fill muds, mud-filled coastal lakes	–	–	–	0	–	–	0	–	–	+	–	+	+	0	+	–
Group II Dominantly sand, high to very high permeability, low water-holding capacity, low compressibility, low shrink-swell potential, good drainage, low ridge and depressed relief, high shear strength, low plasticity	Beach, foredunes, stabilized eolian blowouts, vegetated barrier flats, wind-deflation troughs and storm runnels, washover channels, Pleistocene barrier and strandplain sands	+	+	+	0	+	+	+	+	+	+	0	–	–	–	–	+
Group III Dominantly clayey sand and silt, low permeability, moderate drainage, moderate water-holding capacity, low to moderate compressibility and shrink-swell potential, level relief with local mounds and ridges, high shear strength	Pleistocene fluvial, distributary, and delta-front sands, including levee and crevasse splay deposits	+	+	+	+	+	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 coastal marsh; not mapped because of scale, narrow band along mainland shore	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
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	Inland marsh, fresh-water, ephemeral	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Group VI Wind-tidal flat and salt marsh, permanently high water table, very low permeability, high water-holding capacity, very poor drainage, very poor load-bearing strength, very high corrosivity, subject to frequent tidal inundations, high biologic productivity on salt marsh	Wind-tidal flat (salt marsh rare or absent)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 6 (continued)—

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 VIII Dominantly sand with clay dunes common; wind-tidal flat with properties similar to Group VI; clay dunes with properties similar to Group I; subject to intense wind deflation	Transitional wind-tidal flat and eolian sand sheet, clay dune accretion	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–
Group IX Mixed sand, silt, and clay with properties similar to Group III; active dunes predominantly clay, older dunes have higher sand and caliche content; subject to intense eolian processes	Clay-sand dunes, active, accretionary; clay-sand dunes, inactive, grass- or brush-covered; eolian accretionary bars and ridges on wind-tidal flats	+	+	+	+	+	0	0	0	+	0	+	0	0	+	0	0
Group X Dominantly sand with varying vegetative cover, moderate to very high permeability, low to moderate water-holding capacity, low compressibility, shrink-swell potential, and plasticity, high shear strength, fair drainage; active dune blowout areas subject to intense wind deflation	Eolian sand sheet with and without relief grain; sand sheet deflation area; moderately and well-stabilized dune and sand sheet; active dune blowout area	+	+	+	–	0	+	+	+	+	+	0	–	–	–	–	+
Group XI Dominantly friable sand; very high permeability; low compressibility, plasticity, and shrink-swell potential, high shear strength, good drainage; unstable due to migration and subject to intense eolian processes	Active dune complex in sand sheet area; back-island dune field, fore-island blowout dune, coppice dune field and/or sandflat	+	+	+	–	–	–	–	0	0	+	–	–	–	–	–	0
Group XII Dominantly silt and fine sand; thin and locally discontinuous veneer with physical properties similar to Group X; underlying substrate resembles Group I (deltaic muds) and Group III (calichified fluvial sands and silts, deltaic distributary sands)	Loess sheet over calichified Pleistocene fluvial units; loess sheet over Pleistcene deltaic mud and calichified sand	THIN VENEER OVER VARIABLE SUBSTRATE: USE WITH CAUTION															

*Compare to land resouce units and their suitability for various coastal activities and land uses (table 15).

ground installations, such as basements and tunnels, as well as the burial of cables and pipelines. Excavatability of the various land groups is controlled by degree of consolidation, presence of caliche, moisture content, and similar factors affecting ease of digging with conventional machinery. Use of lands for waste disposal includes septic-system waste disposal, solid-waste disposal, and unlined liquid-waste retention ponds on the land surface; different modes of waste disposal require different physical properties. Use of the land groups for surface water storage includes dams or dikes to impound water, unlined surface reservoirs (for example, stock tanks) fed by surface waters, and unlined surface reservoirs that intersect the ground-water table.

Principal physical groups and land areas outlined on the *Physical Properties Map* include dominantly clay and mud soils and substrates, sand soils and substrates, soils and substrates of clayey sands and silts, fresh- to brackish-water coastal marshes (not mapped because of map scale), inland fresh-water marshes, wind-tidal flats and rare salt marshes (too small to show on map) with frequent tidal inundation, made land and spoil, areas transitional between wind-tidal flat and the eolian sand sheet with clay dune accretion, active and inactive clay-sand dunes, other areas within the South Texas eolian sand sheet, unstable sand subject to eolian processes and migration of active dunes, and areas covered by a thin veneer of loess (silt) sediments. Statistics for the *Physical Properties Map* are shown on table 7.

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 6 and 7 in a qualitative manner only. Available test data within the Kingsville map area are too limited and too local in distribution to ascribe precise quantitative parameters to the various

Table 7. Areal extent, length, and number of individual environmental units shown on Physical Properties Map, Kingsville map area, Texas.† (Table pertains only to that part of each county occurring within the Kingsville map area. All values are in square miles unless otherwise indicated by symbol.)

SPECIAL USE ENVIRONMENTAL MAP UNITS	Brooks County°	Kenedy County°	Kleberg County°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Kingsville map area (excluding offshore area)	Percentage of Kingsville 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, channel-fill muds, mud-filled coastal lakes	0	0	82.3	–	82.3	3.5
GROUP II. Dominantly sand, high to very high permeability, low water-holding capacity, low compressibility, low shrink-swell potential, good drainage, low ridge and depressed relief, high shear strength, low plasticity. Geologic units include Modern barrier island sands (beach, foredunes, stabilized eolian blowouts, vegetated barrier flats, wind-deflation troughs and storm runnels, washover channels), and Pleistocene barrier-strandplain sands	0	21	16.2	–	37.2	1.6
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 Pleistocene fluvial-distributary (includes levee and crevasse splay) and delta-front sands, silt and local undifferentiated clay, delta-front facies may be covered by loess or mud veneer	0	0	122	–	122	5.3
GROUP IV. Coastal marsh, fresh to brackish, not mapped because of scale, narrow band along mainland shore	–	–	–	–	–	–
GROUP V. Inland marsh, fresh-water, ephemeral, alternately wet and dry, variable substrate, commonly mud, low to moderate permeability, moderate water-holding capacity, poor drainage, poor to moderate load-bearing strength, moderately high organic content, subject to flooding, locally thin mud may veneer sand substrate. Geologic units include fresh-water marsh and fresh-water marsh-filled wind deflation areas; local ephemeral fresh-water marsh in eolian blowout areas not mapped	0	0	12.2	–	12.2	0.5
GROUP VI. Wind-tidal flat, salt marsh rare or absent, sand with minor amounts of mud and algal mat laminations, alternatively submergent (0-2 feet) and emergent, unvegetated, subject to intense eolian transport of sand, local depressed areas with soft substrate, properties similar to Group II. Geologic units include several wind-tidal flat facies	0	160.3	29.6	–	189.9	8.2
GROUP VII. Made land and spoil, properties highly variable, mixed mud, silt, sand, and shell, reworked spoil commonly sandy and shelly with moderate sorting similar to Group III. Geologic units include subaerial spoil heaps or mounds, subaerial reworked spoil, subaqueous spoil, made land	0	15.8	5.1	–	20.9	0.9

Table 7 (continued)—

GROUP VIII. Transitional wind-tidal flat and eolian sand sheet, brief periods of tidal inundation alternating with longer sustained periods of wind deflation and clay-dune accretion, numerous clay dunes with properties similar to Group I, wind-tidal flat properties similar to Group VI, essentially an area of wind destruction of eolian sand sheet	0	65	0.5	–	65.5	2.8
GROUP IX. Clay-sand dunes and dune complexes, active and inactive, sparsely and heavily vegetated respectively, see Geologic map to differentiate dunes, mixed sand, silt, and clay with variable properties similar to Group III, older vegetated dune complexes have higher sand and caliche content, currently active dunes high in clay content Geologic units include inactive, brush-covered clay-sand dune complex, active, grass-covered clay-sand dunes, and eolian accretionary bars and ridges (rincons, potreros)	0.6	19.7	31	–	51.3	2.2
GROUP X. Eolian sand sheet, poorly to well stabilized with grass, brush, and live oaks, see Geologic map to differentiate vegetation cover, moderate to very high permeability, low to moderate water-holding capacity, low compressibility, low shrink-swell potential, good to fair drainage, high shear strength, low plasticity, shallow water table, flat to hummocky or ridge-like topography Geologic units include active dune blowout area, sand sheet with strong relict grain, sand sheet with no relict grain, sand sheet deflation area, moderately stabilized dune and sand sheet, and well-stabilized dune and sand sheet	10.3	1063	37	–	1110.3	47.9
GROUP XI. Active dune complex, sand, friable, very high permeability, low water-holding capacity, low compressibility, low shrink-swell potential, good drainage, high shear strength, low plasticity, unstable due to migration, local relief up to 30 feet Geologic units include active dune complex in sand sheet area, back-island dune field, fore-island blowout dune, and coppice dune and sand flats	0.05	75.3	13	–	88.35	3.8
GROUP XII. Loess sheet, silt and fine sand, thin and locally discontinuous, overlying fluvial or deltaic bay sand and mud, locally sandy near underlying Pleistocene channel bodies, loess variable thickness, properties similar to Group X, underlying non-eolian sediments resemble Groups I and III, engineering plans should involve consideration of depth of silt and sand and nature of subadjacent Pleistocene sediment Geologic units include sand sheet overlying deltaic facies and sand sheet overlying fluvial facies	1.7	54	300	–	355.7	15.3
Pit or quarry, commonly caliche-cemented fluvial and deltaic deposits■	0	10	8	–	18	–
Solid-waste disposal site, sanitary landfills, and open dumps■	0	1	3	–	4	–
Active or potentially active fault, based on lineament or grain displayed on aerial photographs▲	1	172	126	–	299	–

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 a 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

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.

Preliminary evaluation of the quantification of resource capability units in the Corpus Christi area (Kier and Bell, 1974; units derived in part from *Environmental Geology Map* of the Corpus Christi Atlas) indicates that this statistical review of engineering test data does generally distinguish land units. Direct extrapolation of numerical data from the Corpus Christi area to the physical properties groups of the Kingsville map area should be undertaken with caution, but a similar analysis of engineering test data in the Kingsville area would probably permit similar generalized quantification of these natural land units.

In addition to the major physical land types shown, principal aerial photographic lineations and potentially active faults are plotted. Current waste disposal sites, sanitary landfills and open dumps, and pits and quarries are shown on the map.

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 north of the Modern bay-estuary-lagoon system and Santa Gertrudis Creek. Materials represent deposits from overbanking fluvial and deltaic streams of Pleistocene age, as well as from mud-filled coastal lakes and mud-filled abandoned channels. Principal soils developed on these fine-grained substrates include clay soil types of the Victoria series—fine-grained and poorly drained soils.

Materials classed in this physical group have low permeability. Accordingly, they form secure hosts for several kinds of disposed wastes (table 6) 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 0.1 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, high to 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. In the Kingsville map area, Group I lands are a minor land type, in contrast to areas further north and east along the coast. Slightly more than 82 square miles, or only 3.5 percent of the Kingsville map area, are underlain by the land group. Large areas beneath the loess deposits east of U. S. Highway 77 (Group XII) are composed of Group I lands.

Group II Lands

Materials of this group are dominantly fine- to medium-grained clean sands. In the Kingsville area, these sands form a major part of the Modern Padre barrier island, including the beach, foredunes, stabilized eolian blowouts, washover channels, wind-deflation troughs and storm runnels, and vegetated barrier flats. They compose parts of an ancient (Pleistocene) Ingleside barrier island and strandplain system that extends southward from Encinal Peninsula (see Corpus Christi map area) to Point of Rocks on the north shore of Baffin Bay. For 7 or 8 miles north of Point of Rocks, eolian processes have modified the Pleistocene barrier strandplain; these lands are grouped predominantly in Group X lands. Principal soils developed on these sand deposits in the Kingsville map area are the Galveston, Mustang, and Rahal 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, perched aquifers. Occurrence of local ground-water supplies and the high permeability of sands make this group highly unsatisfactory for solid- or liquid-waste disposal (table 6). 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 limit the amount of ground-water recharge to the shallow aquifer. Approximately 37 square miles, or less than 2 percent of the Kingsville map area, are included in Group II lands. This is the principal land type of Padre Island and the Pleistocene barrier-strandplain system.

Group III Lands

Materials of Group III are dominantly clayey sands and silts. In the Kingsville area, these occur mainly as narrow, elongate belts situated in the coastal uplands north of Santa Gertrudis Creek and Alazan Bay. The narrow belts, aligned normal to the coast, represent ancient (Pleistocene) deltaic distributary channel silts and sands. Group III lands also extend roughly parallel to the coast just inland of the Pleistocene Ingleside barrier-strandplain system. These represent Pleistocene marine sheet sands and interbedded muds and silts of delta-front and reworked delta origin. Locally, these delta-front deposits are covered with a veneer of loess or lagoon-lacustrine mud. Soils developed on the older deltaic distributary and delta-front muddy sands and silts include principally the loam soils of the Clareville and Orelia series.

Earth materials classed in this physical group exhibit permeabilities that are moderately low but generally sufficient to host septic tanks (table 6). Suitability of sites for solid-waste disposal is marginal to poor. As a result of the admixture of clays in these sands and silts, water-holding capacity, plasticity, shrink-swell potential, and compressibility are higher than for the sand materials of Group II but are significantly lower than for 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 5 percent of the Kingsville map area (excluding offshore), covering approximately 122 square miles. These lands are restricted to the coastal uplands in the northern one-quarter of the mapped area. This land group underlies parts of the loess-covered plains of the South Texas eolian sheet (Group XII), especially west of U. S. Highway 77.

Group IV Lands

Lands in this physical group include fresh- to brackish-water coastal marshlands that occur in narrow bands generally associated with subaerial storm berms along the mainland shore (west shore of Laguna Madre and Baffin Bay shorelines). 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 6). 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 are not shown on the *Physical Properties Map* or the *Environmental Geology Map* because their limited areal extent cannot be accurately shown on maps of this scale.

Group V Lands

Lands included in this group embrace fresh-water marshes that are not subjected to salt-water flooding except during high hurricane-surge floods. The fresh-water marshes are developed in lowlands on Pleistocene delta-front sheet sand areas inland of the northwest shore of Alazan Bay. Also, fresh-water marsh develops in wind-deflation depressions formed on the Pleistocene Ingleside barrier-strandplain system north of Point of Rocks. Fresh-water marsh in the Kingsville area is ephemeral, being developed mainly during wet climatic periods and reduced or absent during more frequent dry conditions. From the standpoint of physical use, fresh-water marshes are comparable to the fresh- to brackish-water marshlands (table 6), the principal distinction being that the former are rarely subjected to salt-water inundation.

Lands classed in Group V are subject to fresh-water flooding, have depressed relief, and are characterized by a permanently high water table that essentially intersects the ground surface. Permeability is generally 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 occupy about 12 square miles of land in the Kingsville map area, making up about 0.5 percent of the total mapped area; areal extent is dependent on climatic conditions—wet periods favor development of fresh-water marsh, and dry periods result in areal decrease of marsh vegetation.

Group VI Lands

Lands classed in this group include wind-tidal flats and rare to absent salt marshes, both developed along the coastlines of the bays and estuaries and subject to frequent, periodic inundation by salt water. 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 thus subject to a greater impact by wave activity. Except for a narrow band of salt marsh along segments of the bay and lagoon shorelines, this marsh is rare to absent in the mapped area.

Wind-tidal flats, the products primarily of wind-generated tides, are well-developed in the Kingsville map area along the back side of Padre Island, across Laguna Madre in the Land-Cut Area, in lowlands around the bay shore, and at the mouth of the major drainages entering the bays and estuaries. Most of the local tidal flats are barren sandflats that support little or no vegetation. Some mud is also deposited in the wind-tidal flat area by the small creeks draining the uplands and from suspended sediment in flood tides that are ponded within depressed areas of the flats. Algal laminations are common in the shallow subsurface layers reflecting the frequent development of algal mats in response to flooding by tidal inundation. Following submergent periods, these areas are subject to desiccation and are then exposed to intensive wind activity and eolian transport of the dried surface sediment composed of sand- and silt-sized clay pellets. Depressional areas on the wind-tidal flats, which locally accumulate muddy sediment, tend to remain soft and pond water that may reach extreme hypersalinities. Except for storm-generated tides, wind tides are actually small, 18 to 24 inches, but extensive low-lying areas are subject to wind-tidal inundation in the Kingsville map area. Wind-tidal flats cover about 190 square miles, or more than 8 percent of the total mapped area. Lack of stabilization and repeated flooding of these lands preclude most types of physical use.

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 and several tributary channels dredged to provide access to oil well sites. Small areas of made land occur at Malaquite Beach Development within the Padre Island National Seashore and at oil well pads built into Laguna Salada. Physical properties of spoil and made land are highly variable, dictated in part by the kind of natural material dredged or utilized (table 6). 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 21 square miles or 0.9 percent of the map area.

Group VIII Lands

Lands included in this category include those lands transitional between the wind-tidal flats and the eolian sand sheet. Wind tides occasionally flood these lands to very shallow depths, but more commonly the lands experience long, dry periods characterized by intense wind deflation and accretion of clay dunes. Accordingly, physical properties of these lands are variable—areas of clay-dune accretion are typically similar to Group I lands, whereas the sandy interdune and wind-tidal flat areas are similar to Group VI lands. Because of the intense eolian activity (this is essentially an area of destruction of the eolian sand sheet) and the occasional salt-water flooding by wind tides, Group VIII lands are not suited to most land uses (table 6). These transitional lands occupy more than 65 square miles or almost 3 percent of the Kingsville map area.

Group IX Lands

Materials of Group IX are dominantly a mixture of fine sand, silt, and clay with physical properties similar to Group III lands. Group IX lands represent both active and inactive clay-sand dunes formed where eolian processes actively erode sand- and silt-sized clay fragments formed on the desiccated surfaces of occasionally flooded lowlands located just upwind of the dunes. Inactive clay-sand dune complexes are stabilized by extensive grass and brush vegetation and may be partially calichified. Active dune complexes are predominantly clay with limited vegetation development. Soils developed on clay-sand dunes are of the Point Isabel series.

Group IX lands characterize only the surface; substrate properties may be highly variable. Hummocky topography and variable substrate may preclude most land uses, though physical properties appear to favor most kinds of construction (table 6). Presently inactive clay-sand dune complexes are unsuitable for most uses.

Group IX lands comprise about 51 square miles or slightly more than 2 percent of the mapped area.

Group X Lands

Group X lands include those lands in the Kingsville map area that are part of the eolian sand sheet not characterized by active dune migration. These lands are variously covered with vegetation and thus are poorly to well stabilized with live-oak mottes, brush, and grasses. Physical properties that generally favor use of these lands for road construction include high shear strength, low shrink-swell potential, low compressibility, and low plasticity (table 6). Further, these lands appear suitable for most foundation construction and shallow subsurface installations of various kinds. Because of their high permeability and low water-holding capacity, these lands are rarely suitable for solid- or liquid-waste disposal.

Locally within Group X lands, the sandy substrates may grade into silty deposits with decreased permeability and greater compressibility. Similarly, where Group X deposits are thin, subjacent Pleistocene deposits may exhibit variable physical properties; in these areas, Groups X lands are similar to Group XII lands.

Group X lands are the principal land type in the Kingsville map area, covering over 1,110 square miles or almost 48 percent of the mapped area. Soils developed in these sparsely to well-vegetated eolian sand areas are the fine sandy soils of Sarita, Nueces, and Falfurrias series. Principal current use of these lands is for range and pasture land. Units included in these lands range from active dune blowout areas (barren, little to no vegetation) to well-stabilized dune complexes covered by live-oak mottes. Group X lands are not particularly well drained due to a lack of integrated drainage—a reflection of the hummocky to ridgelike topography.

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 gulfside of Padre Island (fore-island blowout dunes) and along the landward side of the island as large back-island dune fields and coppice dunes and sandflats. On the eolian sand sheet west of Laguna Madre, the active dune areas are included in Group XI lands. 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 (table 6). Group XI lands comprise almost 4 percent of the Kingsville map area, totaling more than 88 square miles.

Group XII Lands

The second most extensive land type in the Kingsville map area is the region covered by a thin veneer of silt- and fine sand-sized windblown sediment—an extensive loess sheet developed south and west of Kingsville between Olmos and Santa Gertrudis Creeks. Underlying substrates include Pleistocene fluvial sands and silts lying west of U. S. Highway 77 and deltaic muds, silts, and sands lying east of the highway. Though Group XII physical properties and resulting limitations on land use are similar to Group X, the underlying substrate is characterized by physical properties similar to Groups I and III. Plans that involve depths below the loess veneer should consider the physical properties of the Pleistocene substrate.

Group XII lands cover almost 356 square miles or over 15 percent of the mapped area. Current land use is mainly range and pasture land but crop farming is also common. Principal soils developed on the loess veneer are the fine sandy loam and sandy clay loam soils of the Delfina and Nueces series.

Potential for 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 a report by 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. Land-surface subsidence and surface faulting are not presently major problems in the Kingsville map area.

Land-surface subsidence.—Land-surface subsidence is closely related to water-level declines (decline of the piezometric surface) in the upper Coastal Zone (Brown and others, 1974; Gabrysch and Bonnet, 1975). Monitoring of water levels in selected wells in the Kingsville area between 1932-33 and 1968-69 (Shafer and Baker, 1973) shows declines of the piezometric surface in excess of 200 feet (fig. 27). Pumping of ground water for municipal use accounts for the sharpest water-level decline; industrial pumping for a gas plant located near the Jim Wells-Kleberg county line (off the map) also causes significant water-level decline (Shafer and Baker, 1973). In the upper Coastal Zone, ground-water withdrawal of this magnitude would generally cause measurable (more than 0.2 feet) land-surface subsidence. Data presently available do not indicate measurable subsidence in the Kingsville area.

Potable ground-water supplies in the Kingsville area are withdrawn from the Pliocene Goliad Sand—a deep, consolidated, high-sand aquifer. Low clay content and consolidated nature of the Goliad aquifer mitigate processes of clay dewatering and subsequent load adjustment that are common in the Galveston-Houston area. In addition, volume of ground water withdrawn and ultimately available for withdrawal in the Kingsville area is markedly less than in the upper Coastal Zone.

Although subsidence is caused predominantly by ground-water withdrawal, local subsidence may result from other activities. Oil production and related withdrawals of water and sand have resulted in subsidence at Goose Creek oil field (Pratt and Johnson, 1926) and in the Corpus Christi area. Sulfur production has also caused local subsidence (Sheets, 1947; Deere, 1961). In addition, proposed production of potential geothermal resources in the Coastal Zone may result in fluid withdrawals on a scale that may cause eventual subsidence of the land surface (Kreitler, 1976).

Surface faulting.—Approximately 300 linear miles of aerial photographic lineations occur within the Kingsville map area. These lineations are undoubtedly of structural origin and probably represent faults or joints and fractures that may become faults. No active surface faults are known in the Kingsville map area. The most severe area of known active surface faulting in the Texas Coastal Zone is in the Houston area and at least one active fault occurs in the Corpus Christi area (Brown and others, 1974). Studies in the upper Coastal Zone (Kreitler, 1976) demonstrate a close relationship among trends of linear anomalies recognized from aerial photographs, known inactive and active surface faults, and land-surface projections of subsurface faults. These associations suggest that all of these features are related and 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, such as fluid withdrawal, cause increased frequency and activity of surface fault movement (Brown and others, 1974). In light of the reasons discussed previously to explain the lack of land-surface subsidence in the Kingsville area, it seems likely that activation of surface faults due to fluid withdrawal will not be a major problem in the mapped area.

Aerial photographic lineations are also expressed by topographic anomalies (compare lineations shown on *Physical Properties Map* with *Topography and Bathymetry Map*) and by the distribution of active dune complexes and deflation areas (fig. 28). Topographically expressed lineations may be related to scarps developed parallel to trends of presently inactive surface faults. A major lineation expressed by topography appears to extend eastward from Gyp Hill dome near Falfurrias (west of the map area) to the Cayo Lake area. A relationship between this surface lineation and a fault associated with salt-dome tectonics is suggested, as has been demonstrated in the upper Coastal Zone (Kreitler, 1976).

In the Kingsville area, there is also a suggested relationship between the distribution of active dune complexes (and related deflation-interdune areas) and aerial photographic lineations (fig. 28). Proximity of active dune complexes to lineations suggests that the lineations in some way control the position of active dunes. A possible explanation is that linear anomalies are surface expressions of subsurface features that act as hydrologic barriers to control the relative level of the ground-water table. Areas where the ground-water table is higher are more susceptible to limited deflation as wind processes are only effective down to the shallow depth of the wet sands. Areas with lower relative ground-water levels have better drainage, and commonly dry sands are more susceptible to eolian processes. Prominent lineations can be recognized in the Candelaria Lake-Santa Rosa Ranch deflation complex where boundaries between deflation areas (high water table, occasionally flooded, poor drainage) and active dune blowout and sand sheet areas (low water table, good drainage) are distinct lineations generally *not* parallel to prevailing wind regimes.

The *Physical Properties Map* of this Atlas shows the location and distribution of approximately 300 miles of linear surface anomalies. Some of these lineations appear to be surface expressions of subsurface features (hydrologic barriers) controlling relative

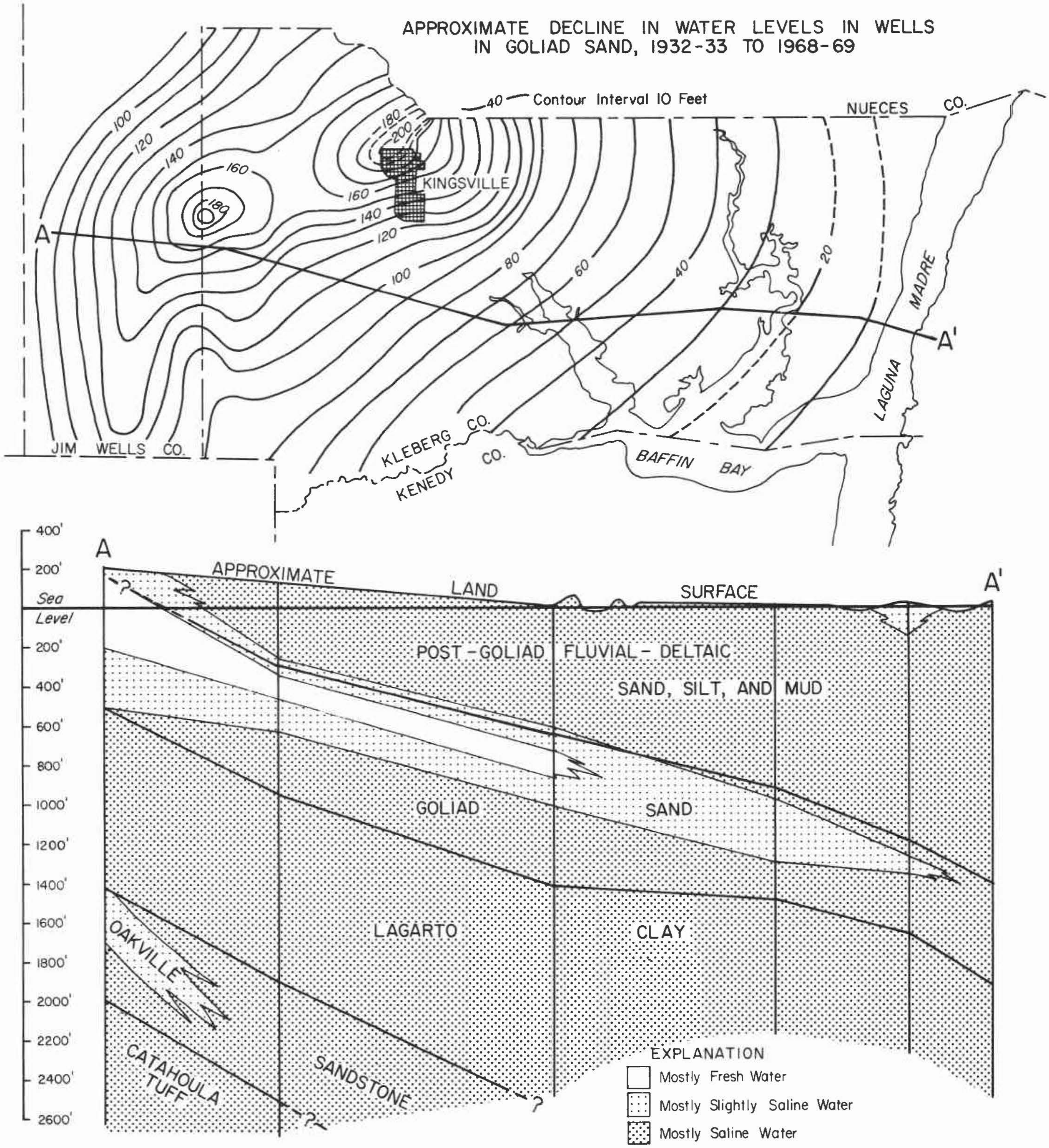


Figure 27. Piezometric decline in the Goliad aquifer, Kingsville area. Note the cone of depression caused by municipal wells in Kingsville. Cross section illustrates the distribution of fresh water within the area. After Shafer and Baker (1973).

ground-water levels. Some lineations may be related to subsurface faults or inactive surface faults; activation of these faults could occur with significant fluid withdrawal, and location of such faults would 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 should either be planned to avoid areas near these linear features or designed and engineered to accommodate potential movement and displacement.

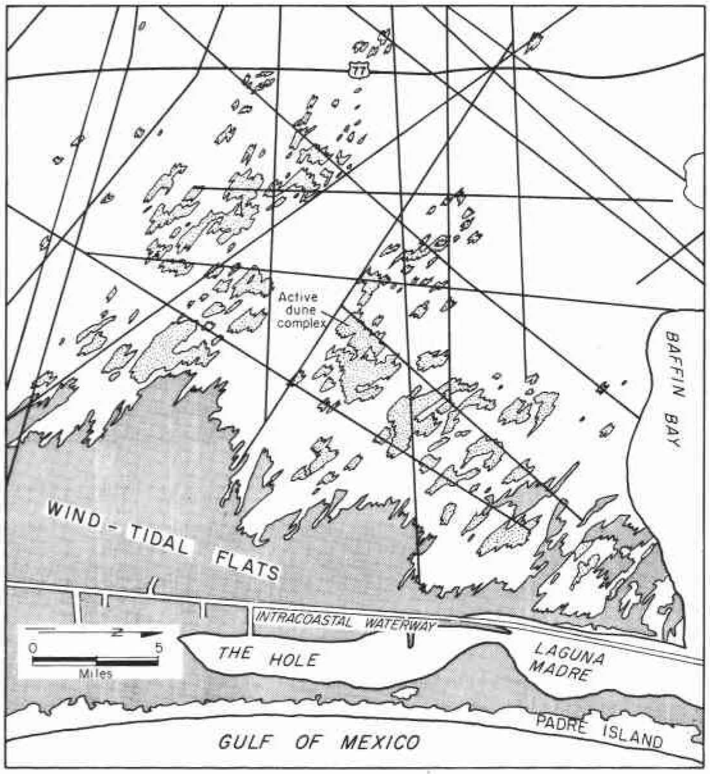


Figure 28. Possible effect of ground water on the occurrence and distribution of banner dunes. Aerial photographic linears of structural origin may divide the sand sheet into distinctive, shallow hydrologic systems. Sand within areas having deeper water tables may be more prone to blowout and dune migration than areas with shallow water tables.

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 Kingsville map area include placement of solid wastes in dumps or landfills and disposal of human wastes through septic fields.

Requirements for safe disposal of solid and liquid wastes differ. Solid wastes generally require confinement to avoid leakage of leachate into nearby surface- or ground-water supplies until normal chemical and bacterial processes can mollify harmful materials. Solid-waste disposal should occur in sites composed of impermeable materials such as clay soils and substrates. Surface topography and 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 in septic field systems, by direct subsurface disposal, and by dumping wastes offshore. Septic field 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. Fine sand, silt, and clay mixtures in sediments generally provide the necessary moderate transmission of liquid waste in addition to 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 twelve basic land types discussed previously may be grouped into four main solid-waste suitability groups; suitability for liquid-waste disposal can also be evaluated within these four main groups.

From a physical standpoint (table 6), lands mapped as Group I on the *Physical Properties Map* provide good and generally secure hosts for solid-waste disposal; lands graded as Groups III and IX constitute hosts of only marginal suitability that should be carefully tested and monitored if utilized. Lands classed as Groups II, X, and XI have high permeabilities and very little capacity to hold disposed solid wastes securely. Wetlands of Groups IV, V, VI, and VIII 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; similarly, Group XII lands constitute a thin, discontinuous veneer of silt and fine sand over substrate with varying physical properties and also require thorough testing and evaluation prior to use for waste disposal. Site-specific studies should be undertaken to verify the suitability of each current and proposed disposal site.

Group I materials, chiefly mud and clay soils and substrates, provide secure sites for solid-waste disposal and will eliminate most problems of leachate contamination of surface and ground waters. Excavated clays provide excellent backfill or impermeable cover for disposed wastes. A principal limitation of lands in this group is their normally flat to depressed relief. Proper siting and grading can reduce ponding over filled areas. The high plasticity of these materials may produce some difficulty in 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, X, 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. Groups II and X 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 in many areas of the Texas Coastal Zone and are commonly used for waste disposal. Such abandoned pits preclude the expense of excavation as sandy backfill is available and easily bulldozed, and the 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 Groups III and IX on the *Physical Properties Map* consist of clayey sand and silty soils and substrates. They are normally less permeable than sands of Groups II, X, and XI but more permeable than clays of Group I. Groups III and IX lands are generally suitable for liquid-waste disposal such as septic field systems; moderate permeability and reactive materials allow for modification of effluent over short lateral distances. However, these lands are only marginally suitable for solid-waste disposal. Careful testing, monitoring, and maintenance are necessary to locate proper solid- and liquid-waste disposal sites in these lands.

Wetlands of the Kingsville area (Groups IV, V, VI, VIII), including fresh- to brackish-water coastal marshes (not mapped because of scale), extensive wind-tidal flats, and inland, ephemeral fresh-water marshes, make poor sites for waste disposal because of permanently high water tables and frequent flooding.

Made or reclaimed lands and areas of spoil (Group VII) are characterized by variable physical properties. Group XII lands are a veneer of silt and fine sand sediment over Pleistocene fluvial and deltaic sands, silts, and muds; proper use of these lands should involve evaluation of the physical properties of the variable substrates beneath the loess cover. Thus, Groups VII and XII lands should be used with caution—adequate site testing and evaluation should precede actual use.

Within the Kingsville map area, four solid-waste disposal sites, including sanitary landfills and open dumps, were in operation in 1968. Location of these sites is based on a 1968 survey by the Texas State Health Department. Of these solid-waste disposal sites, one is within host materials that are physically secure, according to the evaluation of physical properties units. The three remaining sites are located in lands constituting a host of unknown quality—Group XII lands characterized by a thin veneer of loess. These three sites may intersect the Pleistocene fluvial and deltaic substrate, and their suitability should be determined by the characteristics of these subjacent deposits. Waste disposal sites in these lands should be preceded by thorough testing and evaluation. 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 throughout the Texas Coastal Zone.

Within the Kingsville map area, only 3.5 percent of the total mapped area provides adequate and secure natural hosts for waste disposal. About 7.8 percent of the area is classed as marginal from a physical standpoint, and nearly 65 percent constitutes poor disposal potential because of a high water table, high soil and substrate permeability, or a potential for hurricane-surge flooding. About 16 percent of the mapped area contains hosts of questionable quality which should be extensively tested and evaluated before use as waste disposal sites. Secure hosts are located near Kingsville, the principal population center. Secure lands occur north of Santa Gertrudis Creek and Alazan Bay on the coastal uplands.

It should be emphasized that secure and favorable lands are also generally those of higher economic value as agricultural lands. On the other hand, much of 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. A comparison of bay-line erosion or deposition displayed on the *Active Processes Map* with physical substrate types shown on the *Physical Properties Map* indicates that shorelines cut into sandy substrates are less stable (subject to erosion or deposition) than those cut into mud and clay 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 Kingsville map area. These include: (1) subaqueous environments and assemblages of the bays, estuaries, lagoons, 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, but including wind-tidal flat and transitional areas which are frequently flooded by wind-driven tides. 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 relict serpulid reefs and inland fresh-water marsh. 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 well-stabilized eolian dune complexes support extensive areas of live-oak mottes and typical "motte-grasses" (Johnston, 1955).

Figure 29 is a schematic representation of three transects across principal subaqueous and subaerial environments in the Kingsville map area. Transect A can be visualized as a cross section along a line from Laguna Madre south of the Land-Cut Area onto the eolian sand sheet. Transect B represents a cross-sectional view from Laguna Madre across the wind-tidal flats through transitional lands and up onto the eolian plain. Transect C is an idealized profile across Padre Island and into Laguna Madre. No horizontal scale is suggested in these illustrative diagrams; vertical scale is in feet. The three transects (fig. 29A, B, C) illustrate general lateral relationships among the various biologic assemblages and their position relative to land elevation. Refer to table 8 for a more complete listing of the flora and fauna characteristic of the various environments; figure 29 can aid in visualizing their spatial relationships.

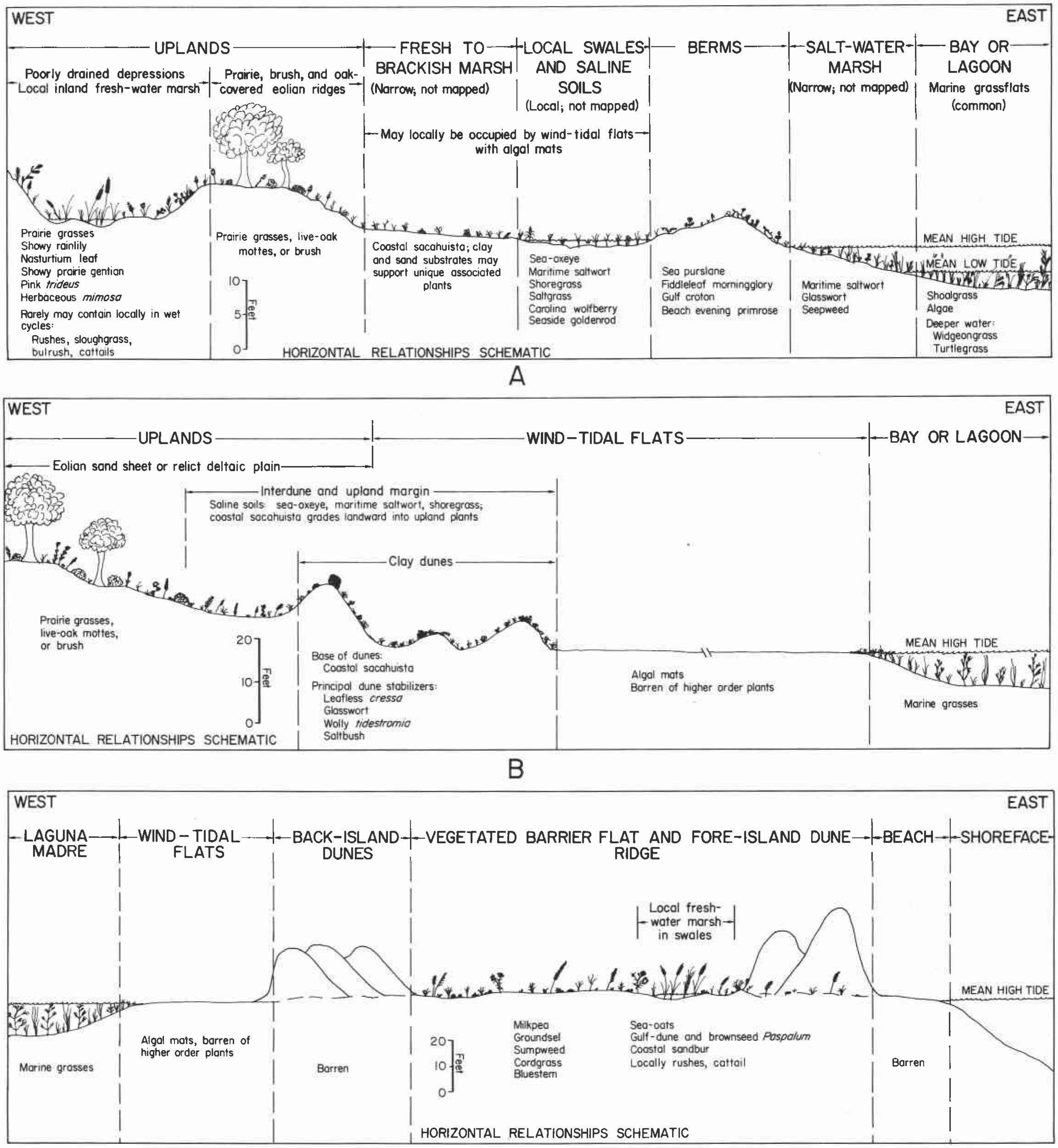


Figure 29. Profiles of plant communities within environments extending from bay, lagoon, or Gulf to coastal uplands or Padre Island. (A) Profile characteristic of mainland side of Laguna Madre. (B) Profile typical of mainland bounded by broad wind-tidal flats. (C) Profile across Padre Island. Plant morphology is highly schematic. In part after Johnston (1955).

Table 8. Common macro-biologic assemblages within Texas coastal environments, Kingsville map area, Texas.*

SUBAQUEOUS, PRINCIPALLY BENTHONIC ASSEMBLAGES

SHELF (INNER) AND LOWER SHOREFACE:
Atrina, Dinocardium, Dosinia, Aequipecten, Tellina, Pecten (clams); *Murex, Architectonica, Phalium, Terebra, Oliva* (snails); *Callianassa* (mud shrimp); *Luidia* (starfish); *Mellita* (sand dollar)

UPPER SHOREFACE:
Donax (clam); *Olivella, Terebra, Polinices* (snails); *Luidia* (starfish); *Mellita* (sand dollar)

BAY AND LAGOON MARGIN:
Anomalocardia, Mulinia (clams); sparse *Diplanthera (Halodule) wrightii;* unmapped salt marsh occurs locally, including *Batis maritima* (saltwort), *Salicornia* spp. (glasswort), and *Suaeda* spp. (seepweed)

HYPERSALINE GRASSFLATS:
Anomalocardia, Tellina, Mulinia (clams); *Cerithium* (snail); *Diplanthera (Halodule) wrightii* (shoalgrass), *Ruppia maritima* (widgeongrass), *Thalassia testudinum* (turtlegrass); blue-green algae

RESTRICTED HYPERSALINE BAY AND LAGOON MARGIN:
Anomalocardia, Mulinia (clams); *Balanus* (barnacle); sparse marine grass, some algae

RESTRICTED HYPERSALINE BAY CENTER:
No vegetation; fauna rare to absent, marginal areas may be occupied by clams typical of hypersaline bays, such as *Anomalocardia* and *Mulinia*; one snail, *Acteon*, is also reported; central part of bay without fauna or flora except for rare foraminifers

ENCLOSED HYPERSALINE BAY OR LAGOON CENTER:
Anomalocardia, Tellina, Mulinia (clams); *Cerithium* (snail); sparse *Ruppia maritima* (widgeongrass) and *Thalassia testudinum* (turtlegrass)

SUBAQUEOUS SANDFLAT:
Faunal assemblage similar to Enclosed Hypersaline Bay or Lagoon Center

SERPULID REEFS AND INTERREEF SHOALS:
Relict serpulid reefs—composed of "colonies" of calcareous tubes formed by annelid worms; reef-associated forms include *Brachidontes* (clams), *Menipes* (stone crabs), and *Balanus* (barnacle); green algae

SAND AND OOLITE SHOAL:
Largely barren; rare *Anomalocardia* (clam)

SUBAQUEOUS AND SUBAERIAL SPOIL:
Variable assemblages

FRESH- TO SALINE-WATER BODIES, PONDS, AND PLAYAS:
Blue-green and red algae; locally, floral assemblage similar to assemblage in Poorly Drained Depressions (mud substrate)

SUBAERIAL, PRINCIPALLY FLORAL ASSEMBLAGES

BEACH:
Donax, Dinocardium (clams); *Ocypode* (ghost crab); *Uniola paniculata* (sea-oats); halophytes

VEGETATED BARRIER FLAT, FOREDUNE RIDGE, AND STABILIZED BLOWOUTS:
Uniola paniculata (sea-oats), *Paspalum monostachyum* (gulf-dune paspalum), *P. plicatalum* (brownseed paspalum), *Senecio* spp. (groundsel), *Andropogon* spp. (bluestem), *Galactia* spp. (milkpea), *Spartina* spp. (cordgrass), *Cenchrus incertus* (coastal sandbur), *Iva* spp. (sumpweed); local fresh-water marsh includes *Juncus* spp. (rush) and *Typha* spp. (cattail)

WASHOVER CHANNEL AND FAN, WIND-DEFLATION TROUGH AND STORM RUNNEL:
Largely barren; local algal mats, scattered ponds, and fresh-water marsh (rush, cattail)

ACTIVE DUNES (COPPICE DUNE, BLOWOUTS, AND BACK-ISLAND AND INLAND DUNES):
Largely barren; small rodents, snakes

SANDFLATS (WIND-TIDAL FLATS):
Blue-green and red algae; remainder largely barren

EOLIAN RIDGES AND ACTIVE CLAY-SAND DUNES:
Spartina spartinae (coastal sacahuista), *Cressa nudicaulus* (leafless cressa), *Salicornia* spp. (glasswort), *Atriplex* spp. (saltbush), *Tidestromia lanuginosa lanuginosa* (woolly tidestromia), *Monanthochloe littoralis* (shoregrass), *Batis maritima* (saltwort), *Borrichia frutescens* (sea-oxeye); snakes

BERMS ALONG BAY-LAGOON MARGIN:
Croton punctatus (beach tea), *Sesuvium portulacastrum* (sea purslane), *Ipomoea stolonifera* (fiddleleaf morningglory), *Oenothera drummondii* (beach evening primrose); local swales contain salt- to brackish-water marshes, including *Solidago sempervirens mexicana* (seaside goldenrod), *Lycium carolinianum* (Carolina wolfberry), and other salt-tolerant plants—*Monanthochloe, Batis, Andropogon, Distichlis spicata* (seashore saltgrass)

AREAS OF INTENSE WIND-DEFLATION AND WIND-TIDAL ACTIVITY:
Blue-green and red algae; salt-tolerant grasses including *Spartina spartinae* (coastal sacahuista), *Salicornia* spp. (glasswort), *Atriplex* spp. (saltbush)

INLAND FRESH-WATER MARSH:
Juncus spp. (rush), *Typha* spp. (cattail), *Scirpus* spp. (bulrush), *Spartina pectinata* (sloughgrass); small mammals, snakes, fowl; some areas support floral assemblages as listed under Poorly Drained Depressions (mud substrate)

PRAIRIE GRASSLANDS:
Buchloe dactyloides (buffalograss), *Chloris andropogonoides* (slimspike windmillgrass), *Hilaria belangeri* (creeping mesquite), *Panicum filipes* (filly panicum), *Schedonnardus paniculatus* (tumblegrass), *Aristida roemeriana* (Roemer threeawn), *Desmanthus virgatus depressus* (bundleflower), *Euphorbia albomarginata* (whitemargin euphorbia); *Prosopis* spp. (mesquite), *Opuntia* spp. (pricklypear), *Acacia farnesiana* (huisache), chaparral; fowl, mammals

POORLY DRAINED DEPRESSIONS (MUD SUBSTRATE):
Prairie grasses similar to Prairie Grasslands; *Zephyrantes pulchella* (showy rainlily), *Eryngium nasturiifolium* (nasturtiam leaf), *Tridens conjestus* (pink tridens), *Eustoma russellianum* (showy prairiegenlian), *Mimosa strigillosa* (herbaceous mimosa); rare fresh-water marsh plant assemblages during wet climatic cycles

LOOSE SAND AND LOESS PRAIRIES:
Andropogon scoparius littoralis (seacoast bluestem), *Cenchrus pauciflorus* (mat sandbur), *Chloris cucullata* (hooded windmillgrass), *Bracharia ciliatissima* (fringed signalgrass), *Eragrostis oxylepis* (red lovegrass), scattered live-oak (*Quercus virginiana*) mottes; local fresh-water marsh in low-lying areas (see Inland Fresh-Water Marsh); rodents, mammals, snakes, fowl

POORLY DRAINED DEPRESSIONS (SAND SUBSTRATE):
Transitional with floral assemblage of Loose Sand and Loess Prairies; in addition, *Cephalanthus occidentalis* (common buttonbush), *Chloris petraea* (stiffleaf chloris), *Panicum sphaerocarpon* (roundseed panicum), *Cyperus aristatus* (bearded flatsedge), *Juncus* spp. (rush), *Mimosa strigillosa* (herbaceous mimosa), and several others

LIVE-OAK MOTTES:
Quercus virginiana (live oak), *Vaseyochloa multinervasa* (Texasgrass), *Sporobolus purpurascens* (purple dropseed), *Trichoneura elegans* (silveusgrass), *Paspalum ciliatifolium* (fringeleaf paspalum), *Digitaria texana* (Texas crabgrass), *Cenchrus pauciflorus* (mat sandbur), *Metastelma barbigerum* (thicket threadvine), *Vitis mustangensis* (mustang grape), *Malvaviscus drummondii* (Drummond waxmallow), *Pterocaulon virgatum* (wand blackroot), *Mentzelia texana* (Texas mentzelia), *Yucca treculeana* (trecul yucca), *Sapindus drummondii* (western soapberry); game (deer, rabbit), fowl

BRUSHLAND:
Prosopis juliflora (arboreal mesquite), *Celtis pallida* (spiny hackberry), *Yucca treculeana* (trecul yucca), *Xanthoxylum fagara* (lime pricklyash), *Opuntia* spp. (pricklypear), *Karwinskia humboldtiana* (coyotillo), *Forestiera angustifolia* (narrowleaf forestiera), *Trichloris pluriflora* (fourflower trichloris), *Trichachne insularis* (sourgrass), *Sporobolus wrightii* (big sacaton), *Echinocactus setispinus* (hedgehog cactus); game (deer, rabbit), fowl

FLUVIAL WOODLAND:
Celtis laevigata (sugar hackberry), *Ehretia anacua* (anaqua), *Ulmus crassifolia* (cedar elm), *Clematis pitcheri* (pitcher clematis), *Aster dumosus* (bushy aster), *Prosopis juliflora* (arboreal mesquite), *Acacia farnesiana* (huisache); small mammals, fowl

MADE LAND:
Variable assemblages; only locally vegetated

*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.

The *Environments and Biologic Assemblages Map* is not intended to be a biologic assay of the area but rather to show areal distribution of the type and number of major environments defined by dominant biologic assemblages (table 8). 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 9. Principal sources of data include Johnston (1955) on subaerial flora and Parker (1959, 1960) on subaqueous fauna. Other sources of biologic data are listed in table 2.

Subaqueous Environments and Biologic Assemblages

A total of 13 natural environments and biologic assemblages is delineated for the Kingsville map area (tables 8, 9). 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 relatively high-energy environments associated with shoal areas over reefs and along bay margins; (3) a variety of hypersaline environments within the interior bays and estuaries; and (4) landlocked, fresh- to brackish-water coastal ponds.

The largest variety of environments occurs in the bays and estuaries; faunal and floral diversity, however, is not very great in these hypersaline and frequently turbid waters. These may be considered broadly as: (1) enclosed hypersaline bay environments away from tidal interchange and with relatively restricted circulation; (2) restricted hypersaline bay environments of Baffin and Alazan Bays, Laguna Salada, Laguna de los Olmos, Cayo de Infiernillo, Cayo del Grullo, and Cayo de Hinoso; (3) enclosed-bay and hypersaline bay environments where reef development is prominent (fig. 17); and (4) marginal areas made up chiefly of bay-margin shoals and grassflats (figs. 17, 18). Subaqueous and subaerial spoil is included as the only man-made unit on the map; biologic assemblages developed on spoil depend to a great extent on the age of the spoil and its position relative to a natural environment.

Subaerial Environments and Biologic Assemblages

A total of 17 subaerial or on-land environments and associated biologic assemblages is delineated in the Kingsville map area (tables 8, 9). These are defined chiefly on the basis of floral assemblages or vegetation, though most are coextensive with distinct faunal assemblages, including mammals, reptiles, and birds.

On-land biologic assemblages include a great diversity of floral groups, many of which are unique to this area. Much of the information concerning the on-land flora in the region is based on research by Johnston (1955). General assemblages within the Kingsville region can be grouped broadly into lowland vegetation, upland vegetation, vegetation associated with eolian sand and loess deposits, and vegetation associated with the coastal barrier island. A major type of lowland vegetation of the Coastal Zone is the wetlands. In the Kingsville map area, only the ephemeral fresh-water marshes that occur on coastal lowlands and within wind-deflation depressions are extensively developed (figs. 12, 13). A distinct assemblage of water-tolerant wooded vegetation is sparsely developed along the drainage of the small streams in the northwest part of the Kingsville 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 north of Alazan Bay and Santa Gertrudis Creek, support an extensive prairie grassland. South of Baffin Bay and Santa Gertrudis Creek, the coastal uplands are characterized by extensive wind-deposited sand and loess sheets. Vegetation in these areas includes distinctive grasses, prominent live-oak mottes, and various scrub and brush assemblages.

The vegetation of Padre Island comprises a distinct complex. Inland from the beach and backbeach, which are largely barren, is the well-developed vegetated barrier flat; primary vegetation is salt-tolerant grasses. This vegetated barrier flat is bounded on the bayside by largely barren active dune complexes which are, in turn, bordered by extensive, mostly barren wind-tidal flats. See table 8 for a listing of plants found on the coastal barrier island in the Kingsville map area.

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

Table 9. Areal extent of individual units shown on Environments and Biologic Assemblages Map, Kingsville map area, Texas.† (Table pertains only to that part of each county occurring within the Kingsville map area. All values are in square miles unless otherwise indicated by symbol.) See tables 3 and 7 for conversion values.

SPECIAL USE ENVIRONMENTAL MAP UNITS	Brooks County°	Kenedy County°	Kleberg County°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Kingsville map area (excluding offshore area)	Percentage of Kingsville 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 organisms, principally mollusks, crustaceans, and echinoderms, depth >30 feet	–	–	–	–	–	–
Lower shoreface, open marine, normal salinity (35‰), moderate wave action, sand, silt, and mud, infauna dominant, mud shrimp, mollusks, depth 15 to 30 feet	–	–	–	17.6	–	–
Upper shoreface, surf zone, shifting sand, normal salinity (35‰), mollusks, sand dollars, starfish, crustaceans, depth low tide to 15 feet	–	–	–	22.4	–	–
Bay and lagoon margin, seasonally hypersaline shoal water bordering mainland, sand, some shell, oolites, shifting sandbars, sparse grass, algae, salinity 30 - 80‰, temperature 12-43°C, mollusks, low diversity, depth <3 feet; unmapped salt marsh along shore	0	1.4	1.4	–	2.8	0.1
Grassflats, hypersaline, sparse to moderate grass, sand, shell, and muddy sand, salinity 30-80‰, temperature 12-43°C, abundant mollusks, low diversity, algae, depth <4 feet	0	10	18	–	28	1.2
Restricted hypersaline bay and lagoon margin, away from tidal influence, rare river input, local oolites, muddy sand, salinity 5-80‰, normally >30‰, temperature 12-43°C, sparse grass, clams, low population and diversity, algae, depth <6 feet, thin band of salt marsh along mainland shore	0	19.2	38	–	57.2	2.5
Restricted bay center, hypersaline, closed to tidal input, rare river influence, bottom euxinic, laminated mud in deeper parts, restricted from Laguna Madre by reef sill, salinity 5-80‰, commonly >30‰, barren or rare organisms, depth 6 to 12 feet	0	19.5	18	–	37.5	1.6
Enclosed hypersaline bay or lagoon center, away from tidal or river influence, mud, mottled, salinity 30-80‰, abundant mollusks, low diversity, depth 4 to 12 feet	0	11.5	3	–	14.5	0.6
Subaqueous sandflat, hypersaline, barren to sparse grass, salinity 30-80‰, temperature 12-43°C, locally abundant clams; "The Hole" restricted by spoil sill, radical salinity and temperature changes, depth to 3 feet	0	15	0	–	15	0.6
Serpulid reefs (relict) and interreef shoals, shell, sand, reef rock, beach rock near mouth of Baffin Bay, high wave-energy, ridge or mound bathymetry, salinity 5-80‰, temperature 12-43°C, depth to 6 feet	0	5.5	5	–	10.5	0.5
Sand and oolite shoal, high wave and current energy, mounds, rare clam infauna, grass absent, salinity 30-80‰, temperature 12-43°C, depth 4 to 7 feet	0	0.5	0	–	0.5	0.02
Subaqueous and subaerial spoil, artificial, sand, silt, mud, shell, normally poorly sorted, assemblage depends on age and local setting, depth and elevation variable	0	15.8	2	–	17.8	0.8
Fresh to saline water bodies, landlocked ponds, playas, variable substrate, playas and coastal bodies temporarily saline	0.3	7.5	5.5	–	13.3	0.6

Table 9 (continued)—

SUBAERIAL ENVIRONMENTS AND ASSEMBLAGES (Principally floral assemblages)						
Beach, swash zone, high wave-energy, sand, shell, mollusks and crustacean infauna, back-beach sea-oats and halophytes, dunes, ghost crab, low tide to +5 feet	0	1.4	0.3	–	1.7	0.07
Vegetated barrier flat, foredune ridge, stabilized blowouts, sand, shell, relief 5 to 45 feet, salt-tolerant grasses, vines, local fresh-water marsh, ghost crab, rodents, snakes, fowl	0	16	10.1	–	26.1	1.1
Washover channel, fan, and wind-deflation trough and storm runnel, sand, local mud, barren, algal mats, local ponds and fresh-water marsh	0	4.3	0.5	–	4.8	0.2
Active dunes, coppice dune, blowouts, back-island dunes, inland dunes, barren, relief 3 to 40 feet, rodents, snakes	0.05	80	12.2	–	92.25	4
Sandflats, wind-tidal, local mud, algal mats, emergent-submergent, -1 foot to +2 feet MSL; and barren lower stream courses, ephemeral, sand	0	157	33.5	–	190.5	8.2
Eolian ridges and active clay-sand dunes, accretionary, intense wind, salt-tolerant grasses, snakes	0.3	18.7	5	–	24	1
Berms along bay-lagoon margin, storm deposits, sand, shell, local salt and brackish-water marsh in swales and ponds, salt-tolerant grasses, snakes, fowl; unmappable narrow band of salt-water marsh along shore	0	1.4	0.8	–	2.2	0.1
Intense wind-deflation and wind-tidal activity, erosion of sand sheet, salt-tolerant grasses on small unmapped clay dunes, algal mats	0	65	0.5	–	65.5	2.8
Inland fresh-water marsh, sand or mud, rushes, cattail, sloughgrass, mammals, snakes, fowl, small unmapped marshes in sand and loess areas; some areas occupied by high-moisture, non-marsh plants	0	0	12.2	–	12.2	0.5
Prairie grasslands, flat to gently rolling upland, mud, silt, sand, uncultivated, distinctive grasses, mesquite, cactus, huisache, chaparral, fowl, mammals	0	0	138	–	138	6
Poorly drained depressions, mud substrate, occasionally flooded, locally seasonal hydrophytes, other high-moisture plants and prairie grasses	0	0	5.3	–	5.3	0.2
Loose sand and loess prairies, bunch grasses, commonly overgrazed, scattered oak mottes, fresh-water marsh in blowouts and depressions in wet cycles, rodents, mammals, snakes, fowl	7.3	634	272.9	–	914.2	39.4
Poorly drained depressions, sand substrate, shallow water table, occasionally flooded, seasonal high-moisture plants, transitional with loose sand prairie plants	2.6	142	1.6	–	146.2	6.3
Live-oak mottes, stabilized sand dunes and ridges, hummocky, dense moderate to dwarf oak, distinctive grasses, fowl, abundant game, climax vegetation	0.8	191	0	–	191.8	8.3
Brushland, moderately stabilized dunes, inactive clay-sand dunes, some loess deposits, mesquite, chaparral, other scrub, distinctive grasses, cactus, game, fowl, climax vegetation	1.35	157.5	148	–	306.85	13.2
Fluvial woodland, short timber, sparse, discontinuous, some hardwood, mesquite, huisache, mammals, fowl	0.3	0.4	4	–	4.7	0.2
Made land, filled, graded, sand, mud, locally some vegetation	0	0.005	0.1	–	0.105	0.005

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

°Only a part of each county lies within map area
—Data not measured or unit not applicable

Brownsville regions. Second, it is an area endowed with extensive mineral resources—notably oil, gas, and chemical raw materials. Third, it is an area with fertile and productive lands that support significant 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 limitation 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, and intense eolian (wind) processes; 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 estuarine 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.

The Kingsville map area includes a unique portion of the Texas Coastal Zone. Many of the problems and conflicts in land and resource use mentioned in the preceding paragraphs are not yet in evidence in the Kingsville area. Several factors combine to create this unusual situation, including (1) the Gulf shoreline and Padre Island within the map area, which are federally protected (as the Padre Island National Seashore) from indiscriminate shoreline construction, overbuilding of access roads, clearing of lands and devegetation of dunes, and other practices that elsewhere are the result of intensive and often conflicting use of the delicate barrier island environment; (2) a low population density which tends to minimize, though not eliminate, problems of conflicting utilization of the natural resources of this portion of the Texas Coastal Zone; and (3) a predominantly agricultural economy based on large-scale cattle ranching and limited farming (mainly in support of the ranching interests). The unique qualities of the Kingsville area result in a minimum of the kinds of difficulties experienced in more populous areas of the Texas coast. Modifications of these unique qualities, however, such as a growing population, changing policies concerning recreational use of Federal lands, or changes in the basic economic structure of the area could result in problems not now apparent.

Current land use in the Kingsville map area is classed in 13 major use categories on the *Current Land Use Map* of this Atlas. Most of the information utilized in compiling this map was taken or derived from 7.5-minute U. S. Geological Survey topographic maps and similar Tobin controlled photomosaics (fig. 3); 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. 3). 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 whenever new coastwide aerial photography becomes available.

Major classes of current or potential land use in the Kingsville area include agricultural lands, wooded lands, fresh-water marsh, urban lands, government lands (State and Federal), general recreational lands, made and reclaimed lands, dredged spoil and barren lands, and lands transitional between the wind-tidal flat and eolian sand sheet area. The major classes—agricultural, urban, and barren 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 10. In addition, the *Current Land Use Map* of this Atlas shows location and distribution within the Kingsville map area of 53 oil and gas fields, 11 educational sites, 18 pits and quarries, 4 solid-waste disposal sites, 2 offshore petroleum production platforms, and 2 airfields. Major pipeline and transportation-navigation networks are also 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 64 percent of the Kingsville map area is used for agriculture. Of total agricultural lands, only about 4 percent is under cultivation, with the remaining 96 percent used for range and pasture land. Principal use of cultivated lands, situated almost entirely on the Pleistocene coastal uplands around and south of Kingsville in Kleberg County, is for production of grain sorghum, cotton, and vegetables. Range and pasture land cover 61 percent of the total mapped area and are managed by large privately and corporately owned

Table 10. Areal extent and number of individual units shown on Current Land Use Map, Kingsville map area, Texas.† (Table pertains only to that part of each county occurring within the Kingsville map area. All values are in square miles unless otherwise indicated by symbol.) See tables 3 and 7 for conversion values.

SPECIAL USE ENVIRONMENTAL MAP UNITS	Brooks County°	Kenedy County°	Kleberg County°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Kingsville map area (excluding offshore area)	Percentage of Kingsville 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 on thin Holocene-Modern eolian sand sheet covering Pleistocene fluvial-deltaic sand and mud facies	0	0.8	62	–	62.8	2.7
Range-pasture, uncultivated or permanently removed from crop use, some local silage fields, land use varies adjacent to residential-urban areas, predominantly grass and scrub-covered eolian sand sheet, rincons and potreros within land-cut area, Pleistocene fluvial-deltaic sand and mud	11.85	890	512.5	–	1414.35	61
Live-oak mottes, extensive complexes of mottes on stabilized eolian dunes, scattered cattle throughout, wildlife locally abundant	0.8	191	0	–	191.8	8.3
Fresh-water marsh, ephemeral, flooded by rains, wind-deflated depressions on Pleistocene barrier-strandplain, abandoned upper estuarine areas, and depressions on distal Pleistocene delta and interdistributary areas, marsh in eolian blowouts not mapped, periodically vegetated with rushes, cattails, sloughgrass, wildlife locally abundant, marshes flourish only during wet climatic cycles	0	0	11.4	–	11.4	0.5
Residential-urban, commercial and residential development, includes Kingsville and small rural villages and settlements, may include some minor industrial areas	0	0.5	5	–	5.5	0.2
Industrial, municipal works, refineries-chemical plants, agricultural plants, and other facilities	0	0.2	0.2	–	0.4	0.02
Park and recreational facility, formally defined federal, state, and most county, and municipal facilities such as ball parks, athletic fields, golf courses, includes some private facilities	0	78	25	–	103	4.4
Government land, federal and state, excluding recreational and educational, includes defense department property, major tracts only, may be inactive or abandoned	0	0	6	–	6	0.3
Made land, filled, graded, composed of barrier island sand	0	0.01	0.1	–	0.11	0.005
Spoil, subaerial land resulting from dredging, some waterfowl, locally used for fishing sites, relatively barren areas within lagoon and land-cut area	0	13.2	0.5	–	13.7	0.6
Barren land, sand, active dunes, wind-tidal flats (lighter shade), coppice dune fields, Padre Island National Seashore undifferentiated	0.05	230	22	–	252.05	10.9
Transitional area between wind-tidal flat and eolian sand sheet area, alternating wind deflation and tidal flooding, abundant clay dunes, erosional remnants of sand sheet, sparse vegetation, poor rangeland on erosional islands and clay dunes	0	65	0.5	–	65.5	2.8
Oil or gas field■	0	30[29]■	37[24]■	0	67[53]■	2.9
Education site, public school, college, university■	0	2	9	–	11	–
Pit or quarry, commonly caliche in Pleistocene fluvial-deltaic facies beneath thin loess sheet■	0	10	8	–	18	–
Solid-waste disposal site, sanitary and open sites■	0	1	3	–	4	–
Pipeline, major lines only, incomplete	–	–	–	–	–	–
Offshore petroleum production platform, bay or Gulf■	0	0	1	1	1	–
Airfield, paved, graded, or sod■	0	2	0	–	2	–

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

–Data not measured or unit not applicable
■Number of specific occurrences of map feature

ranches, including the King Ranch, the largest ranch in the United States. Beef cattle are the principal product of the ranches in the map area. Range and pasture land cover large portions of the Pleistocene uplands, moderately stabilized brush- and grass-covered eolian sand sheet areas, and much of the loess-covered areas south and west of Kingsville.

Wooded Lands

Approximately 192 square miles, or 8 percent of the Kingsville map area, are wooded and are largely associated with stands of live-oak mottes on stabilized eolian sand dunes. The thick oak mottes are associated with a variety of grasses, vines, and other small plants. Primarily, the mottes are habitats for abundant wildlife; scattered cattle graze on motte-associated vegetation.

Fresh-Water Marsh

Fresh-water marshlands cover only about 11 square miles or about 0.5 percent of the Kingsville map area. These lands occur in low areas occasionally flooded or moist during wet climatic periods; these are ephemeral lands in the map area. Fresh-water marsh, characterized by rushes (*Juncus*), cattail (*Typha*), and sloughgrass (*Spartina pectinata*), develops in depressions on the Pleistocene delta and interdistributary areas, in wind-deflation lowlands on the Pleistocene barrier strandplain, and in other low-lying areas. Marshes are noticeably developed only during wet periods.

Little direct use is made of the marshlands in the Kingsville area. Principal current use is for a wildlife habitat; marshes are present mainly west of Laguna Madre and north of Alazan Bay. A literature review and land use evaluation of Texas wetlands are given by Fruh and others (1972).

Urban and Industrial Lands

Several small population centers are present in the mapped area included in the Kingsville Atlas. About 5 to 6 square miles, or less than 0.5 percent of the map area, are classed as residential-urban or industrial. The largest center is Kingsville in Kleberg County, with smaller urban areas including Ricardo, Riviera, and Sarita. Several smaller towns and settlements—Loyola Beach, Riviera Beach, Mifflin, Armstrong, and several ranch complexes—define the remaining urban 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 locally some minor industrial developments; and (2) industrial areas, including municipal works, agricultural products plants, and chemical and refining plants.

Parks and Recreational Facilities

Over 4 percent of the land within the Kingsville map area is included in this land use category. Most of the 103 square miles is occupied by the Padre Island National Seashore, authorized by the U. S. Congress in 1962. All of Padre Island in the map area is included within National Seashore boundaries. Also included in this category are State, county, and municipal facilities present principally in the Kingsville area and along Cayo del Grullo between Riviera Beach and Loyola Beach.

Transitional and Barren Lands

More than 252 square miles of barren lands, as well as more than 65 square miles of poorly vegetated lands transitional between wind-tidal flats and the eolian sand sheet, account for almost 14 percent of the land in the Kingsville map area. Barren lands include areas of active dune fields and extensive lowlands subject to frequent flooding by wind-generated tides. These lands are generally devoid of vegetation. Scattered stands of bunch grasses in an active eolian area trap sand in the form of coppice dunes. Barchan dunes are the dominant landform in the active dune fields on the mainland. On the wind-tidal flats, algal mats form following periods of inundation; mats of blue-green and, occasionally, red algae form a leathery surface that tends to crack in an irregular polygonal pattern upon drying. Lands transitional between wind-tidal flats and the eroded edges of the eolian sand sheet are generally characterized by poorly developed grass vegetation. Wind-tidal flooding is infrequent; wind deflation is the dominant physical process, and clay dunes are a common landform in the transitional lands.

Principal land use of barren and transitional lands is limited to a minor wildlife habitat. Transitional lands may support poor rangeland on clay dunes and remnant, erosional islands. Similar environments are common on Padre Island, but are not differentiated on the *Current Land Use Map*; see the *Environmental Geology Map*, *Environments and Biologic Assemblages Map*, and

Physical Properties Map for a review of the nature of the lands within the Padre Island National Seashore area.

Other Land Use Categories

Other types of current land use comprise more than 18 percent of the total mapped area. The 53 oil and gas fields shown on the Kingsville map cover an area of 67 square miles or slightly less than 3 percent of the total mapped area. Much of this land, however, is used simultaneously for other purposes. Some 6 square miles of land exist as government land, including principally the Kingsville Naval Air Station; included also are abandoned Naval auxiliary fields that have been released by the Federal government. Only major tracts of government land are included in this category.

Slightly more than 0.1 square mile of made land occurs in the Kingsville map area. The Malaquite Beach Development at the northernmost part of Padre Island National Seashore within the map area consists of a restaurant, showers, and similar facilities for tourists and campers using the park. Several oil well pads extend into Laguna Salada to support oil and gas development of the Riviera (presently inactive) and Sarita (active) fields. Subaerial spoil from dredging, situated mainly along land cuts of the Intracoastal Waterway and along the tributary channels dredged principally for access to oil well sites, has limited, primarily recreational, use. Spoil banks offer habitat for some waterfowl and shoal areas favorable for fishing. Almost 14 square miles of subaerial spoil are present within the Kingsville map area.

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 type and 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 those areas of 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 utilized; 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 and an extensive petrochemical industrial complex. In addition, the Coastal Zone contains important resources of chemical raw materials—sulfur, salt, and shell for lime. Mineral and energy resources in the Kingsville map area consist almost entirely of oil and gas. Though the contribution to the area's economy by petroleum and natural gas is decidedly major, the Kingsville area is not particularly rich with other commercially available mineral or energy resources.

Water, particularly ground water, is a resource of major importance along the arid South Texas coast. Principal fresh-water aquifer in the Kingsville area is the Goliad Sand of Pliocene age. The Goliad Sand ranges in depth from several hundred feet near the west boundary of the Kingsville Atlas to over 1,400 feet beneath Padre Island (fig. 27). It is composed predominantly of sand or sandstone of fluvial origin.

Ground-water investigations indicate that fresh-water resources in Kenedy County are large, but that "mining" of fresh ground water is presently occurring in western Kleberg and southern Jim Wells (off the map) Counties (Shafer and Baker, 1973). Mining of ground water occurs when rates of withdrawal exceed rates of natural recharge. In western Kleberg and southern Jim Wells Counties, rate of withdrawal in the late 1960's was 13.8 mgd (million gallons per day), and rate of natural recharge was estimated to be 7 mgd. Pumping of ground water is mainly for public supply in Kleberg County and industrial use in southern Jim Wells County. In these areas, ground-water withdrawal has resulted in large cones of depression developed on the piezometric surface as determined by measurements of water levels in selected wells (fig. 27). Kenedy County ground-water use (2.8 mgd) is mainly for rural-domestic and livestock purposes and is greatly exceeded by natural recharge (14 mgd). Part of the 14 mgd natural recharge is diverted toward the Kingsville area in response to sharp water-level declines there and resultant steepening of hydraulic gradients towards those municipal wells. Fresh ground-water supplies in the immediate Kingsville area are limited due to inadequate rates of recharge. Availability of fresh ground water in most of western Kenedy County (west of U. S. Highway 77) is very favorable.

The *Mineral and Energy Resources Map* of the Kingsville Atlas shows the occurrence and distribution of all known mineral deposits, including oil and gas fields, serpulid reef and shell deposits, clay deposits, and general fill and aggregate materials. Also shown are existing pits and quarries and the energy-distribution network, which is outlined by all major pipeline facilities, major power or utility transmission lines, and the petroleum production platforms in the bay and Gulf waters. On the *Mineral and Energy Resources* map in the area between Santa Gertrudis and San Fernando Creeks, the color patterns for sand and mud substrates were inadvertently reversed. Satistical data for each map unit are tabulated in table 11.

Oil and Natural Gas

A total of 41 oil and gas fields are currently producing within the mapped area; only the major active and inactive fields are indicated on the *Mineral and Energy Resources Map*. Of the 41 fields, 8 produce both oil and gas, 2 are oil fields, and 31 currently produce only gas. Most of the producing reservoirs are traps associated with down-to-the-coast gravity faults trending nearly parallel to the present shoreline, as well as in stratigraphic traps related to pinch-out of sands of ancient barrier-bar systems; the chief producing unit is the Frio Formation. Of these 41 fields, 8 are developed below the waters of Laguna Salada, Cayo del Grullo, and Laguna Madre; the remainder are on land. Two oil and gas platforms are shown on the map, one exists off Point of Rocks in Baffin Bay and the other production platform is offshore of Little Shell Beach in the Gulf of Mexico. No significant oil production and only limited

Table 11. Areal extent and number of individual units shown on Mineral and Energy Resources Map, Kingsville map area, Texas.† (Table pertains only to that part of each county occurring within the Kingsville map area. All values are in square miles unless otherwise indicated by symbol.) See tables 3 and 7 for conversion values.

SPECIAL USE ENVIRONMENTAL MAP UNITS	Brooks County°	Kenedy County°	Kleberg County°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Kingsville map area (excluding offshore area)	Percentage of Kingsville map area covered by map unit (excluding offshore area)
Sand includes all subaerial sandy deposits, distributary sand and silt with local mud, barrier-strandplain sand, eolian sands, wind-tidal flat sands and silts, and subaerial and subaqueous spoil; see Physical Properties Map for specific description	12.4	1460.3	547.2	–	2019.9	87
Mud, includes all subaerial muddy deposits, interdistributary mud, marsh and swamp facies, filled lakes, clay dunes; see Physical Properties Map for specific description	0.3	11	99.5	–	110.8	4.8
Serpulid reef, area of prominent serpulid marine worm (*Annelida*) colonies, nonliving, calcium carbonate, buried reef not included, some calcite-cemented sand beach rock locally, sandy and shelly interreef areas	0	5.5	5	–	10.5	0.5
Pit or quarry, commonly caliche-cemented fluvial and deltaic sands■	0	10	8	–	18	–
Oil or gas field■	0	30[29]■	37[24]■	0	67[53]■	2.9
Utility line or cable, major power transmission line, incomplete	–	–	–	–	–	–
Pipeline, major lines only, incomplete	–	–	–	–	–	–
Offshore petroleum production platform, bay or Gulf■	0	0	1	1	1	–

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

–Data not measured or unit not applicable
■Number of specific occurrences of map feature

gas production currently exists within the mapped offshore area; Federal blocks farther offshore may eventually produce some quantities of oil and gas.

Cumulative production of crude oil in the Kingsville map area was approximately 0.5 billion barrels through 1973. Crude oil production in 1973 was 1.1 million barrels from 10 fields. The largest field in the area is Sarita, just south of Laguna Salada, which has produced about 17 million barrels of oil from 71 pay zones.

Gas is produced from a total of 39 fields in the mapped area, with annual production currently exceeding 208 billion cubic feet. Nine fields—North Alazan, El Piastle, El Piastle Deep, Madero, East Madero, Murdock Pass, Rita, Sarita, and Stillman—each produced over 5 billion cubic feet of gas in 1973.

The production of oil and natural gas figures most prominently in the total economy of the Kingsville area. Though considered to be a ranching area, the economic impact of petroleum and natural gas far exceeds that of the agricultural industries. Approximately 70 square miles of land and water within the map area are included in 41 active fields of the area; the major nonagricultural land use in the Kingsville map area is directly related to oil and gas production.

Constructional Raw Materials

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

Most of the gravel supply of the Kingsville area comes from sources further inland; some crushed stone must be imported from Central Texas. The existing sources of coarse aggregate are rapidly becoming depleted; future supplies must come from sources farther inland. Although the unit value for bulk constructional materials is generally only around $1.00 per ton, their bulk and volume require significant transportation costs, at least $0.05 per ton-mile. Such constructional materials are absolutely essential to the heavy construction of the industrial and urban parts of the area, and their availability at the lowest possible cost is desirable.

Crushed stone, in the form of caliche (calcium carbonate), is the only constructional raw material produced on a significant scale within the Kingsville map area. Pits south of Kingsville and along U. S. Highway 77 testify to additional efforts to produce caliche 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 common only north of Santa Gertrudis Creek within the map area, as indicated on the *Mineral and Energy Resources Map* of this Atlas. The processes involve calcining or partial calcining of the clay to give an indurated or hardened material, forming either a lightweight or a standard-weight aggregate. The artificial product is obtained at a higher cost than the natural material, but prices will become increasingly more competitive as imports from longer distances become necessary.

Industrial sands.—Certain of the sand deposits of the Coastal Zone have potential industrial or specialty uses. In contrast to ordinary fill sand, sands of higher 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 Corpus Christi and Houston areas, but there is little potential for any sand deposits in the Kingsville area being used to supply these central and upper Coastal Zone markets. Modern beach and dune sands near the Kingsville map area have been analyzed 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 Kingsville 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 significant, no production is known.

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

Serpulid reefs.—More than 10 square miles (0.5 percent of the map area) in Laguna Madre, Baffin and Alazan Bays, Laguna Salada, and Cayo del Grullo are characterized by the presence of nonliving reefs comprised almost wholly of serpulid worm tubes. The serpulid marine worm (*Annelida*) secretes narrow calcium-carbonate tubes that form sizable rock masses when cemented together. Such material might possibly have value as a constructional raw material, similar to the *Crassostrea* (oyster) reefs prevalent in the bays further north along the coast. No testing of this material for such use is known; primary value of these rocks is the favorable habitat they provide for the abundant fish present in the bays. Serpulid reefs would be a limited finite resource in this area as they are no longer living. The reefs were presumably destroyed by hypersalinities now common in bay waters.

Summary

The Kingsville area contains a limited 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. Some mineral resources within the map area are present in almost limitless supply, such as common clay and fill sand, but neither have been developed significantly, mainly because of a lack of local demand for these materials. Petroleum and natural gas constitute the vast bulk of the area's mineral wealth. Reserves of oil and natural gas remain large, 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. Though not actually an industrial region, the Kingsville area will face drastic economic changes if the petroleum industry begins to decline; oil and natural gas constitute the main economic base of the area, even though agriculture (mainly ranching) is the major current land use in the mapped area.

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 areas subject to flooding due to hurricane-aftermath rainfall, a characterization of the bay and Gulf shorelines in their present state (erosional, depositional, or stabilized), and delineation of lands subject to wind-dominated processes, including erosion, deposition, and wind-tidal flooding. In addition, such features as general depositional rates within the bays, subaqueous areas of high energy, and areas of spoil reworking are indicated. Statistical data for each map unit are given in table 12.

Hurricane Flooding

Flooding by hurricane surges is a dramatic and highly significant physical process throughout the Coastal Zone and is of prime consideration in use of coastal lowlands. In the mapped portion of the Kingsville area, a total of 288 square miles of lowlands was flooded by storm surges of Hurricanes *Carla* in 1961 and *Beulah* in 1967; this is approximately 12 percent of the entire mapped area. Most of the area included in this figure is related to Hurricane *Beulah* which made landfall just south of Port Isabel. Data for areas inundated by marine waters associated with the Hurricane *Carla* storm surge (landfall at Pass Cavallo in Port Lavaca area) are incomplete for the Kingsville area. 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 Baffin Bay could conceivably flood more than 1,000 square miles of the map area if the hurricane-tidal surge reached 25 feet above mean sea level.

More than 500 square miles in the Kingsville area were subject to fresh-water flooding in 1967 as a result of the passage of Hurricane *Beulah* and rainfall from aftermath storms. Many hurricanes, particularly of this type (McGowen and others, 1970; Brown and others, 1974), drop large amounts of precipitation which result in excessive stream flooding along most of the coast. In the Kingsville map area, integrated drainages are the exception, and extensive ponding of fresh waters occurred in 1967 in the depressions and poorly drained areas of the brush- and grass-covered loess sheet and moderately stabilized eolian dune areas. The poor drainage accentuated the effects of hurricane-related fresh-water flooding.

Table 12. Areal extent, length, and number of individual units shown on Active Processes Map, Kingsville map area, Texas.† (Table pertains only to that part of each county occurring within the Kingsville map area. All values are in square miles unless otherwise indicated by symbol.) See tables 3 and 7 for conversion values.

SPECIAL USE ENVIRONMENTAL MAP UNITS	Brooks County°	Kenedy County°	Kleberg County°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Kingsville map area (excluding offshore area)	Percentage of Kingsville 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	–	–	–	4	–	–
Site of active or potential hurricane washover channel■	0	31	0	–	31	–
Shoreline, erosional, eolian processes active along Gulf side of barriers and along lagoon shoreline▲	0	65.5	39	–	104.5	–
Shoreline, depositional, accretion, eolian processes active along Gulf side of barriers and along lagoon shoreline▲	0	68.5	65.5	–	134	–
Shoreline in depositional-erosional equilibrium, eolian processes active along Gulf side of barriers and along lagoon margin▲	0	10	29.5	–	39.5	–
Area of slow to moderate deposition within bay, predominantly suspension deposition in deeper bay, accretion in some marginal areas	0	78.4	79.2	–	157.6	6.8
Area of active reworking and redistribution of subaqueous spoil by waves and currents within lagoon	0	11	1.5	–	12.5	0.5
Area of moderate to high wave-energy, shallow (1-3 feet), sand, locally oolites, dead serpulid reefs and beach rock, shoal areas	0	6	5	–	11	0.5
Area of wind-tidal flooding, commonly generated by persistent north (winter) or southeast (summer) winds, alternating submergence and emergence, extensive wind-driven sand transport during exposure, algal mat development during submergence, fluvial sand locally deposited on flats at mouth of ephemeral streams entering Baffin Bay	0	167.3	29.6	–	196.9	8.5
Area of intensive wind deflation, occasional wind-tidal flooding, and extensive clay-dune accretion along land side of lagoon, includes eolian accretion of rincons and potreros, zone of destruction of eolian sand sheet; also includes active clay-dune accretion on the margin of wind-tidal flats adjacent to Baffin Bay and on the margins of playas throughout sand sheet*	0.3	15	4.8	–	20.1	0.9
Eolian sand dunes, active, back-island longitudinal dune fields, barrier island blowouts, barchan dunes in large banner dune complexes within inland sand sheet, areas of active eolian sand transport and deposition, deflation on windward side of migrating dunes*	0.05	50	5	–	55.05	2.4
Area inundated by marine water, Hurricanes *Carla* and *Beulah* storm surge tide, *Carla* data incomplete and unavailable for most of area, flood area was similar to that of Hurricane *Beulah*	0	238	50.1	–	288.1	12.4
Area inundated by marine water, Hurricane *Beulah* storm surge tide only	0	179	50	–	229	10
Area inundated by river flooding and rainfall runoff, Hurricane *Beulah* rainfall and aftermath storms, extensive ponding in depressions and poorly drained areas	4	489	24	–	517	22.3
Hurricane *Beulah* recording tide or river gage, high water-mark elevation, datum mean sea level■	0	0	1	–	1	–
Hurricane *Beulah* storm surge and river flooding debris or driftline elevation, datum mean sea level■	0	8	11	–	19	–
*Map color patterns overlap where active processes occur in the same area, resulting in a unique color code as follows:						
a Area of intensive wind-deflation covered by Hurricane *Beulah* river or rainfall flooding	0	4	0	–	4	0.2
b Area of intensive wind-deflation covered by Hurricane *Beulah* storm surge tide	0	45	0.2	–	45.2	2
c Eolian sand dunes covered by Hurricane *Carla* storm surge tide	0	0	1.5	–	1.5	0.07
d Eolian sand dunes covered by Hurricane *Beulah* storm surge tide	0	23	5.7	–	28.7	1.2
e Eolian sand dunes covered by Hurricane *Beulah* river or rainfall flooding	0	0.7	0	–	0.7	0.03

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

In addition, 31 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.

Shoreline Processes

The state of a shoreline, whether erosional, depositional, or in natural equilibrium, is largely determined by natural processes (figs. 8, 9) which are commonly altered by a variety of shoreline activities involving construction. On the *Active Processes Map*, approximately 278 linear miles of bay and Gulf shorelines in the Kingsville map area are characterized by a specific, dominant active process.

The nature of shorelines shown on the *Active Processes Map* reflects the state of knowledge concerning *long-term* shoreline conditions as of the early 1970's. Such determinations are based mainly on observational data and limited aerial photography and are subject to revision by more detailed, comprehensive historical shoreline monitoring programs. Recently, Morton and Pieper (1977a, 1977b) have documented the *long-term* trends and delineated *short-term* changes for the Gulf shoreline in the Kingsville area. *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 Gulf shoreline in the Kingsville area is shown on the *Active Processes Map* as being dominantly erosional. Based on historical shoreline monitoring, this portion of the Gulf coast has been subject to loss of land for the last 10 to 15 years (Morton and Pieper, 1977a). However, over the long term (for almost the last 100 years), this portion of the Gulf shoreline has been accretionary or in natural equilibrium. On the *Active Processes Map*, the Gulf shoreline extending north from Yarborough Pass is shown as an equilibrium shoreline in the vicinity of Little Shell Beach and as a depositional (accretionary) shoreline further to the north. Historical shoreline monitoring of this portion of the Gulf shoreline in the Kingsville area supports this determination as reflecting *long-term* shoreline conditions (Morton and Pieper, 1977b). However, for the last 10 to 15 years, this same segment of the shoreline has been erosional.

Similar refinement of knowledge of shoreline conditions for the bays, lagunas, and cayos in the Kingsville area is not yet possible. Detailed, comprehensive historical shoreline monitoring will be necessary before definitive assessments can be made.

Within the area, approximately 40 linear miles, or about 14 percent of the total shoreline in the area, are naturally stabilized or are essentially in erosional-depositional equilibrium; that is, the shoreline is undergoing neither erosion nor accretion. The principal cause of shoreline stabilization in the Kingsville area is a natural balance between wave and current energy impinging on the bay and Gulf shores and the availability of an adequate sediment supply. Along the Texas coast to the north and northeast, salt marsh is the principal natural agent of shoreline stabilization, but in the wind-dominated portion of the coast south of Corpus Christi, the environmental position of salt marsh is replaced by the extensive areas subject to wind-tidal flooding. Salt marsh is present in the Kingsville area in narrow zones and along only a minor portion of the shorelines within the map area; they are not large enough to be mapped as separate environments. Along the bay shorelines, equilibrium exists either in or downcurrent from wind-tidal flats in Laguna Salada, Cayo del Grullo, and the northwest shore of Alazan Bay. A comparison of figure 9 and the *Active Processes Map* illustrates the close relationship of wind-tidal flats (which are located in low areas commonly receiving a sand supply from creeks or numerous unnamed smaller drainages around the bays) and the inferred direction of current movement along bay shores. The southeast shore of Alazan Bay is in equilibrium as a result of the sediment blown into Alazan Bay by the prevailing southeasterlies off the wind-modified Pleistocene deltaic and barrier-strandplain substrate. The shoreline of Little Shell Beach is considered to be essentially in equilibrium due to the influx of an adequate supply of sediment from longshore drift transport (fig. 8) and onshore movement of sand and shell debris from the inner shelf. Wave and current activity along the Padre Island shore is high but is compensated for by this sediment supply.

Approximately 134 linear miles, or about 48 percent of the total shoreline of the mapped area, are undergoing some degree of accretion or net gain in land. These are invariably shorelines receiving a surplus volume of sediment. In Laguna Madre, the wind-tidal flat environments are expanding due to the addition of windblown sediment, sediment input from hurricane-tidal surge, and reworking of subaerial spoil along dredged canals in the Land-Cut Area. This influx of sediment is distributed by tidal currents across the flats to the interface with Laguna waters. Wave and current energy in Laguna Madre is not sufficiently strong to compensate for the large supply of sediment. However, extensive areas of subaerial spoil along the Intracoastal Waterway and associated canals within Laguna Madre are being modified by the currents and waves and are undergoing net accretion. Shorelines of well-developed wind-tidal flats at the mouths of creeks and smaller, unnamed drainages surrounding Baffin Bay and the associated bays, lagoons, and cayos are also accretionary. Sediment is transported by these integrated drainage systems to the tidal flats and eventually carried across the flats to the bay waters by the shallow tides and small, braided tidal channels. Additional input comes from windblown sediment carried by the prevailing southeasterly winds.

About 105 linear miles of shoreline, or 38 percent of the total bay and Gulf shoreline in the Kingsville map area, are undergoing some degree of erosion or net land loss. The principal areas of shoreline erosion are along shores exposed to the prevailing and dominant seasonal winds. Southeasterly winds are the dominant winds in the Kingsville map area and generate waves across Baffin and Alazan Bays and up the length of Cayo del Grullo. Because of the wind-generated waves and currents and the lack of adequate sediment supply due to wind erosion of loose sediment, the northwest shores of Baffin Bay, Alazan Bay, and the Riviera Beach headlands area are undergoing erosion. Similarly, northerly winds are effective in the Kingsville area and are responsible for shoreline erosion along most of the south shore of Baffin Bay, including the Black Bluff area. The high energy due to longshore currents, wave impact, and wind deflation results in an erosional regime for much of the Gulf shoreline. Other examples of erosional shorelines in the map area are portions of the west shore of Laguna Madre. The main cause of shoreline erosion in the Kingsville map area is a less than adequate source of nourishing sandy sediments along a relatively high-energy portion of the coast and shore.

In short, the state of a shoreline, whether erosional, depositional, or in equilibrium, is largely a function of natural processes. Chief among these are availability of a sediment source and intensity of wave activity (fig. 9). This natural balance can be altered only on a local basis. A common practice is to construct groins or other obstructions that check the lateral movements of longshore currents and sediments along the shoreline, but each alteration in the natural process is simply compensated for in another place. For example, construction of a jetty or groin along an erosional shoreline of the Texas coast will trap sediment immediately upcurrent from the structure but may generate even more serious erosion downcurrent from the structure. In certain cases, specific local management or alteration of shoreline processes may be necessary, but modification cannot be effected 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. The Gulf shoreline in the Kingsville map area is federally protected as a part of the Padre Island National Seashore; thus, shoreline construction may not be a problem in the immediate area. However, improper management practices followed along the shoreline to the north or the south could result in modification of the shoreline in the map area. In addition, various management or recreational activities and constructions along the coast by Federal agencies or changes in current Coastal Zone management practices and priorities could also result in eventual modification of the shoreline in the National Seashore area. The present status of the Gulf shoreline, much of which is erosional in the Kingsville map area, is inferred from the physical condition of this part of the coast.

Wind-Dominated Processes

The dominant physical process in the Kingsville area is the wind. Nearly all topographic features within the Kingsville map area are affected by the strong, persistent southeasterly winds. As a result of the wind influences, more than 270 square miles are subject to intense wind deflation, active eolian sand transport and deposition, or wind-tidal flooding. These wind-dominant environments do not include the extensive areas covered by a loess (windblown silt) veneer.

More than 20 square miles are subject to a variety of wind-influenced processes including wind deflation, clay-dune accretion downwind from nearby source areas, accretion of rincons and potreros, wind destruction of the eolian sand sheet, and occasional wind-tidal flooding. Small, subcircular to elliptical playas are sites of wind deflation—erosion of surficial sand or clay-sand fragments such that the surface is actually lowered. Commonly such deflated areas are bordered on their downwind side by clay-sand dunes which are maintained by active accretion of clayey sand-sized fragments (clay pellets) eroded off the dried, mud-cracked surface of a nearby source area. Eolian ridges (potreros) and remnant erosional islands (rincons) project above the wind-tidal flats, including Mesquite Rincon, Tres Marias Islands, El Toro Island, Calabasas Islands, Potrero Lopeno, Potrero Farias, Potrero de las Canelas, Potrero Cortado, Potrero Grande, and Potrero de los Caballos. Accretionary ridges reflect growth of these features on their windward side (fig. 19). Fisk (1959) suggests such features represent remnants of the eolian plain along the west side of Laguna Madre that are now deflated, frayed, and mostly covered by wind-tidal flats in the embayment west of the Land-Cut Area (figs. 19, 20). Fringing the west side of Laguna Madre is the wind-frayed edge of the eolian sand sheet. Wind deflation has strongly influenced the low-lying, generally southeast-northwest-trending areas along this western margin. Some parts of the map area are subject to wind-tidal flooding on infrequent occasions. These are broad flats within high tidal flats (3-4 feet above MSL) landward of the large re-entrant of Laguna Madre west of the Land-Cut Area.

Active eolian transport and deposition of sand form a striking topography in the Kingsville area. Strong, dry prevailing southeast winds move sand grains from the beach, fore-island dune ridges, and hurricane-washover channels and fans onto the back-island areas where large fields of active dunes, predominantly aligned parallel to the easterly resultant wind directions, form and migrate across Padre Island. On the mainland, Pleistocene barrier-strandplain sands are the likely source of the initial eolian sands blown inland to form the South Texas eolian plain. Large triangular-shaped lobes (banner dune fields) extend inland along the west edge of Kenedy County (fig. 22, 23). Barchan dunes characterize the active portions of these banner dune complexes. Over 55 square miles of active eolian sand dunes and blowouts are mapped on the *Active Processes Map*; these represent only the present-day eolian activity and are a part of the long history of the wind-dominated development of this portion of the Texas coast.

Almost 200 square miles of the Kingsville map area are subject to wind-tidal flooding (fig. 18). Though tidal ranges are small and wind tides rarely exceed 18 to 24 inches, large areas of lowlands are intermittently flooded by saline waters. Wind-tidal flats in Laguna Madre developed principally on predominantly sandy deposits derived from the barrier island. These wind-tidal flats occur all along the landward side of Padre Island. In the Land-Cut Area, tidal flats rest on a sand lobe derived from Padre Island that effectively divides Laguna Madre into southern and northern lagoons. Wind-tidal flats also occur where the small streams and creeks enter the marine waters of Laguna Salada, Cayo del Grullo, Cayo del Infiernillo, Cayo de Hinoso, and Cayo del Mazon in the northern third of the map area (fig. 14). Several other low-lying areas fringing the bays, lagoons, and cayos are also subject to inundation by the wind-driven tides.

Other Active Processes

Several other active processes, in many ways less dramatic than hurricane flooding, shoreline processes, and the pervasive wind-dominated 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. In Laguna Madre, Baffin Bay, and other bays, lagunas, and cayos in the Kingsville map area, the rate of sediment deposition is very slow to moderate. Fine-grained sediment settles out of suspension in the deeper portions of the bays. The shallow water bodies in the map area, though subject to persistent winds, do not form large swells and intense wave activity; astronomical tidal range is very limited. In the shoal water areas, however, along the headlands of the mouth of Baffin Bay and Laguna Salada, moderate to high wave energy impinges on subaqueous deposits of oolites, other aragonite-coated grains, and quartz sand. Beach rock is commonly exposed to wave activity in these areas. Shoal waters over relict serpulid reefs and interreef areas are also areas characterized by high wave energy. Margins of the bay-lagoon system are so shallow that the waves and currents in the bays, lagoons, and cayos are sufficiently strong to keep fine-grained sediment in suspension, at times resulting in high water turbidity. Deeper water areas (6 to 12 feet below MSL) are not subject to this wave energy except in times of very strong storms.

Along the Gulf shore, the lower shoreface and shelf are subject to significant wave and current activity only during storms, when larger storm swells impinge on the bottom. In the offshore water exceeding 8 feet in depth, suspension deposition of fine-grained sediment and reworking of surficial bottom sediments by burrowing organisms are the most common operative processes. In offshore waters less than 8 feet deep which compose the upper shoreface (normal surf or breaker zone), wave and current energy is sufficiently strong to transport and deposit sandy and silty sediments to form shifting, subaqueous bars. Along Padre Island, the longshore currents from the south and north are focused, and wave fronts moving due west impinge nearly directly on the beach (fig. 8).

Another prominent physical process in the Texas Coastal Zone is the reworking and redistribution of subaqueous spoil dredged from the channels of the Intracoastal Waterway. More than 12 square miles of the loose, uncompacted sediment are now subject to subaqueous redeposition. Spoil has thus become a major sediment source within Laguna Madre.

The major active processes of the Kingsville area are treated here only in a qualitative manner. Unfortunately, much of the observation and monitoring necessary for quantitative assessment of the nature and effects of active processes has not been initiated within the Coastal Zone. Further, certain important processes, such as water-circulation patterns in the bays and estuaries, are inadequately known. For certain processes, statistical or numerical models have been developed, but few of these have been sufficiently tested against observed processes in the field. Similarly, the vast array of natural variables within the bay-estuary-lagoon system is poorly understood and, therefore, not yet included in theoretical modeling. Since active processes are not only a vital expression of the Coastal Zone environment but are also 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 shown in table 13.

Man-Made Features

Features delineated as man made are derived, in part, from the *Current Land Use Map* and illustrate man's impact on the Kingsville area. A very minor aspect of man's activity here is urban and industrial construction; indicated are limited urban and residential areas and industrial areas. A major alteration by man in the Kingsville map area is the presence of extensive dredged spoil and made land. Spoil is concentrated along land cuts and intrabay dredged channels of the Intracoastal Waterway and its various branches in Laguna Madre. Made or reclaimed land occurs at the Malaquite Beach Development on Padre Island, where the Federal government has established a camping center for visitors to Padre Island National Seashore, and in Laguna Salada, where "pads" for oil and gas well sites were constructed in the bay waters. Made land areas within the urban and residential area of Kingsville were omitted. Also extracted from the *Current Land Use Map* are solid-waste disposal sites, sanitary landfills, and other open dumps.

The major pipeline networks of the area are indicated and are also part of the *Mineral and Energy Resources* and *Current Land Use Maps*; they include only the major lines and are, of necessity, incomplete. Several sources, including the Railroad Commission of Texas (1971) and Transcontinental Gas Pipe Line Corporation (1970), were used in the compilation of the pipeline networks of the area. Two constructed platforms used in oil and gas production are indicated on the map; one is located off Point of Rocks at the mouth of Baffin Bay, and the second is located in the Gulf of Mexico offshore from Little Shell Beach.

A significant type of coastal or shoreline construction is the building of piers, jetties, and groins. Principal concentration of constructed piers and jetties is at Loyola Beach on the west shore of Cayo del Grullo. Most of the jetties and piers are privately operated for fishing and recreation.

Water Systems

The surface water systems of the Kingsville map area include almost 500 square miles of both natural and artificially constructed water bodies excluding the Gulf. The natural water systems include about 12 square miles of fresh-water bodies (streams and natural lakes and ponds) and about 381 square miles of marine water bodies exclusive of the Gulf. More than 212 square miles of the marine water bodies are actually wind-tidal flats, intermittently flooded by bay and lagoonal waters; the remaining 169 square miles of marine waters are lagoons, bays, and cayos in the Kingsville map area. The principal fresh-water streams of the area are the Santa Gertrudis, Tunas, Olmos, and San Fernando Creeks. Petronila Creek (fig. 9; see Corpus Christi map area) empties into the wind-tidal flat area of Cayo del Mazon.

Table 13. Areal extent, length, and number of individual environmental units shown on Man-Made Features and Water Systems Map, Kingsville map area, Texas.† (Table pertains only to that part of each county occurring within the Kingsville map area. All values are in square miles unless otherwise indicated by symbol.) See tables 3 and 7 for conversion values.

SPECIAL USE ENVIRONMENTAL MAP UNITS	Brooks County°	Kenedy County°	Kleberg County°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Kingsville map area (excluding offshore area)	Percentage of Kingsville map area covered by map unit (excluding offshore area)
MANMADE FEATURES						
Urban and residential area, Kingsville and minor villages	0	0.5	5	–	5.5	0.24
Industrial area, located near Kingsville, includes isolated industrial developments	0	0.2	0.2	–	0.4	0.2
Made land, filled, graded, composed of barrier island sand	0	0.01	0.1	–	0.11	0.005
Subaerial spoil, includes spoil heaps or mounds and reworked spoil, small wash areas common	0	13.2	0.5	–	13.7	0.6
Subaqueous spoil, in part reworked by waves and currents	0	2.6	0.3	–	2.9	0.1
Jetty or pier, individual structure or area of numerous structures	–	–	–	–	–	–
Pipeline, major lines only, incomplete	–	–	–	–	–	–
Offshore petroleum production platform, bay or Gulf■	0	0	1	1	1	–
Airfield, paved, graded, or sod■	0	2	0	–	2	–
Solid-waste disposal site, sanitary and open sites■	0	1	3	–	4	–
WATER SYSTEMS						
Open ocean	–	–	–	–	–	–
Lagoon, bay or estuary, variable salinity depending upon rainfall and runoff	0	84.4	84.2	–	168.6	7.3
Transportation canal and channel, including intracoastal system and other ship channels▲	0	68.4	12.4	–	80.8	–
Wind-tidal flats, intermittently flooded by bay and lagoonal waters‡	0	183	29.6	–	212.6	9.2
Stream, natural drainage, ephemeral	–	–	–	–	–	–
Lake or pond, natural with minimum modification, perennial	0.2	3	1.5	–	4.7	0.2
Lake or pond, playa, natural with minimum modification, ephemeral	0.1	4.5	2.5	–	7.1	0.3
Artificial reservoir, flood control, municipal water supply, industrial purposes or recreation	0	0	1.5	–	1.5	0.1
Navigable streams▲	0	0	0	–	0	–
Bay, estuary, lagoon shoreline▲	0	125	134	–	259	–
Gulf shoreline▲	0	40	12.4	–	52.4	–

†Data accuracy approximately 90 to 95 percent; area determined by point-count method and linear values determined by map measuring wheel
°Only a 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
‡Includes transitional wind-tidal flat and eolian sand

Although tide levels are low, most streams in the map area are characterized by extensive wind-tidal flats where they enter the bay waters; these wind-tidal flats represent a transition zone between the small creeks and the marine water bodies.

A number of natural lakes and ponds covering about 12 square miles are concentrated in the low-lying areas on the poorly drained Modern-Holocene eolian sand and loess sheet deposits, in swales and depressions on Pleistocene delta-front mud and sand, and on barrier-strandplain sand deposits. Some of these small shallow ponds contain water throughout the year (perennial), but most contain water only after significant rainfall (ephemeral). Lakes and ponds on the eolian sand and loess deposits occupy shallow depressions called playa lakes that generally lie windward of clay-sand dunes. On the eolian sand sheet, nearly all clay-sand dunes are active, deriving their clay clasts from clay chips and mud curls broken loose from the dried surface of ephemeral lakes or playas. In loess-covered regions south of Kingsville, both active and inactive clay-sand dune complexes are associated with the natural lakes and ponds. Most water-filled depressions on the loess sheets are simple wind-deflation depressions not supporting any dune complex on the downwind side because of a lack of sand or clay-sand detritus. Large areas on the eolian sand sheet east and south of Mifflin and southeast of Armstrong are characterized by a lack of many ephemeral and perennial lakes or ponds. These areas do not have an integrated drainage system; other regions of the eolian sand sheet also lack integrated drainage which is reflected in the abundance of lakes or ponds. In these areas of abundant ponds and playas, wind deflation may have proceeded down to a muddy substrate leaving a naturally sealed pond. In other cases, wind erosion may intersect a water table within a shallow aquifer and, as a result, may be supplied with ground water. Substrate composition, consequently, may control the differential distribution of areas with ponds and areas without ponds or playas. The lake-poor regions generally occur in areas with low water tables. All of these natural lakes and ponds are very shallow.

A third type of natural fresh-water body in the Kingsville area is the ephemeral stream. These natural drainage systems flow generally in response to heavy rainfall and are located predominantly in the northern one-third of the Kingsville map area. Integrated drainages are developed on the Pleistocene fluvial-deltaic surfaces and, to a lesser extent, on the loess-covered Pleistocene deposits south of Kingsville and west of Cayo del Grullo. Significant natural streams are not present in the hummocky topography of the eolian sand sheet.

The major marine water bodies in the mapped area are Baffin and Alazan Bays, Laguna Madre, Laguna Salada, Laguna de los Olmos, Cayo del Grullo, Cayo del Infiernillo, and Cayo de Hinoso. Wind-tidal flat areas are intermittently covered by bay and lagoonal waters in Cayo del Mazon and Comitas Lake as well as several other bordering areas in the Baffin Bay region. The largest area of wind-tidal flats occurs in Laguna Madre along the bay shore of Padre Island, across the Laguna in the Land-Cut Area, and along the mainland shore west of The Hole. Marine bay waters in the Baffin Bay system range from less than 6°/₀₀ to more than 75°/₀₀ depending on available fresh-water input. Laguna Madre averages between 50 and 60°/₀₀, with the exception of the sill-restricted area called The Hole, which is subject to extreme salinity, thermal, and dissolved oxygen fluctuations. Open ocean waters, of course, have a normal marine salinity of approximately 35°/₀₀, but the closest connections with such waters lie more than 50 miles to the north (Aransas Pass) and to the south (Mansfield Pass). The various subdivisions of the bay and offshore environments are delineated on the *Environments and Biologic Assemblages Map.*

Artificial water bodies consist of the Intracoastal Waterway and associated channels within Laguna Madre and surface reservoirs near Kingsville. In 1949, the Intracoastal Waterway was constructed across Laguna Madre in the Land-Cut Area to complete this major transportation canal between Port Isabel on the south and Corpus Christi to the north. Nearly 81 linear miles of the Waterway and associated minor channels are present within the Kingsville map area. These are constructed as land cuts across the wind-tidal flat region east of the eolian accretionary ridges (potreros, rincons) and as dredged channels within the shallow waters of Laguna Madre. Associated minor channels were dredged to provide access to oil well locations. One major channel was dredged for access to Yarborough Pass, an artificial channel cut through Padre Island in the early forties. The man-made channel was never open for any significant period of time due to active sand accretion across the mouth of the Pass.

A smaller number of artificial surface reservoirs (covering about 1.5 square miles) have been constructed in the northwest portion of the mapped area. They are used for flood control, private water supplies, and recreation.

RAINFALL, STREAM DISCHARGE, AND SURFACE SALINITY MAP

The *Rainfall, Stream Discharge, and Surface Salinity Map* of this Atlas summarizes certain salient climatic features for the Kingsville map area. Data were selected for the three-year period from 1965 to 1967, for which detailed and continuous coverage exists. It is not intended that the data be precisely and statistically valid, but rather the map depicts the general climatic and salinity character of the area.

Rainfall recorded as precipitation in inches per month is shown for four stations within the map area, including Armstrong, Sarita, and Kingsville, and outside the map area in Falfurrias. Data for the 1965-1967 period were taken from reports of the U. S. Weather Service and are shown graphically on the map. Certain precipitation extremes are not shown to scale, but are indicated above the appropriate maxima on the graphs.

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 one station, station 8-2124, on Los Olmos Creek near Falfurrias (off the map).

Measurements of surface salinity were compiled from 18 stations within northern and southern Laguna Madre, Baffin Bay, Alazan Bay, Laguna de los Olmos, Laguna Salada, and Cayo del Grullo. Data for the eight stations shown in Laguna Madre were obtained from yearly reports of the Texas Parks and Wildlife Department (Martinez, 1965, 1966, 1967) and are shown for the same period of time covered by discharge and rainfall data; measurements from four of these stations are shown graphically. Surface salinity data for the 10 stations shown in Baffin and Alazan Bays, Laguna Salada, Laguna de los Olmos, and Cayo del Grullo cover the period of September 1951 to March 1953 (Breuer, 1957). The 1951-1953 salinity data were used because they provided three years of records after construction of the Intracoastal Waterway. Surface salinity of the bays and Laguna Madre is contoured for three general periods: (1) extremely low surface 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 surface salinity.

Though data shown are limited, the correlation between precipitation and discharge for the three-year period covered is obvious, with the greatest discharge coinciding with periods of high rainfall. During periods of high rainfall and large fresh-water discharge, surface salinity in the bays is reduced and ranges from less than 6°/₀₀ to about 20°/₀₀. Lowest salinities are recorded in the upper part of Cayo del Grullo and Laguna de los Olmos during periods of maximum stream discharge; highest salinities occur in the restricted south end of northern Laguna Madre (fig. 9).

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 in Laguna Madre (1965-1967), salinities ranged from less than 56°/₀₀ to more than 58°/₀₀. During the 1951-1953 period, the more restricted Baffin Bay and associated bays, lagunas, and cayos ranged from 62°/₀₀ near the mouth of Baffin Bay to over 75°/₀₀ near the head of Alazan Bay, the highest maximum reading for salinity recorded during this period.

Calculated average surface salinities in Laguna Madre (1965-1967) ranged from less than 42°/₀₀ in the more northerly part of upper Laguna Madre to over 44°/₀₀ in the restricted south portion of the Laguna. Calculated average surface salinities of Baffin Bay and associated water bodies (1951-1953) ranged from a low of just less than 50°/₀₀ in Laguna de los Olmos to over 54°/₀₀ in Cayo del Grullo. Salinity contours show variation in average surface salinity and illustrate the marked influence of river discharge in reducing salinity and the lack of significant tidal interchange in the Kingsville map area, resulting in surface waters characterized by hypersalinity.

Though data shown on the map cover two separate areas during two separate time periods, the general pattern for any one period of high salinity conditions (low rainfall, low stream discharge) is the same; that is, Baffin Bay and associated bays, lagunas, and cayos tend to be more restricted than Laguna Madre which does have limited interchange with normal salinity Gulf waters. Interchange occurs along the Intracoastal Waterway from Gulf waters entering Laguna Madre from Aransas Pass to the north and the Mansfield and Brazos Santiago Passes to the south.

Present bay-estuary-lagoon surface salinity patterns are more moderate than existed prior to dredging of the Intracoastal Waterway. Though hypersaline waters are still the rule, particularly during dry climatic periods, some normal salinity water interchange does occur via the deep waterway channels. Such interchange acts to modify salinity of restricted lagoon waters.

Day-to-day 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 zero or sea level to nearly 125 feet in the northwest corner of the Kingsville map area. Topographic control used for this map, scale 1:250,000, and on the *Environmental Geology Map*, scale 1:125,000, was compiled from U. S. Geological Survey detailed 7.5-minute topographic maps at a scale of 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. 3). Depths range from zero or mean sea level to more than -30 feet. Deepest areas are within the dredged channels and the inner shelf area of the Gulf. Depth of the artificially maintained navigation channels varies according to project depths and certain specifications but is commonly 9 to 12 feet.

From the *Topography and Bathymetry Map*, a slope map can be constructed, although in the low-relief and flat-lying Coastal Zone more details and a better presentation of configuration are obtained by shaded contour intervals. Areas of shifting sand dunes (fore-island blowout dunes, back-island dune fields, and active portions of the banner dune complexes) are characterized by changing elevations; these areas are mapped separately.

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 effect of hurricane-tidal surge of various heights can also be determined. Perusal of the map clearly shows the impact of the southeasterly winds on the region. Similarly, the surface expression of the stronger aerial photographic linears is clearly outlined by topographic configuration.

Table 14 gives land and bay-Gulf bottom areas 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 can be determined immediately. Areas of shifting sand dunes, characterized by changing topographic expression and elevation, are considered apart from the regular topographic intervals and are so indicated on table 14.

RESOURCE CAPABILITY: UTILITY IN LAND AND WATER MANAGEMENT

A basic goal of the Environmental Geologic Atlas of the Texas Coastal Zone is a regional inventory of the natural resources of the Zone. Flexible management of the Texas Coastal Zone should be based on the natural capability of resource and environment units. Such units were first termed *natural resource capability units* by Brown and others (1971). These units are derived from the maps included in this Atlas (table 15). The term *land and water resource unit* is a more appropriate name for these basic environmental elements. St. Clair and others (1975) defined 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).

Table 14. Areal extent of each 5-foot topographic contour interval and each 6-foot bathymetric contour interval shown on Topography and Bathymetry Map, Kingsville map area, Texas.† (Table pertains only to that part of each county occurring within the Kingsville map area. All values are in square miles unless otherwise indicated by symbol.) See tables 3 and 7 for conversion values.

SPECIAL USE ENVIRONMENTAL MAP UNITS		Brooks County°	Kenedy County°	Kleberg County°	Offshore (not included in county areas)	Total area, length, or number of map unit(s) in Kingsville map area (excluding offshore area)	Percentage of Kingsville map area covered by map unit (excluding offshore area)
TOPOGRAPHY — ABOVE SEA LEVEL (feet)	120 - 125	0	0	0.1	–	0.1	0.005
	115 - 120	0	0	1.5	–	1.5	0.07
	110 - 115	0	0	3	–	3	0.13
	105 - 110	0	0	5.6	–	5.6	0.2
	100 - 105	0	0	7	–	7	0.3
	95 - 100	0	0	12	–	12	0.5
	90 - 95	0.05	0.05	13	–	13.1	0.6
	85 - 90	0.02	0.05	15	–	15.07	0.7
	80 - 85	0.8	1	18	–	19.8	0.8
	75 - 80	2.3	2	23	–	27.3	1.2
	70 - 75	2.3	8	24	–	34.3	1.5
	65 - 70	1.7	11	26	–	38.7	1.7
	60 - 65	0.7	21	26	–	47.7	2
	55 - 60	0.5	20	27	–	47.5	2
	50 - 55	1.5	32	26	–	59.5	2.6
	45 - 50	2.5	51	30	–	83.5	3.6
	40 - 45	0.3	78	23	–	101.3	4.3
	35 - 40	0	97	28	–	125	5.4
	30 - 35	0	128	34	–	162	7.0
	25 - 30	0	163	40	–	203	8.7
	20 - 25	0	150	36	–	186	8.0
	15 - 20	0	172	50	–	222	9.6
	10 - 15	0	132	68	–	200	8.6
	5 - 10	0	94	56	–	150	6.5
	0 - 5	0	234	48	–	282	12.2
SEA LEVEL							
BATHYMETRY — BELOW SEA LEVEL (feet)	0 - 6	0	52.6	47	6	99.6	4.4
	6 - 12	0	28	30	7	58	2.4
	12 - 18	0	18	8.7	10	26.7	1.1
	18 - 24	0	0	0	7	–	–
	24 - 30	0	0	0	9	–	–
	30 -	–	–	–	–	–	–
	Shifting sand dunes♦	0	74.6	5	–	79.6	3.4

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

°Only a part of each county lies within map area

–Data not measured or unit not applicable

♦Area not included in other units above

Table 15. 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		ACTIVITIES: LIQUID-WASTE DISPOSAL			SOLID-WASTE DISPOSAL	SHORELINE CONSTRUCTION		COASTAL AND INLAND CONSTRUCTION				COASTAL, INLAND, AND OFFSHORE CONSTRUCTION									
		Surface disposal of untreated liquid wastes	Shallow subsurface disposal of untreated liquid wastes	Maintenance of feed lots	Disposal of solid-waste materials	Construction of jetties, groins, and piers	Construction of storm barriers and/or seawalls	Light construction	Construction of highways (excluding causeways)	Heavy construction	Flooding as a result of dam construction	Construction of production platforms and other oil well development activities	Placement of pipelines and/or subsurface cables	Dredging of canals and channels, and spoil disposal	Excavation, including extraction of natural materials	Filling for development	Draining of wetlands	Devegetation	Traversing with vehicles, including marsh buggies, air boats, dune buggies, and motorcycles	Light recreational activities, including hiking, nature trails, and pleasure boating	Use of herbicides, pesticides, insecticides
WATER RESOURCE UNITS: BAYS, ESTUARIES, AND LAGOONS	River-influenced bay, including prodelta and delta front	X	X		X	0	X					0	0	X		X					
	Enclosed bay	X	X		X	0	X					0	0	0		0					
	Living oyster reefs and related areas	X	X		X	X	X					X	X	X	X	X					
	Dead oyster and serpulid reefs and related areas	X	X		X	0	X					0	0	X	0	X					
	Grassflats	X	X		X	X	X					X	X	X		X		X	X		
	Mobil bay-margin sand	X	X		X	X	X					X	X	X	X	X					
	Open bay, lower end with tidal influence	X	X		X	0	X					0	0	X		X					
	Subaqueous spoil	X	X		X	0	0					0	0	0		0					
	Inlets and subaqueous tidal deltas	X	X		X	X	X					X	X	X		X					
	Tidal flats	X	X		X	0	0	X	X	X		0	0	0	X	X					
LAND RESOURCE UNITS: COASTAL WETLANDS	Salt-water marsh	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Fresh-water marsh	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Swamps	X	X		X			X	X	X	X	X	X	X	X	X	X	X	X	0	X
COASTAL BARRIERS	Beach and shoreface	X	X		X	X	X	X	X	X		X	0	X	X	X			0		0
	Fore-island dunes and vegetated barrier flat	X	X	X	X		X	‡	‡	‡		‡	0	X	X	‡		X	X	‡	X
	Washover areas	X	X	X	X	X	X	X	X	X		X	X	X	0	X					0
	Blowouts and back-island dune fields	X	X	X	X			X	X	X		X	0	X	0			X	0		X
	Wind-tidal flats	X	X	X	X		0	X	X	X		0	0	0	0	X					0
COASTAL PLAINS	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)

Significant problems unlikely (blank)

X Undesirable—significant problems likely

0 Possible problems

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

This 13-county map will soon be released for sale by the Bureau of Economic Geology.

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

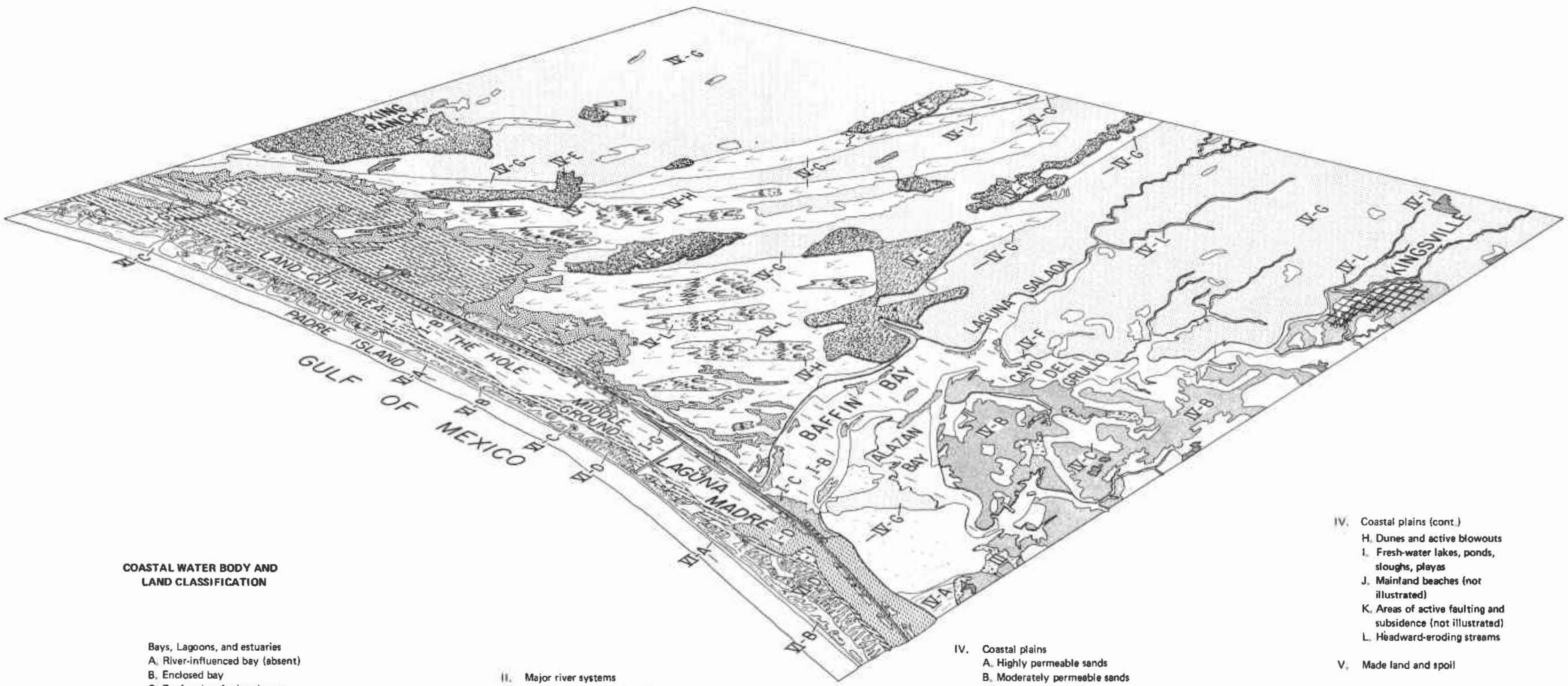
Evaluation of land and water resource units depends upon the human activities that result in the use of these units. Wide varieties of land and water use activities occur within the Coastal Zone (table 15); other activities will develop as population and urban-industrial expansion continues in the Zone. For each human activity or use, it is important to understand the qualitative and quantitative requirements that the activity will impose on any natural environment.

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

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

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 Kingsville area (fig. 30) illustrates the nature and distribution of land and water resource units; detailed, cartographically accurate maps can be constructed (derived from the *Environmental Geology Map*) to chart these vital environmental units. In any area, these basic resource units can be evaluated in terms of current and projected human activities; the limits of their capabilities for various uses allow for the development of guidelines permitting maximum use and minimum environmental degradation.

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



COASTAL WATER BODY AND LAND CLASSIFICATION

Bays, Lagoons, and estuaries
A. River-influenced bay (absent)
B. Enclosed bay
C. Reef and reef-related areas
D. Grassflats
E. Mobil bay-margin sands (not illustrated)
F. Tidally influenced open bay (absent)
G. Subaqueous spoil
H. Tidal inlet and tidal delta (absent)
I. Wind-tidal flats
J. Transitional wind-tidal flats

II. Major river systems
A. Point-bar sands (absent)
B. Overbank muds and silts (absent)
C. Water including related lakes and playas (not illustrated)

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. Vegetated (stabilized) sand-sheet and loess plains

IV. Coastal plains (cont.)
H. Dunes and active blowouts
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. Fore-island dunes and vegetated barrier flats
C. Washover areas
D. Active dunes
E. Tidal flats (absent)
F. Swales (absent)

Figure 30. Schematic map of land and water resource units, Kingsville map area.

COASTAL PROBLEMS: OBSERVATIONS AND RECOMMENDATIONS

The Kingsville area is unique along the Texas coast because of its low population density, limited industrial development, and federally protected Padre Island National Seashore. Nevertheless, it appears likely that eventually population expansion will occur in the area with resulting accelerated use of available natural resources. Any increased use of resources in the region will result in some degree of alteration of the natural state. Several types of resource use may be predicted: (1) use of resources, such as mineral deposits, that are finite and nonrenewable leading 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. The Kingsville area has experienced the least human impact of the entire Texas Coastal Zone.

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, normal waves and currents, and stream runoff. Redistributed spoil in many cases covers organically productive, vital coastal environments such as grassflats and salt marshes, altering them indefinitely to barren, unproductive sandflats.

EXCESSIVE CUTTING OF CHANNELS AND CREATION OF SPOIL BANKS SHOULD BE AVOIDED. WHERE POSSIBLE, SPOIL SHOULD NOT BE PILED ON BAY BOTTOMS OR ALONG BAY MARGINS WHERE IT IS SUBJECT TO REWORKING, BUT SHOULD BE CARRIED INLAND OR

DISPOSED OF OFFSHORE. CHANNELS NO LONGER USED SHOULD BE CLOSED AND FILLED TO RESTORE THE ORIGINAL LAND AND BAY-BOTTOM CONFIGURATIONS.

DEVEGETATION

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

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

SHORELINE CONSTRUCTION

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

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

WASTE DISPOSAL

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

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

FILLING AND LAND RECLAMATION

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

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

ARTIFICIAL PASSES

A number of artificial passes between inland bays and the Gulf have been cut in the barriers of the Texas Coastal Zone (for example, the presently closed Yarborough Pass in the Kingsville area); 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. These problems are treated in more detail by Brown and others (1974).

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 bay modifies the height of storm-surge tides. Funnel-shaped bays, for example, tend to intensify the height of storm surges. Stability of the barrier islands is a critical factor; unvegetated, low-relief barriers provide less deterrent to storm surges than do stabilized, vegetated barriers.

Hurricanes can breach barrier islands, creating washover or storm channels. Hurricane-tidal surge reaches the bay through these storm channels, as well as through the normal tidal passes. Storm channels across the barriers become inactive after passage of the storm but exist as depressions in the barrier though 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 Kingsville area exist in three states: erosional, depositional (accretionary), and naturally stabilized in depositional-erosional equilibrium. 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.

Land-surface subsidence is prominent only in the Greater Houston area, but also affects some land area near Corpus Christi and in the Bay City-Freeport and Beaumont-Port Arthur areas (Brown and others, 1974). 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

The Kingsville area is unique among the other regions of the Texas Coastal Zone. Its low population density, limited industrial development, and federally protected Padre Island National Seashore minimize to some degree the problems of varied and extensive land and water use experienced in more populous and industrialized regions. Even in the Kingsville area, however, seemingly inevitable population growth eventually will affect land and water use both in the magnitude of resource use and in the degree of competition among various uses for particular resources. At present, ground-water withdrawal is limited; oil and gas, the most significant economic support in the region are gradually declining; Coastal Zone management policies are constantly undergoing revision. Thus, the unique features in the Kingsville area will slowly become subjected to the impact of growth and change just as other areas of the Texas coast.

With increased and more competitive use of Coastal Zone lands and waters, voluntary or obligatory management policies must be developed. If these policies are to be prudent and fair, they must be based on an adequate inventory of natural resources, including composition and properties, related physical, chemical, and biologic processes, and natural capability to sustain varied and specific uses.

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

REFERENCES

Alaniz, R. T., and Goodwin, R. H., 1974, Recent sediments of a hypersaline estuary bay: Gulf Coast Assoc. Geol. Socs. Trans., v. XXIV, p. 308-313.

Andrews, P. B., 1964, Serpulid reefs, Baffin Bay, southeast Texas, *in* Depositional environments, south-central Texas coast: Gulf Coast Assoc. Geol. Socs., Field Trip Guidebook, Oct. 28-31, 1964, p. 101-120.

______ 1970, Facies and genesis of a hurricane-washover fan, St. Joseph Island, central Texas coast: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 67, 147 p.

Baker, E. T., Jr., 1971, Relation of ponded floodwater from Hurricane Beulah to ground water in Kleberg, Kenedy, and Willacy Counties, Texas: Texas Water Devel. Board Rept. 138, 33 p.

Beck, M. W., and Henderson, B. H., 1928, Soil survey of Cameron County, Texas: U. S. Bur. Chemistry and Soils, ser. 1923, no. 17, p. 537-575.

Behrens, E. W., 1963, Buried Pleistocene river valleys in Aransas and Baffin Bays, Texas: Univ. Texas, Marine Sci. Inst. Pub., v. 9, p. 7-18.

______ 1964, Oolite formation in Baffin Bay and Laguna Madre, Texas, *in* Depositional environments, south-central Texas coast: Gulf Coast Assoc. Geol. Socs., Field Trip Guidebook, Oct. 28-31, 1964, p. 82-100.

______ 1966, Surface salinities for Baffin Bay and Laguna Madre, Texas, April 1964-March 1966: Univ. Texas, Marine Sci. Inst. Pub., v. 11, p. 168-173.

Bernard, H. A., and LeBlanc, R. J., 1965, Resume of the Quaternary geology of the northwestern Gulf of Mexico province, *in* Wright, H. E., Jr., and Frey, D. G., eds., The Quaternary of the United States: Princeton, N. J., Princeton Univ. Press, p. 137-185.

Breuer, J. P., 1957, An ecological survey of Baffin and Alazan Bays, Texas: Univ. Texas, Marine Sci. Inst. Pub., v. 4, no. 2, p. 134-155.

Brewton, J. L., in preparation, Late Cenozoic depositional systems, South Texas coastal plain: Univ. Texas, Austin, Ph.D. dissert.

Brown, L. F., Jr., Fisher, W. L., Erxleben, A. W., and McGowen, J. H., 1971, Resource capability units—their utility in land- and water-use management with examples from the Texas Coastal Zone: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 71-1, 22 p.

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

______, Morton, R. A., McGowen, J. H., Kreitler, C. W., and Fisher, W. L., 1974, Natural hazards of the Texas Coastal Zone: Univ. Texas, Austin, Bur. Econ. Geology, 13 p., 7 maps.

Bullard, F. M., 1942, Source of beach and river sands on the Gulf coast of Texas: Geol. Soc. America Bull., v. 53, no. 7, p. 1021-1044.

Carr, J. T., Jr., 1967, The climate and physiography of Texas: Texas Water Devel. Board Rept. 53, 27 p.

Coffey, George N., 1909, Clay dunes: Jour. Geology, v. 17, p. 754-755.

Collier, A. W., and Hedgpeth, J. W., 1950, An introduction to the hydrography of tidal waters of Texas: Univ. Texas, Marine Sci. Inst. Pub., v. 1, no. 2, p. 120-194.

Curray, J. R., 1960, Sediments and history of Holocene transgression, continental shelf, northwest Gulf of Mexico, *in* Shepard, F. P., Phleger, F. B., and van Andel, T. H., eds., Recent sediments, northwest Gulf of Mexico: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 221-266.

Dalrymple, D. W., 1964, Recent sedimentary facies of Baffin Bay, Texas: Rice Univ., Ph.D. dissert., 192 p.

Deere, D. V., 1961, Subsidence due to mining—A case history from the Gulf coast region of Texas, *in* Mining engineering series—Proceedings of the 4th symposium on rock mechanics: Pennsylvania State Univ. Mineral Industries Expt. Sta. Bull. 76, p. 59-64.

Fisher, W. L., Brown, L. F., Jr., Scott, A. J., and McGowen, J. H., 1969, Delta systems in the exploration for oil and gas: a research colloquium: Univ. Texas, Austin, Bur. Econ. Geology, 212 p.

______, McGowen, J. H., Brown, L. F., Jr., and Groat, C. G., 1972. Environmental geologic atlas of the Texas Coastal Zone—Galveston-Houston area: Univ. Texas, Austin, Bur. Econ. Geology, 91 p., 9 maps.

Fisk, H. N., 1959, Padre Island and the Laguna Madre flats, coastal south Texas: La. State Univ., 2d Coastal Geography Conf., April 1959, p. 103-151.

Frazier, D. E., 1974, Depositional-episodes: their relationship to the Quaternary stratigraphic framework in the northwestern portion of the Gulf Basin: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 74-1, 28 p.

Freeman, T., 1962, Quiet water oolites from Laguna Madre, Texas: Jour. Sed. Petrology, v. 32, p. 475-483.

Frishman, S. A., 1969, Geochemistry of oolites, Baffin Bay, Texas: Univ. Texas, Austin, Master's thesis, 82 p.

Fruh, E. G., and others, 1972, The management of bay and estuarine systems—Phase I—A conceptual report: Austin, Texas, Office of the Governor, Coastal Resources Management Program, Div. Planning Coordination, coordinated through Univ. Texas, Austin, Div. Nat. Resources and Environment, p. F1-F36.

Gabrysch, R. K., and Bonnet, C. W., 1975, Land-surface subsidence in the Houston-Galveston region, Texas: Texas Water Devel. Board Rept. 188, 19 p.

Garner, L. E., 1967, Sand resources of Texas Gulf coast: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 60, 85 p.

Hayes, M. O., 1967, Hurricanes as geological agents: Case studies of Hurricanes Carla, 1961, and Cindy, 1963: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 61, 56 p.

Hedgpeth, J. W., 1947, The Laguna Madre of Texas: 12th North Am. Wildlife Conf., Trans., p. 364-380.

Huffman, G. G., and Price, W. A., 1949, Clay dune formation near Corpus Christi, Texas: Jour. Sed. Petrology, v. 19, no. 3, p. 118-127.

Hunter, R. E., 1972, Traverse across central Padre Island, *in* Modern depositional environments and processes, northern and central Padre Island, Texas: Gulf Coast Assoc. Geol. Socs., Padre Island Natl. Seashore Field Guide, Oct. 14, pt. I, p. 24-25.

______, Hill, G. W., and Dickinson, K. A., 1972a, Traverse across northern Padre Island, *in* Modern depositional environments and processes, northern and central Padre Island, Texas: Gulf Coast Assoc. Geol. Socs., Padre Island Natl. Seashore Field Guide, Oct. 14, pt. I, p. 4-17.

______, Watson, R. L., Hill, G. W., and Dickinson, K. A., 1972b, Geology of Padre Island, Part I, *in* Modern depositional environments and processes, northern and central Padre Island, Texas: Gulf Coast Assoc. Geol. Scos., Padre Island Natl. Seashore Field Guide, Oct. 14, pt. I, p. 1-27.

Johnston, M. C., 1955, Vegetation of the eolian plain and associated features of southern Texas: Univ. Texas [Austin], Ph.D. dissert., 167 p.

Kier, R. S., and Bell, D. L., 1974, Quantification of resource capability units, Corpus Christi area, *in* Wermund, E. G., ed., Approaches to environmental geology: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 81, p. 152-183.

______, White, W. A., Fisher, W. L., Bell, Dennis, Patton, P. C., and Woodman, J. T., 1974, Establishment of operational guidelines for Texas Coastal Zone Management—Final report on resource capability units II: Land resources of the Coastal Bend region, Texas: Univ. Texas, Austin, Bur. Econ. Geology, Div. Nat. Resources and Environment, 266 p.

Kreitler, Charles W., 1976, Lineations and faults in the Texas Coastal Zone: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 85, 32 p.

Lohse, E. A., 1952, Shallow marine sediments of the Rio Grande delta: Univ. Texas [Austin], Ph.D. dissert., 113 p.

______ 1958, Geochronology of mud flats through varve analysis, *in* Sedimentology of South Texas: Corpus Christi Geol. Soc. Guidebook, p. 47.

Lundelius, E. L., Jr., 1972, Fossil vertebrates from the late Pleistocene Ingleside fauna, San Patricio County, Texas: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 77, 74 p.

Martinez, Rudy, 1965, Coastal hydrographic and meteorological study: Texas Parks and Wildlife Dept., Coastal Fisheries Proj. Rept., p. 169-210.

______ 1966, Coastal hydrographic and meteorological study: Texas Parks and Wildlife Dept., Coastal Fisheries Proj. Rept., p. 105-146.

______ 1967, Coastal hydrographic and meteorological study: Texas Parks and Wildlife Dept., Coastal Fisheries Proj. Rept., p. 77-112.

McGowen, J. H., 1970, Gum Hollow fan delta, Nueces Bay, Texas: Univ. Texas, Austin, Bur. Econ. Geology Rept. Inv. 69, 91 p.

______, and Brewton, J. L., 1975, Historical changes and related coastal processes, Gulf and mainland shorelines, Matagorda Bay area, Texas: Univ. Texas, Austin, Bur. Econ. Geology, 72 p., 16 maps.

______, Groat, C. G., Brown, L. F., Jr., Fisher, W. L., and Scott, A. J., 1970, Effects of Hurricane Celia—A focus on environmental geologic problems of the Texas Coastal Zone: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 70-3, 35 p.

McMahan, C. A., project leader, 1965-1967, Ecology of principal waterfowl foods of Laguna Madre: Texas Parks and Wildlife Dept., Federal Aid in Wildlife Restoration Act, Texas, Job Progress Rept. No. 17.

Melton, F. A., 1940, A tentative classification of sand dunes, its application to dune history in the southern High Plains: Jour. Geology, v. 48, no. 2, p. 113-174.

Morton, Robert A., and Pieper, Mary J., 1977a, Shoreline changes on central Padre Island (Yarborough Pass to Mansfield Channel), An analysis of historical changes of the Texas Gulf shoreline: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 77-2, 35 p.

______ 1977b, Shoreline changes on Mustang Island and North Padre Island (Aransas Pass to Yarborough Pass), An analysis of historical changes of the Texas Gulf shoreline: Univ. Texas, Austin, Bur. Econ. Geology Geol. Circ. 77-1, 45 p.

Nelson, H. F., and Bray, E. E., 1970, Stratigraphy and history of the Holocene sediments in the Sabine-High Island area, Gulf of Mexico, *in* Morgan, J. P., and Shaver, R. H., eds., Deltaic sedimentation, modern and ancient: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 15, p. 48-77.

Orton, Robert, 1964, The climate of Texas and the adjacent Gulf waters: U. S. Dept. Commerce, Weather Bur. Rept. 16, 195 p.

______ 1969, Map of Texas showing normal precipitation deficiency in inches: Austin, Texas, U. S. Dept. Commerce, Environmental Sci. Services Adm., Weather Bur.

Parker, R. H., 1959, Macro-invertebrate assemblages of central Texas coastal bays and Laguna Madre: Am. Assoc. Petroleum Geologists Bull., v. 43, p. 2100-2166.

______ 1960, Ecology and distributional patterns of marine macro-invertebrates, northern Gulf of Mexico, *in* Shepard, F. P., Phleger, F. B., and van Andel, T. H., eds., Recent sediments, northwest Gulf of Mexico: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 302-337.

Pratt, W. E., and Johnson, D. W., 1926, Local subsidence of the Goose Creek oil field: Jour. Geology, v. 34, p. 577-590.

Price, W. A., 1933, Role of diastrophism in topography of Corpus Christi area, south Texas: Am. Assoc. Petroleum Geologists Bull., v. 17, no. 8, p. 907-962.

______ 1958, Sedimentology and Quaternary geomorphology of south Texas: Gulf Coast Assoc. Geol. Socs. Trans., v. 8, p. 41-75.

______ 1963, Physiochemical and environmental factors in clay dune genesis: Jour. Sed. Petrology, v. 33, p. 766-778.

______, and Gunter, Gordon, 1942, Certain recent geological and biological changes in south Texas, with consideration of probable causes: Texas Acad. Sci. Proc. and Trans., 1942, v. 26, p. 138-156 [1943].

______, and Kornicker, L. S., 1961, Marine and lagoonal deposits in clay dunes, Gulf Coast, Texas: Jour. Sed. Petrology, v. 31, no. 2, p. 245-255.

Railroad Commission of Texas, 1971, Map of Gulf coast area showing pipelines that carry liquid hydro-carbons and products exclusive of dry gas: Railroad Comm. of Texas.

Rusnak, G. A., 1960, Sediments of Laguna Madre, Texas, *in* Shepard, F. P., Phleger, F. B., and van Andel, T. H., eds., Recent sediments, northwest Gulf of Mexico: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 153-196.

Scott, A. J., Hayes, M. O., Andrews, P. B., Siler, W. L., and Behrens, E. W., 1964, Depositional environments, south-central Texas coast: Gulf Coast Assoc. Geol. Socs., Field Trip Guidebook, Oct. 28-31, 1964, 170 p.

Shafer, G. H., and Baker, E. T., Jr., 1973, Ground-water resources of Kleberg, Kenedy, and southern Jim Wells Counties, Texas: Texas Water Devel. Board Rept. 173, 162 p.

Sheets, M. M., 1947, Diastrophism during historic time in Gulf Coastal Plain: Am. Assoc. Petroleum Geologists Bull., v. 31, p. 201-226.

Simmons, E. G., 1957, An ecological survey of the upper Laguna Madre of Texas: Univ. Texas, Marine Sci. Inst. Pub., v. 4, no. 2, p. 156-200.

St. Clair, A. E., Proctor, C. V., Jr., Fisher, W. L., Kreitler, C. W., and McGowen, J. H., 1975, Land and water resources—Houston-Galveston Area Council: Univ. Texas, Austin, Bur. Econ. Geology Land Resources Lab. Series, 25 p.

Stokes, W. L., 1968, Multiple parallel-truncation bedding planes—A feature of wind-deposited sandstone formations: Jour. Sed. Petrology, v. 38, no. 1, p. 510-515.

Transcontinental Gas Pipe Line Corporation, 1970, Map of Texas Gulf coast and Texas continental shelf showing natural gas pipe lines: Houston, Texas, Transcontinental Gas Pipe Line Corp., Gas Supply Dept., prepared by M. F. Stanley and R. W. Evans.

U. S. Army Corps of Engineers, 1962, Report on Hurricane Carla 9-12 September 1961: U. S. Army Corps Engineers, Galveston Dist., 29 p., tables, plates, appendix.

_______ 1968, Report on Hurricane Beulah 8-21 September 1967: U. S. Army Corps Engineers, Galveston Dist., 26 p., tables, plates.

Watson, R. L., 1968, Origin of shell beaches, Padre Island, Texas: Univ. Texas, Austin, Master's thesis, 121 p.

_______ 1971, Origin of shell beaches, Padre Island, Texas: Jour. Sed. Petrology, v. 41, no. 4, p. 1105-1111.

_______ 1972, Longshore variations in beach sediment and origin of the shell beaches, *in* Modern depositional environments and processes, northern and central Padre Island, Texas: Gulf Coast Assoc. Geol. Socs., Padre Island Natl. Seashore Field Guide, Oct. 14, pt. I, p. 17-24.

Wilkinson, B. H., 1973, Matagorda Island—The evolution of a Gulf coast barrier complex: Univ. Texas, Austin, Ph.D. dissert., 178 p. [1974].

_______, McGowen, J. H., and Lewis, C. R., 1975, Ingleside strandplain sand of central Texas coast: Am. Assoc. Petroleum Geologists Bull., v. 59, p. 347-352.