SUBMERGED LANDS OF TEXAS, KINGSVILLE AREA:

SEDIMENTS, GEOCHEMISTRY, BENTHIC MACROINVERTEBRATES, AND ASSOCIATED WETLANDS

W. A. White, T. R. Calnan, R. A. Morton, R. S. Kimble, T. G. Littleton, J. H. McGowen, and H. S. Nance

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BUREAU OF ECONOMIC GEOLOGY

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Cover: Kingsville area as shown on a National Aeronautics and Space Administration Landsat multispectral scanner image.

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PREFACE

The utility of the Bureau of Economic Geology's Environmental Geologic Atlas series (Brown, 1972–1980) in presenting needed coastal information for State, Federal, regional, and local agencies and for private businesses and individuals provided the impetus for a more detailed inventory of the submerged coastal lands of Texas. This resulting atlas of the Kingsville area is the last of seven atlases that focus on the submerged lands and coastal wetlands of Texas from the Rio Grande to Sabine Lake.

Since 1969, when the Bureau of Economic Geology initiated the Environmental Geologic Atlas Project, the Coastal Zone has continued to be an area of population, industrial, transportational, commercial, and recreational growth and development. Much of the development directly and indirectly affects submerged lands. For example, approximately 1,000 applications a year are processed by the General Land Office of Texas for various types of easements and permits within submerged and associated State coastal lands. Consolidated tonnage handled by Texas ports increased from about 193 million tons in 1970 to more than 245 million tons in 1985. In 1987, commercial and recreational fishing activities, together, had an economic impact (direct and indirect) of around $1.9 billion. Mineral receipts by the State of Texas from offshore areas in FY 1986 were in excess of $88 million.

Submerged lands and associated coastal wetlands of Texas are part of a dynamic natural system that is physically, biologically, and chemically active, yet in a state of natural balance. The system is affected by a variety of processes, climatic conditions, and human activities. Geologically, the bay-estuary-lagoon and inner-shelf systems, which compose the submerged lands of Texas, are evolving and undergoing slow but natural change. Biologically and chemically, these coastal areas and their fringing marshes are highly productive and form an ecosystem in which a variety of flora and fauna are integrally connected. Today, people and their activities are so much a part of the system that they, too, must be considered to be integrally connected to it. Human activities can have a significant and often immediate effect on a local and sometimes regional scale. Investigating and understanding the resulting cause-and-effect relationships are not possible without detailed and comprehensive scientific knowledge of the system's natural basic components.

The atlases of the submerged lands of Texas provide an extensive spatial data base on sediment texture, sediment geochemistry, benthic macroinvertebrates, and associated wetlands. Identifying, mapping, and characterizing these essential components of nearshore coastal environments provide important baseline information for anticipating, managing, and measuring the effects of the multitude of coastal activities that are directly and indirectly tied to submerged lands. Characterization of the State-owned submerged lands is based on the collection and analysis of thousands of bottom samples. Various phases of the study were conducted in cooperation with the U.S. Geological Survey. This atlas series was designed, in part, to complement the Bureau's Environmental Geologic Atlas series by providing significantly updated and detailed information on the submerged lands and associated coastal wetlands of Texas.

William L. Fisher
Director, Bureau of Economic Geology

ABSTRACT

Surface sediment textures, sediment geochemistry, and benthic fauna of the State-owned submerged lands were mapped and described using bottom samples collected at 1-mi (1.6-km) intervals from bays, estuaries, lagoons, and the inner continental shelf. In addition, the distribution of wetlands in adjacent areas was mapped using color-infrared photographs taken in 1979.

Textural maps of the Kingsville area show that mud, sand, and muddy sand are the dominant sediment types in bay-estuary-lagoon and inner-shelf areas. Mud dominates the deeper central areas of the Baffin-Alazan Bay system and grades, near the bay margins, into sandy mud, muddy sand, and sand. Sand and muddy sand are the most abundant sediment types in Laguna Madre and reflect the proximity of this relatively shallow lagoon to sand-rich Padre Island. The mean grain size of sediments in central areas of the Baffin-Alazan Bay system commonly exceeds 7ϕ, and locally reaches 8.1ϕ, which is in marked contrast to Laguna Madre, where the mean grain size rarely exceeds 5ϕ. On the inner shelf, a zone of nearshore sand parallels the coastline except near the southern end of the map area, where it arcs gently seaward. Muddy fine sands lie seaward of the nearshore sand in a band that roughly parallels the sand trend. The muddy sand grades into a narrow belt of sandy mud that in turn grades into mud that is deposited along much of the seaward perimeter of the study area. Sediments on the inner shelf are coarsest at the southern end of the map area, where mean grain size is less than 3ϕ; mean grain size of shelf mud ranges from about 5.5ϕ to 7ϕ.

To show the concentrations of heavy metals and other chemical components in the sediments, 12 elements were selected: total organic carbon, barium, boron, calcium, chromium, copper, iron, lead, manganese, nickel, strontium, and zinc. Concentrations of many of these chemical elements correlate with sediment textures; concentrations are generally highest where fine-grained sediments (muds) are most abundant and lowest where sand is abundant. Normalization of elemental concentrations with percent mud proved to be an effective method for defining trends, making comparisons between bay and shelf areas, and isolating anomalies. In sediments composed predominantly of mud (greater than 75 percent mud), mean concentrations of boron, chromium, copper, iron, lead, manganese, nickel, and zinc are higher in shelf muds than in bay muds. Mean concentrations of total organic carbon, barium, and strontium are higher in bay sediments. Samples containing anomalously high trace metal concentrations were identified by plotting the concentration of the different chemical elements against mud content. A few of these higher than normal concentrations, such as barium in some areas of the Baffin Bay system, are attributed to anthropogenic sources.

Benthic macroinvertebrates found in sediments of the bay-estuary-lagoon system and the inner shelf are primarily polychaetes, bivalves, gastropods, and crustaceans. Polychaetes are the most numerous species, followed by mollusks and crustaceans. On the inner shelf, the greatest number of species per station generally occurs at stations 1 to 5 mi (1.6 to 8.1 km) offshore. In Laguna Madre and the Baffin-Alazan Bay system, species counts were highest at grassflat stations. Distributions of the macroinvertebrates were related to bathymetry and sediment type. The average number of species per station on the inner shelf is generally highest in a depth range of 42 to 60 ft (12.8 to 18.3 m). The highest species counts on the inner shelf generally occur in sediments ranging from 40 to 100 percent sand. Diversity values on the inner shelf are generally high to very high. In Laguna Madre, diversity values are highest at grassflat stations south of the Land-Cut Area and at grassflat stations north of the mouth of Baffin Bay. Using cluster analyses, three macroinvertebrate assemblages were delineated on the inner shelf and four were delineated in the bay-estuary-lagoon system.

Wetlands and associated environments bordering the submerged lands and occurring in more inland areas were classified primarily on the basis of vegetation and general moisture and salinity conditions. In the Kingsville area, 18 map units, including three marsh categories, were used to delineate wetlands. Major marsh units include salt-, brackish-, and fresh-water marshes, each subdivided into "high" and "low" categories according to moisture conditions and vegetation depicted in 1979 photographs. Photographic analysis was confirmed by representative field surveys (1979 to the mid-1980's) and augmented by other available data. Among the most extensive environments mapped outside the broad

wind-tidal flats that flank the lagoon are numerous depressions, originating principally through deflation, which are the sites of ponded water, marshes, and transitional areas on Padre Island and the mainland. Collectively, these numerous small- to moderate-sized, commonly intermittent wetlands compose an important resource in the Kingsville area. Absent in this semiarid region are the extensive proximal salt-water marshes that characterize the intertidal areas along the upper Texas coast. Marine grass-flats, which are extensive in Laguna Madre and less extensive in the Baffin-Alazan Bay system, are among the productive biologic units that characterize the area. Wetlands mapped for this project were compared with those of the Environmental Geologic Atlas of the Texas Coastal Zone (mapped using 1934–1960 photographs). The comparison suggests that some changes, such as the local expansion of marine grasses in areas previously mapped as wind-tidal flats, are in part related to compactional subsidence and relative sea-level rise. Changes are also related to active dune migration and temporal climatic variations marked by above-normal precipitation in 1979.

Keywords: *Alazan Bay, assemblages, atlas, Baffin Bay, barrier islands, bathymetry, bays, benthonic taxa, coastal environment, crustaceans, estuaries, geochemistry, grain size, inner shelf, invertebrates, lagoon, Laguna Madre, major elements, marine geology, marine grasses, marshes, minor elements, mollusks, organic carbon, Padre Island, polychaetes, salt marshes, sampling, sediments, serpulid reef, South Texas, species diversity, statistical analysis, submerged lands, trace elements, trace metals, wetlands, wind-tidal flats*

THE SUBMERGED LANDS OF TEXAS PROJECT

INTRODUCTION

The State-owned submerged lands of Texas encompass almost 6,000 mi^2 (15,540 km^2). They lie below waters of the bay-estuary-lagoon system and the Gulf of Mexico and extend 10.3 mi (16.6 km) seaward from the Gulf shoreline (fig. 1). The importance of these lands and their resources to resident flora and fauna as well as to people is well known and documented; more than one-third of the state's population is concentrated within an area of the Coastal Zone that is only about one-sixteenth of the state's land area. Present and future interactions of human activities (which include energy, mineral, transportational, recreational, and industrial development) with submerged lands demand a comprehensive understanding of the potential short-term and long-term effects of these interactions. Such an understanding must rest largely on a detailed inventory of the basic components of these lands. The Submerged Lands of Texas Project was designed in part to accomplish this objective (McGowen and Morton, 1979).

Initiated in 1975, the Submerged Lands of Texas Project was based primarily on an intensive sampling program in which approximately 6,700 surficial bottom samples were collected at regularly spaced distances across the submerged lands. The sample-collection phase of the study was followed by an analytical phase that included detailed sedimentological, geochemical, and biological analyses. Many of the samples were analyzed to characterize submerged lands in terms of (1) sediment distribution, (2) selected trace and major element concentrations, and (3) benthic macroinvertebrate populations. Additionally, the interconnection of submerged lands with adjacent marshes and associated wetlands led to an expansion of the project to include the distribution of wetlands. Maps and reports derived from the study were published as a series of seven atlases of the Texas coast, divided into areas (fig. 1) similar to those defined in the Bureau's Environmental Geologic Atlas Series (Brown, 1972–1980) and in a special report on submerged lands in Texas (McGowen and Morton, 1979). Each of the submerged lands atlases includes a text describing the maps of sediment types, sediment geochemistry, benthic macroinvertebrates, and wetlands. The atlas of the Corpus Christi area (White and others, 1983) was the first in the Submerged Lands of Texas series; this atlas of the Kingsville area is the seventh and last in the series.

DATA ACQUISITION AND ANALYSES

Surficial sediment samples were taken with grab samplers at sites spaced approximately 1 mi (1.6 km) apart in the bay-estuary-lagoon system and on the inner continental shelf to a distance of about 11.2 mi (18 km) seaward of the Gulf shoreline. Ponar clam-shell grab samplers, having a capacity of approximately 0.065 ft^3 (0.0018 m^3), were used in the bay system, and Smith-McIntyre samplers, having a capacity of 0.46 ft^3 (0.013 m^3), were used on the inner shelf. Sediment penetration depths ranged from 1.5 to 4 inches (4 to 10 cm). Samples were described at the time of collection in terms of sediment type, color, and other visual characteristics (McGowen and Morton, 1979) and were subsampled and stored in containers for quantitative sedimentological, geochemical, and biological analyses in the laboratory. Although acquired data are considered comparable throughout the entire study area, different types of equipment and collection techniques were used in the bays and on the inner shelf. This was primarily because of differences in size, water depths, and wave heights between the two systems, which influenced the effectiveness of different sampling and navigation techniques. For example, precision radio-navigation equipment was used to determine shelf sample localities, whereas less accurate triangulation and dead-reckoning navigation were used in the bays. In addition, in sampling sandy bay sediments, multiple grabs were usually necessary to obtain enough sediment for processing. Bathymetric and geophysical data were also collected during the sampling phase of the Submerged Lands of Texas Project (McGowen and Morton, 1979).

The wetlands study, which was begun after submerged lands sampling ended, was designed to update information on the distribution of wetlands previously mapped as part of the Environmental Geologic Atlas series (Brown, 1972–1980). Wetlands mapping is based primarily on photographic analysis supported by field data.

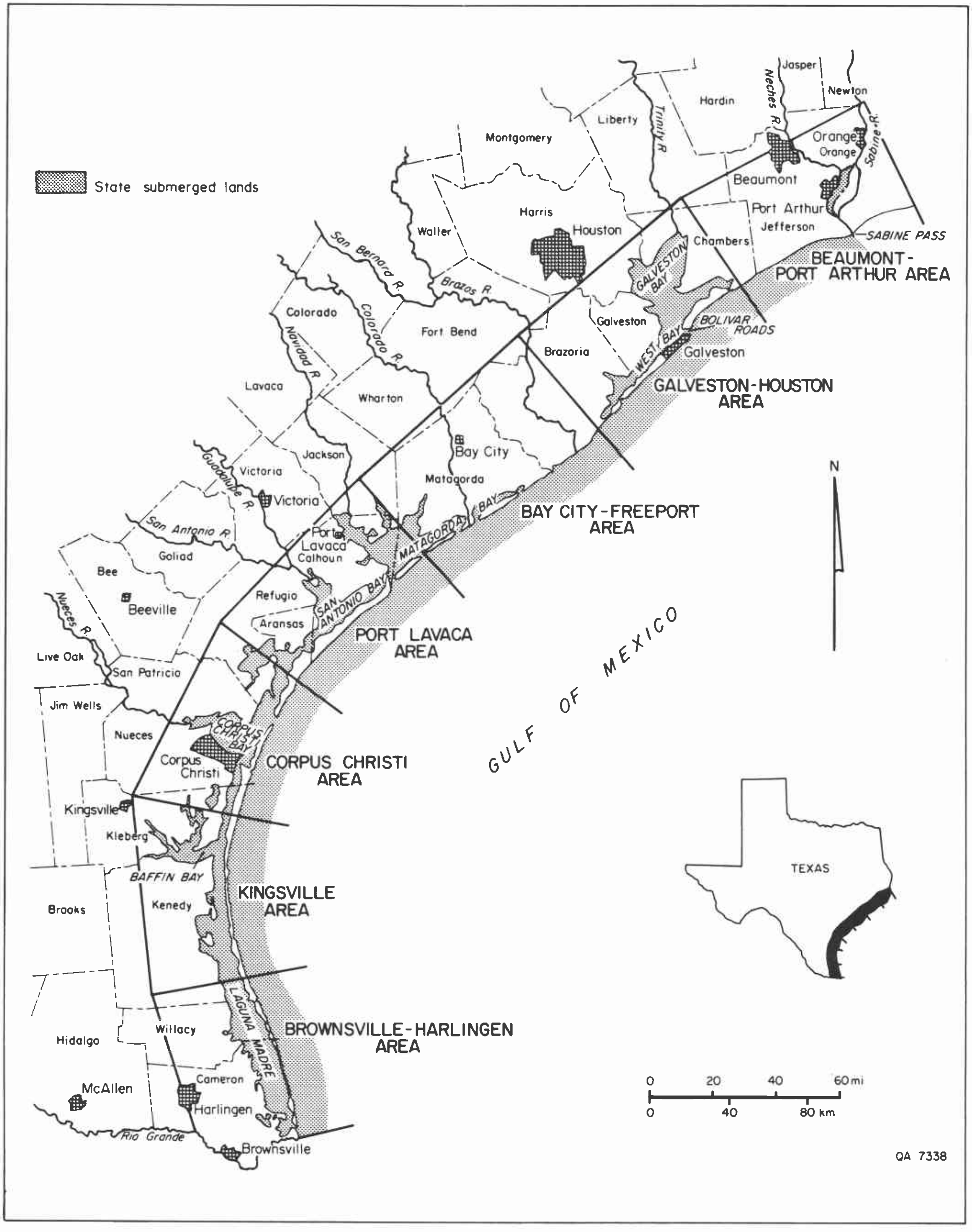

Figure 1. **Index map showing seven area maps that cover the submerged coastal lands of Texas (modified from McGowen and Morton [1979] and Brown [1972-1980]).**

Following are brief, introductory comments on the different analytical phases of the project, dealing with sediments, geochemistry, benthic macroinvertebrates, and wetlands. In-depth discussions of these topics, characterizing the submerged lands and associated wetlands in the Kingsville area, are found in later sections.

Sediments

Textural analyses provided the primary sedimentologic data on the submerged lands. Analyses were performed by the staff of the Bureau of Economic Geology's Sedimentology Laboratory, except for samples from the southern half of the inner shelf in the Brownsville-Harlingen map sheet area (fig. 1), which were analyzed by the U.S. Geological Survey (USGS). Textural analyses included quantitative determination of the gravel, sand, and mud fractions in each sample, followed by more detailed textural analyses of the sand and mud fractions (app. A). Size distribution in the sand fraction was determined with a rapid sediment analyzer (Schlee, 1966) and in the mud (silt and clay) fraction, with a Coulter Counter (Shideler, 1976).

Sediment types are classified on the basis of relative percentages in accordance with the triangular classification system shown in figure 2, in which shell(gravel), sand, and mud are the end members of the triangle, and in figure 3, in which sand, silt, and clay are the end members.

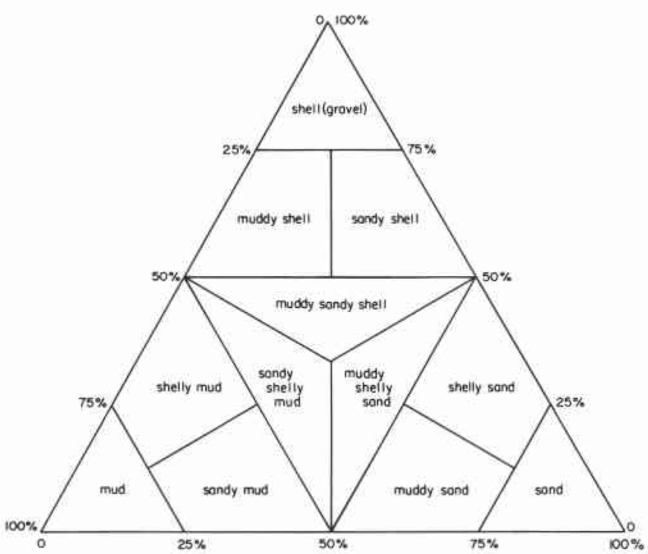

***Figure 2.* Classification of sediment types: shell(gravel) - sand - mud, submerged lands of Texas (from McGowen and Morton [1979]).**

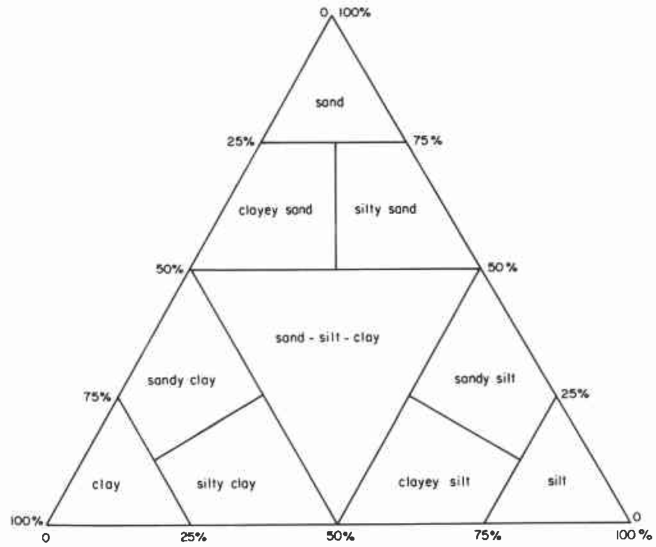

***Figure 3.* Classification of sediment types: sand - silt - clay, submerged lands of Texas (modified from Shepard and Moore [1955]).**

With each sediment sample thus classified, the distributions of the various sediment types were mapped. One map shows the distribution of gravel, sand, and mud and various ratios of these basic components; the second map shows the distribution of sand, silt, and clay. A third map showing the distribution of sand (sand-percent map) and a fourth depicting the distribution of mean grain sizes within the sand and mud fractions complete the suite of textural maps (pl. I) in each submerged lands atlas.

Geochemistry

Geochemical data on submerged lands consist of analyses of whole-sediment samples to determine the concentration of total organic carbon (TOC) and a spectrum of major and trace elements. Such information helps to clarify the relation between sediment size and associated trace metal abundance. More important, the data, when mapped, provide an inventory of the regional distribution of various detectable trace and major elements in the surface sediments of submerged lands.

More than 6,500 samples were analyzed for TOC by staff at the Bureau's Mineral Studies Laboratory, using a wet-combustion technique (Jackson, 1958). Approximately 3,800 samples were analyzed for trace and major element concentrations. The USGS Analytical Laboratories in Reston, Virginia, performed most of these latter analyses using an emission spectrograph and a computerized system of spectral analysis (Dorrzapf, 1973), which provides semiquantitative results (relative standard deviation for each reported concentration being +50 percent and -33 percent).*

Supplementary quantitative analyses of chemical elements in selected samples were conducted by the Bureau's Mineral Studies Laboratory staff, using an inductively coupled plasma-atomic emission spectrometer (ICP-AES). Samples were fused at a high temperature with lithium (tetra:meta) borate and dissolved in dilute hydrochloric acid. The ICP-AES provides highly reproducible data because the variability of duplicate analyses for most elements is less than 2 percent. The accuracy of analyses for most common major and minor elements usually ranges from 100 $\pm$ 1 percent to 100 $\pm$ 5 percent (depending on the element) if the concentration levels fall within the optimal range for quantitative measurement. The optimal range is 5 to 10^4 times the detection limit for each element (C. L. Ho and S. W. Tweedy, personal communication, 1982). The accuracy of analyses of trace elements is not as high, particularly when the concentration is near the minimum level of detection.† Because two different methods of chemical element analysis were used—the computer-assisted emission spectrographic method used by the USGS and the ICP-AES method used by the Bureau of Economic Geology—both sets of data are identified separately on maps and in figures and tables.

Samples were scanned for as many as 65 elements. (The number of elements differed depending on which method of analysis was used.) Twelve elements were selected for mapping: total organic carbon (TOC), barium (Ba), boron (B), calcium (Ca), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), nickel (Ni), strontium (Sr), and zinc (Zn). Trace and major element maps of the Kingsville area, discussed in the section Geochemistry (p. 23), are shown on plates II through IV.

**On the basis of initial calibration conditions, the minimum concentrations (in parts per million) for elements determined by computerized spectrographic analysis of silicate rocks are barium, 2.2; boron, 4.6; chromium, 1.0; copper, 1.5; lead, 6.8; manganese, 1.0; nickel, 1.5; strontium, 1.0; and zinc, 15.*

†The minimum level of detection for each element analyzed by ICP-AES varies depending on the dilution factor resulting from dissolution of the solid sample. The abundance of interfering elements also can affect detection limits. In general, given a dilution factor of 100 (most commonly used in this study), the minimum levels of detection in parts per million are barium, 1; calcium, 7; chromium, 3; copper, 3-5; iron, 2; lead, 40; manganese, 0.5; nickel, 7; strontium, 0.5; and zinc, 1. Minimum level of detection given for lead is for a solid sample.

Benthic Macroinvertebrates

A total of 1,620 benthic samples, consisting of 1,066 samples from the Texas bay-estuary-lagoon system and 554 from the inner shelf, were examined in this study. Live macroinvertebrates were identified (to species level when possible) and counted. Dead mollusks were identified by disarticulated shells and similar criteria, but individual counts of the dead-collected species were made only in the Corpus Christi and Galveston-Houston areas (fig. 1).

Processing the biological samples for analysis included a shipboard phase and a laboratory phase. In the shipboard phase, inner-shelf samples were washed through a 0.5-mm or 1-mm screen and narcotized with a solution of propylene phenoxytol. Bay-estuary-lagoon samples were washed through a 1-mm screen and narcotized with a solution of magnesium sulfate. Processed samples were stored in a neutral solution of 10 percent formalin. Rose bengal was added to the formalin to help distinguish live from dead specimens.

Laboratory processing included further washing of the samples and storage in 70 percent ethanol. Samples were then examined microscopically, and live and whole shells were counted. Fragments of shells were counted only if identifiable characters and at least 50 percent of the shell were preserved. Live and paired (articulated) dead pelecypod valves were counted as one; unpaired (disarticulated) valves were counted as one-half.

Each major invertebrate group (Mollusca, Polychaeta, and Crustacea) is discussed individually, and its distribution is related to sediment texture and bathymetry. In addition, distributions of benthic assemblages and species diversity at each station are shown on plate V. Numerical analyses helped delineate the assemblages. Computer and mapping techniques are discussed in the section Macroinvertebrate Assemblages (p. 58).

Wetlands

Wetlands were interpreted and delineated using National Aeronautics and Space Administration (NASA) stereoscopic, color-infrared (CIR) positive transparencies taken primarily in 1979, at a scale of approximately 1:66,000 (1 inch = approximately 1 mi). Mapping procedures were similar to those used in preparing the Environmental Geologic Atlas series (Brown, 1972–1980); mapping involved extensive interpretation of aerial photographs, field work, and utilization of published data for the region.

The wetland units described and mapped herein are patterned, with some modifications, after those established specifically for the Texas coast in the Environmental Geologic Atlas series. General differences between this mapping effort and the earlier atlas series include the following: (1) photographs used for this study (1979 color-infrared stereopair) are a major improvement over the 1950's–early 1960's (and locally 1930's) black-and-white photomosaics used in the earlier atlases and allow a more accurate and detailed subdivision of map units; (2) more emphasis is placed on detailed subdivision and mapping of the wetlands by focusing specifically on wetlands and excluding the classification of upland areas; (3) additional field observations made in selected areas after the original atlases were prepared provide a more detailed picture of the distribution of plant assemblages in many areas; and (4) improved photographic quality and cartographic capability permit depiction of smaller map areas than was possible on the earlier atlas maps. These smaller map units provide the necessary detail for users who need to enlarge the maps.

Distributions of wetlands and benthic macroinvertebrates are shown together on full-color maps. Base maps were modified from the Environmental Geologic Atlas series (scale 1:125,000 or 1 inch = 2 mi). Shoreline features, such as spoil islands and navigation channels, that have undergone changes since preparation of the earlier atlas were updated by using the 1979 photographs. Highways, other transportation networks, cultural features, and unchanged inland streams and canals were delineated using the original atlas map base. Changes in routes of major highways were selectively updated using county road maps published in 1983 by the Texas Department of Highways and Public Transportation. A much more detailed discussion of wetlands is presented later in this report (p. 67).

KINGSVILLE AREA

The Kingsville map area, as defined in figure 1 and plates I through VI, encompasses the Baffin-Alazan Bay system and parts of Laguna Madre. The bay-estuary-lagoon system, which is separated from the Gulf of Mexico by Padre Island, is characterized by high salinities. Cayo del Grullo and Laguna Salada are part of the Baffin Bay system. Laguna Madre, which is a long narrow lagoon extending north and south of the Kingsville area (fig. 1), has been subdivided informally into lower Laguna Madre (the southern part) and upper Laguna Madre (the northern part). Upper and lower Laguna Madre are separated by extensive wind-tidal flats in the Land-Cut Area but are hydrologically connected under normal conditions by the Intracoastal Waterway. They are connected more completely under storm conditions, when high tides inundate the interlying flats. The Intracoastal Waterway extends from the northern to the southern boundaries of the study area and is bordered along most of its length by dredged spoil. Branch navigation channels, dredged for petroleum exploration and development, extend out from the Intracoastal Waterway in many areas.

The fluvial system in the Kingsville area, which reflects semiarid climatic conditions, is made up of ephemeral creeks, all of which discharge into the Baffin Bay system in the northern third of the map area (fig. 4). Also reflecting the normally dry climatic conditions in this South Texas region is an extensive eolian system (Price, 1958; Brown and others, 1977) that characterizes most of the study area. Active sand dunes are significant features on the mainland as well as on Padre Island.

Kingsville is the only major city in the map area. Riviera, Sarita, and Armstrong are among the small rural communities located along U.S. Highway 77. The Kingsville area is dominated by rangeland, much of which is encompassed by the King and Kenedy Ranches. All of Padre Island in the study area, with the exception of some lagoonward-extending wind-tidal flats, lies

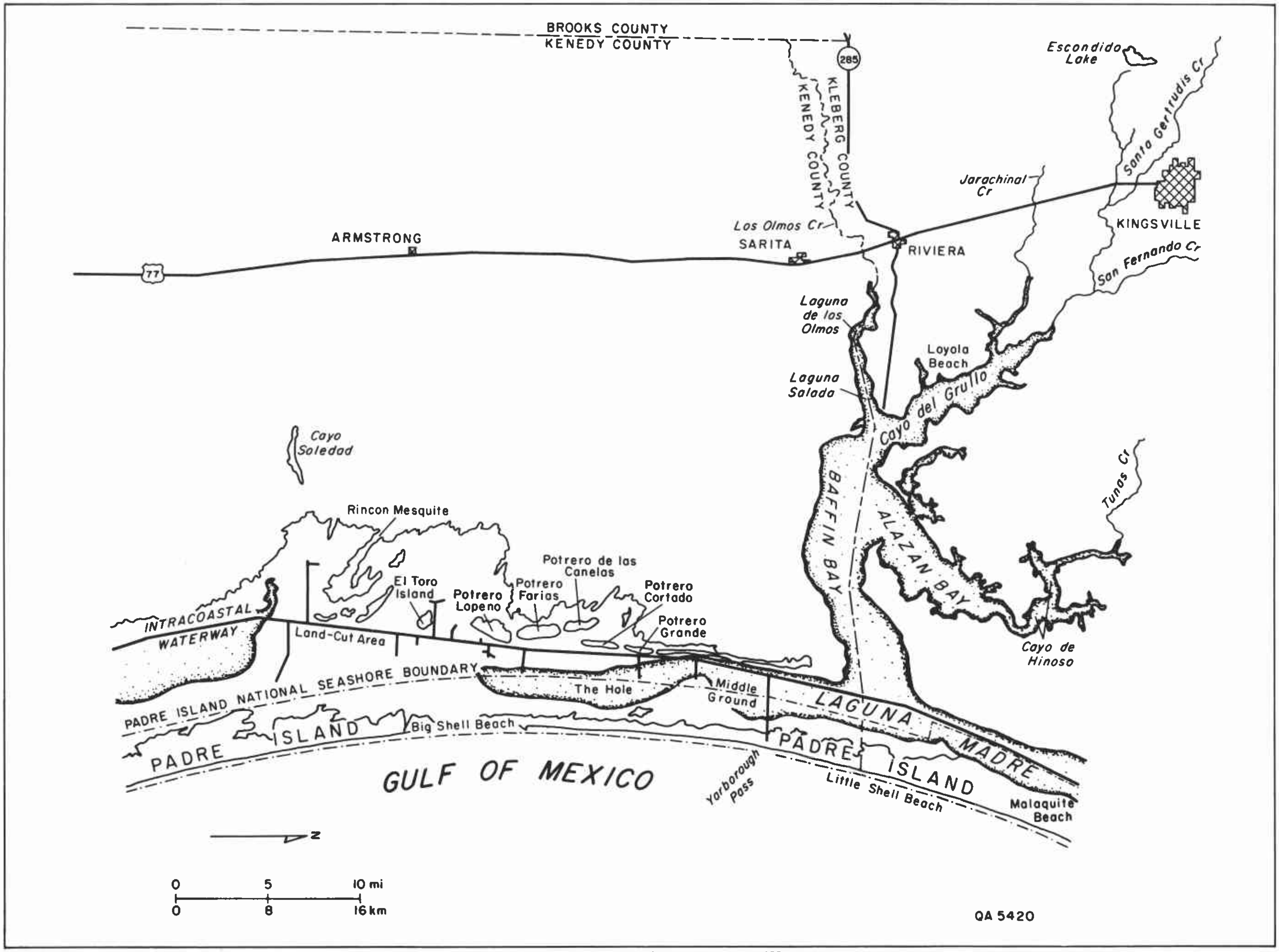

Figure 4. **Index map of the Kingsville area.**

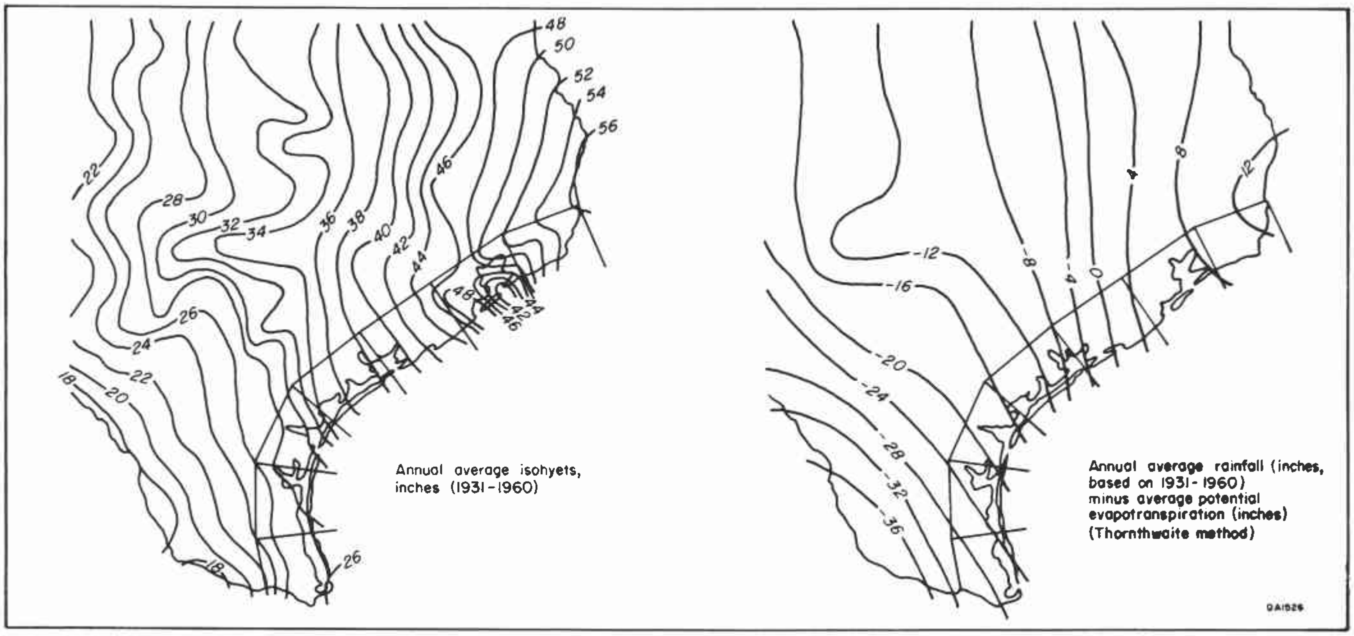

Figure 5. **Regional climatic data, Texas Coastal Zone (after Brown and others [1977]). Calculation of average potential evapotranspiration from Thornthwaite and Mather (1957).**

within the Padre Island National Seashore. A more complete description of the Kingsville area is presented by Brown and others (1977).

CLIMATE

Climate in the Kingsville area is semiarid (Thornthwaite, 1948) (table 1). Average annual rainfall for the period 1931-1960 varied from 26.0 inches (66.0 cm) in the southwestern corner of the map area to 34.5 inches (87.6 cm) in the northeastern part. Along the coastline in the Kingsville area, the annual rainfall ranges from 29.0 inches (73.7 cm) in the south to 34.5 inches (87.6 cm) in the north (Brown and others, 1977). A comparison of average annual precipitation with evapotranspiration for the period 1931-1960 indicates a precipitation deficit of about 19 to 28 inches (48.3 to 71.1 cm) (fig. 5). Precipitation levels in the Kingsville area from 1976 to 1983 are shown in figures 6 through 8. Rainfall is generally concentrated during the late summer and fall months of August, September, and October (Brown and others, 1977). Temperatures in the Kingsville area range from an average winter minimum of 48°F (9°C) to an average summer maximum of 96°F (36°C) (Brown and others, 1977). Between 1931 and 1960, the average annual mean free-air temperature in the area was

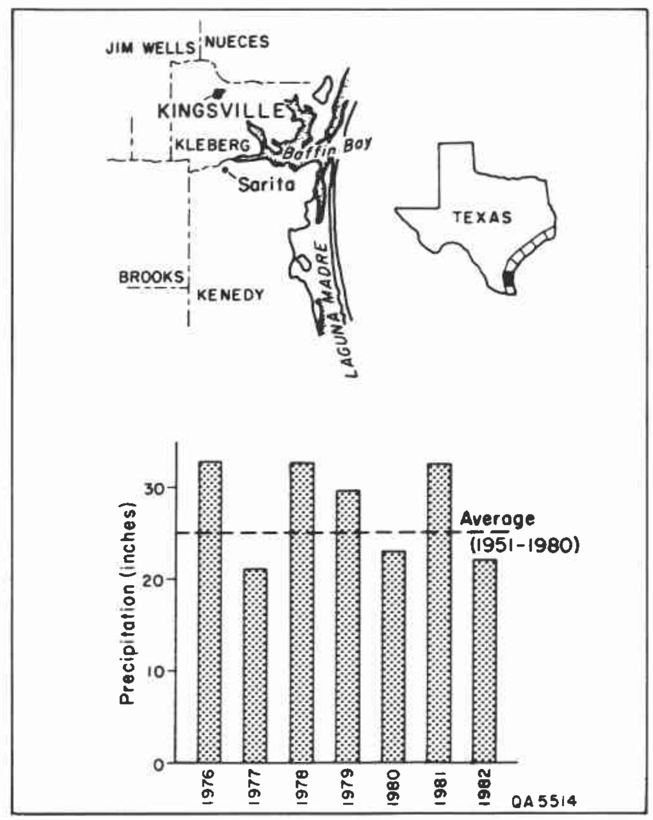

Figure 6. **Annual precipitation in Sarita, Texas, 1976-1982. Compiled from records of the National Weather Service, U.S. Department of Commerce.**

Table 1. Generalized characteristics of active coastal processes and conditions in the Kingsville area.

Climatic zone:	Semiarid (*Thornthwaite, 1948*)
Mean annual precipitation:	26.0 to 34.5 inches (66.0 to 87.6 cm) (*Brown and others, 1977*)
Dominant wind directions:	Southeast, north (*Brown and others, 1977*)
Astronomical tidal range: Bay shoreline Diurnal range: Mean:	 0.3 ft (0.09 m) at Riviera Beach, Baffin Bay (*U.S. Department of Commerce, 1978*) 0.1 ft (0.03 m) at Riviera Beach, Baffin Bay (*U.S. Department of Commerce, 1978*)
Direction of net longshore sediment transport (Gulf shoreline):	Southwestward and northward longshore currents converge near lat 27° N (*Lohse, 1952; Watson, 1968; Brown and others, 1977*)
Net rates of Gulf shoreline erosion over a period of about 100 yr:	Northern two-thirds of Padre Island (Kingsville map area)—primarily accretionary at average rates of 2 to 3 ft/yr (0.6 to 0.9 m/yr) (*Morton and Pieper, 1977a and 1977b*) Southern one-third of Padre Island (Kingsville map area)—primarily erosional at average rates of 1 to 4 ft/yr (0.3 to 1.2 m/yr) (*Morton and Pieper, 1977a*)
Hurricane frequency:	Probability of occurrence along 50-mi (80.5-km) segment of coast in Kingsville area; 7% in any one yr (*Simpson and Lawrence, 1971*)

about 73°F (23°C). Two principal wind regimes dominate the Kingsville area—persistent, southeasterly winds from March through November and short-lived but strong northerly winds from December through February (Brown and others, 1977). Cold fronts individually cause an abrupt drop in air temperature and cumulatively cause a drop in bay-water temperature.

ACTIVE PROCESSES AND NATURAL SYSTEMS

Submerged lands and wetlands are affected by a variety of physical processes that include eolian activity, subsidence, faulting, and relative sea-level rise, and the action of streams and surface runoff, astronomical and wind-generated tides, waves and currents, and tropical storms and hurricanes. Sources of fresh water in the bay-estuary-lagoon system include ephemeral streams and runoff, municipal and industrial return flow, and direct precipitation. From 1941 through 1976, annual average gauged fresh-water inflows (excluding ungauged inflows, diversions, and direct precipitation) into the Laguna Madre-Baffin Bay system were about 335,000 acre-ft (411 million m^3) (fig. 1; Texas Department of Water Resources, 1983). The low inflows in this semiarid region are in marked contrast to those in estuaries along the upper Texas coast, where, for example, annual gauged inflows into the Trinity estuary in the Galveston-Houston area (fig. 1) are about 16 times higher. Gauged inflows that enter the bay-estuary-lagoon system are (1) from creeks that flow into Baffin Bay and (2) from Arroyo Colorado and the North Floodway, which discharge into Laguna Madre in the Brownsville-Harlingen area. Gauged inflows into Baffin Bay and Laguna Madre account for only 17 percent of total fresh-water inflows; ungauged runoff and return flows account for 18 percent, and direct precipitation supplies the remaining 65 percent (Texas Department of Water Resources, 1983).

The bay-estuary-lagoon system is affected very little by daily tides, which are uniformly small (table 1). More significant in this area are wind-generated tides, which affect most bay-lagoon environments and periodically inundate extensive wind-tidal flats that occur landward from Padre Island and at the heads of the bays in the Baffin Bay system. Low precipitation levels and high evapotranspiration rates magnify the

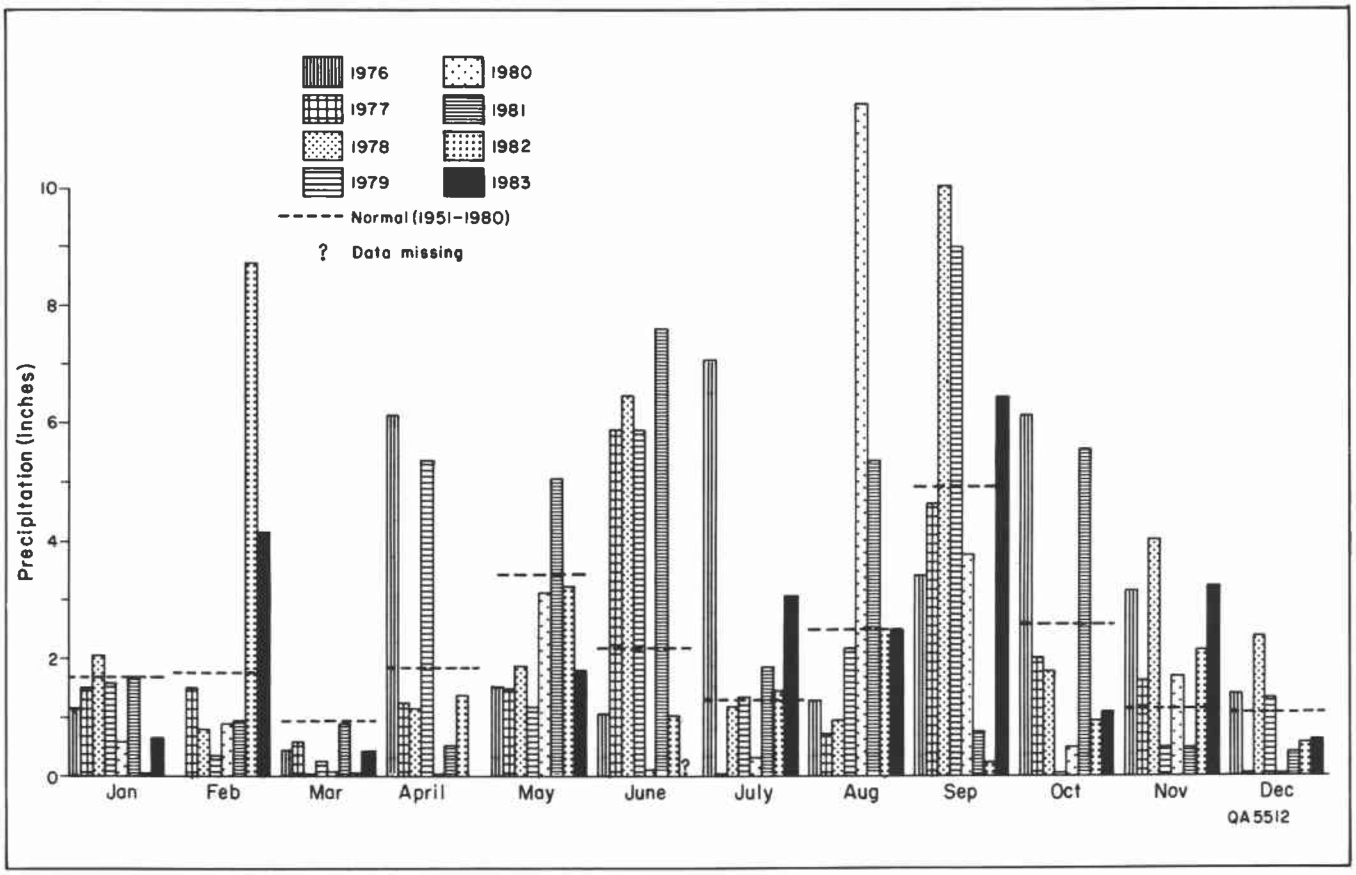

Figure 7. **Monthly precipitation in Sarita, Texas, 1976-1983. Compiled from records of the National Weather Service, U.S. Department of Commerce.**

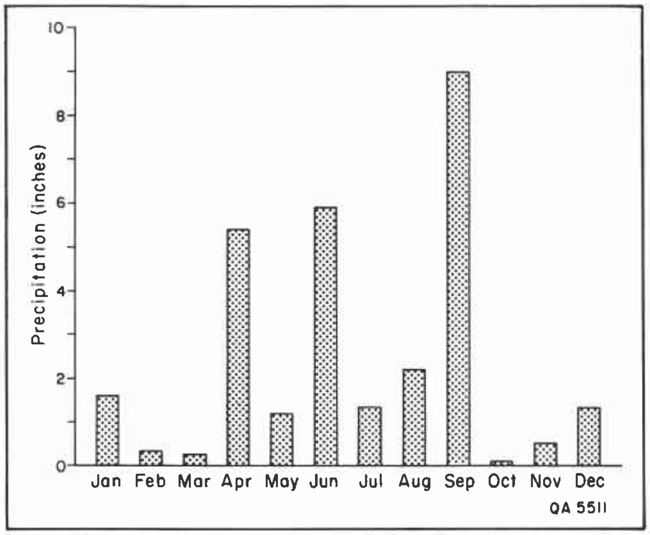

Figure 8. **Monthly precipitation in Sarita, Texas, 1979 (the year aerial photographs were taken for wetlands mapping). Compiled from records of the National Weather Service, U.S. Department of Commerce.**

effect of the wind on land environments, and a large complex eolian system composed of active and inactive elements has formed in this South Texas region. In addition, wind-driven longshore currents are particularly important processes affecting sediment transport and deposition on the inner shelf. A zone of net longshore convergence occurs within the Kingsville area (Lohse, 1952). Other processes affecting environments in the bay-estuary-lagoon and inner shelf systems are listed in table 1.

Active processes are integral components of the natural systems that have operated along the coast during the Pleistocene and Modern-Holocene* Epochs. These natural systems (fig. 9), defined and mapped by Brown and others (1977), reflect natural associations and include (1) the

**The term "Modern," when used in conjunction with Holocene, is in accordance with its usage by Brown and others (1972-1980) to designate those natural systems that have been developing along the Texas coast since about 4,500 years B.P. The use of the term "modern" in other instances implies a more recent (present-day) time frame.*

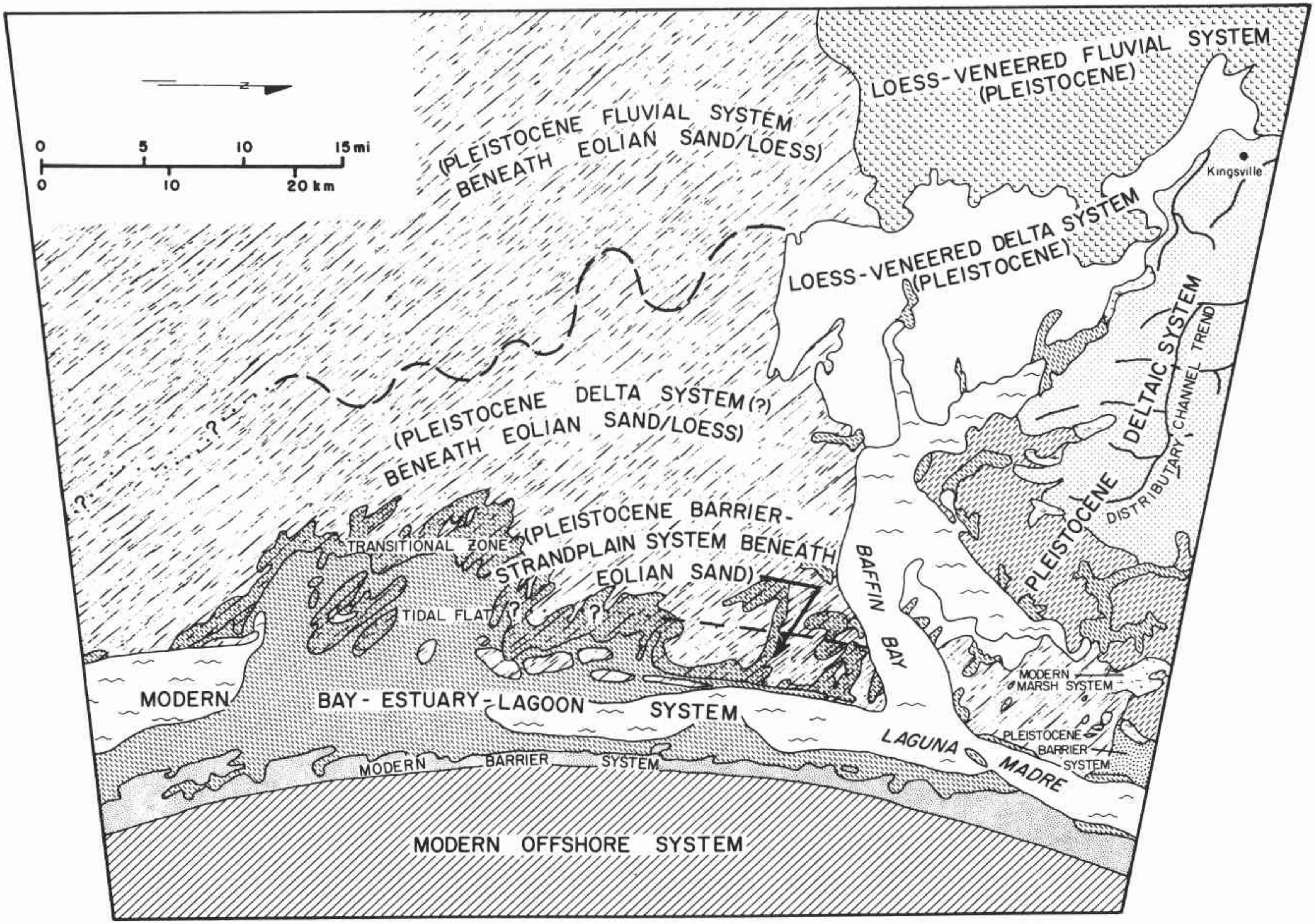

***Figure 9*. Natural systems of the Kingsville area (from Brown and others [1977]).**

offshore system, consisting of the inner continental shelf and the barrier-island shoreface located seaward of the Gulf beaches, (2) the barrier-strandplain system, consisting of modern barrier islands and Pleistocene barrier-strandplains, (3) the bay-estuary-lagoon system, consisting of submerged bay and lagoon environments and extensive wind-tidal flats, (4) the fluvial-deltaic system, consisting of relict and modern environments formed by ancient (Pleistocene) and modern rivers and deltas, and (5) the eolian system, consisting of deflation flats or depressions, active and stabilized dune complexes, and loess sheets. Wetlands consist of the various permanently to intermittently wet environments occurring both in low-lying coastal areas and in association with most of the abovementioned systems. Natural systems and wetlands in the Kingsville area are discussed in the section Coastal Wetlands and Related Environments (p. 70), and a more in-depth discussion of the natural systems is presented by Brown and others (1977).

BATHYMETRY

Bathymetry commonly controls the distribution of sediment textures, sediment geochemistry, and benthic macroinvertebrates. Sounding data, from which bathymetric maps of the bay-estuary-lagoon system were prepared (pl. V), were collected during the sampling phase of the project by measuring water depth at each sampling station (depths are not adjusted to sea-level datum). Bathymetry of the inner shelf (pl. V) was derived from maps published by the National Ocean Survey (McGowen and Morton, 1979).

Baffin Bay, having a maximum water depth of 9 ft (2.7 m), is the deepest bay in the map area. Maximum depths of Alazan Bay, Cayo del Grullo, and Laguna Salada are 6, 5, and 7 ft (1.8, 1.5, and 2.1 m), respectively. Water depths in Laguna Madre reach 8 ft (2.4 m) just north of The Hole and 6 ft (1.8 m) south of the Land-Cut Area. The Gulf Intracoastal Waterway is 12 ft (3.7 m) deep.

Shelf bathymetry near the Gulf shoreline is characterized by a relatively steep slope of approximately 30 ft/mi (5.5 m/km). Gentler slopes occur beyond a distance of about 1 mi (1.6 km) offshore. At approximately 10 mi (16 km) offshore, the slope decreases to about 3 ft/mi (0.6 m/km), and depths along the southern edge of the map sheet area exceed 96 ft (29.3 m) (pl. V).

SALINITY

Salinity affects distributions of marsh vegetation and benthic macroinvertebrates. Water salinities in the bay-estuary-lagoon system in the Kingsville area vary throughout the system, partly because of regional variations caused by fresh-water inflows from rivers and streams and by salt-water interchange from tidal passes. Compounding the complexity of the system are seasonal and cyclic climatic variations that produce substantially higher than normal salinities during dry periods and lower than normal salinities during wet periods.

Salinity data were not collected during the sampling phase of the submerged lands project (1976, 1977, and 1978). Salinities reported for Laguna Madre by the Texas Parks and Wildlife Department (Martinez, 1973, 1974, 1975), for Baffin Bay by Behrens (1966), and for Baffin and Alazan Bays by the Texas Department of Water Resources (unpublished data, 1984, 1985) provide some salinity data for the years 1964 to 1966, 1973 to 1975, and 1984 to 1985 (fig. 10).

Average surface salinities in Laguna Madre are generally above 25 parts per thousand (ppt) and extend into the 40's. Monthly ranges in salinities vary considerably, as demonstrated by a range in measurements of 5 to 27 ppt in October 1973 (fig. 10). The highest salinity at any station was 46.6 ppt in August 1974.

Salinities in Baffin and Alazan Bays are characteristically higher than in Laguna Madre, because water in Laguna Madre is diluted by water entering from lower Laguna Madre during southeasterly winds and from Corpus Christi Bay during northerly winds (Behrens, 1966). Average surface salinities at eight stations in Baffin Bay ranged from approximately 40 ppt in May 1966 to 70 ppt in December 1964 (fig. 10).

Recent salinity data taken at one station in Baffin Bay and at one in Alazan Bay show similar salinities in both bays. Salinities ranged from 23 ppt at both the Alazan and Baffin Bay stations in May 1985 to nearly 42 ppt at the Baffin Bay station in December 1984.

SAMPLE COLLECTION AND ANALYSIS

A total of 845 sediment samples were collected from State-owned submerged lands in the Kingsville area (table 2; pl. VI). Of those

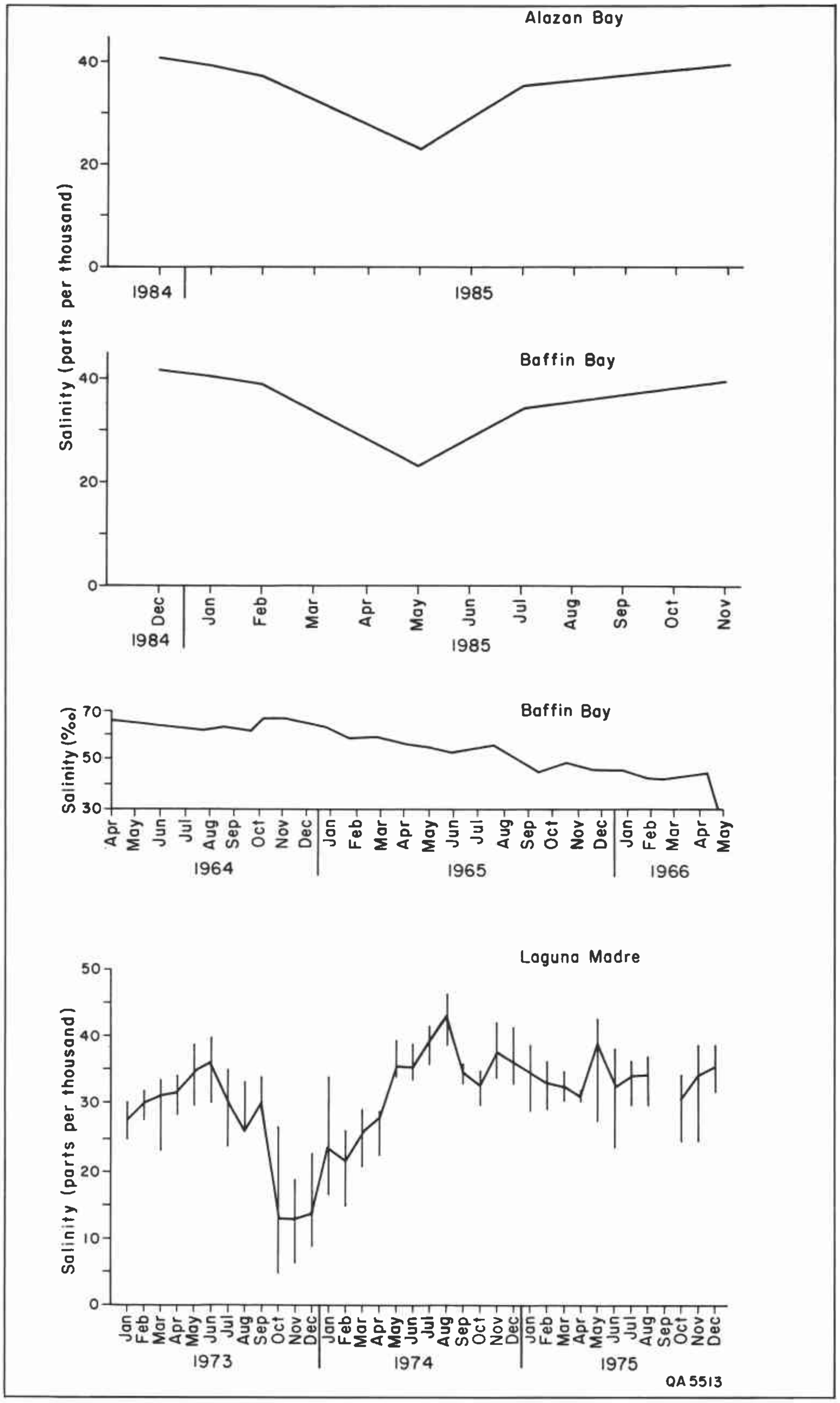

Figure 10. **Monthly means of salinities in Alazan and Baffin Bays and means and ranges of salinities in Laguna Madre, Kingsville area. Compiled from Behrens (1966), Martinez (1973, 1974, 1975), and Texas Department of Water Resources (unpublished data, 1984, 1985).**

Table 2. Number of sediment samples collected and analyzed in bay-estuary-lagoon and inner-shelf systems of the Kingsville area.

Location	Number of samples collected	Number of samples analyzed			
		Texture	TOC	Chemical elements	Benthic macro-invertebrates
Alazan Bay	25	15	25	6	10
Baffin Bay	89	54	89	21	29
Laguna Madre	100	63	86	62	36
Intracoastal Waterway	52	0	28	23	5
Land-Cut Area Channels	11	0	2	2	0
Bay-Estuary-Lagoon Totals	277	132	230	114	80
Inner Shelf Totals	568	200	568	155	81
Submerged Lands Totals	845	332	798	269	161

collected and stored, almost all (798) were analyzed for total organic carbon; 332 were analyzed for textural properties, 161 for benthic macroinvertebrates, and 269 for selected trace and major elements (table 2). The number and location of samples analyzed were determined partly by the need to establish an adequate data base for mapping and interpretation and partly by the need to consider time requirements and costs of the various types of analyses. Methods of analysis are presented in the section Data Acquisition and Analyses (p. 3). Collection dates are given in table 3. All sample locations and identifying numbers are shown on plate VI. Results of the various textural and geochemical analyses of each station are presented in appendix B. Data on benthic macroinvertebrates are presented in appendix C.

Table 3. Sample collection dates for bay-estuary-lagoon and inner-shelf systems.

Location	Sample collection dates
Alazan Bay	Sept. 21 to Sept. 22, 1976
Baffin Bay	Sept. 18 to Sept. 25, 1976
Laguna Madre	Jan. 9, 1977 (stations 72, 73, 75, 77) Feb. 10, 1977 (stations 76, 78, 81, 82) Mar. 18 to Mar. 19, 1977 (stations 140, 143–146, 150–153A, 156–160) Dec. 14 to Dec. 18, 1977 (stations 97, 101–111, 113, 114, 141, 142, 147, 149, 154, 155, 161) Feb. 1 to Feb. 2, 1978 (stations 118–136)
Intracoastal Waterway	Jan. 9, 1977 (stations 1–5) Feb. 10, 1977 (station 6) Mar. 18 to Mar. 19, 1977 (stations 47–53) Dec. 15 to Dec. 19, 1977 (stations 53–93)
Land-Cut Area channels	Dec. 17 to Dec. 21, 1977
Inner shelf	Mar. 2 to Mar. 3, 1976 (stations 984–1088) Mar. 14 to Mar. 16, 1976 (stations 837–983) Apr. 20 to Apr. 22, 1976 (stations 562–836) May 19, 1976 (stations 1089–1149)

SEDIMENTS AND GEOCHEMISTRY

by
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assisted by
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LATE QUATERNARY GEOLOGIC HISTORY

Major depositional and erosional events during the past 150,000 years distributed the surface sediment types found on the inner shelf and in Laguna Madre. These events, which were principally controlled by glacioeustatic changes in sea level during the Sangamonian-Holocene depositional episode (Rusnak, 1960a; Brown and others, 1977) are recorded as (1) aggradational and progradational coastal plain deposits that accumulated during periods of high sea level and (2) erosional unconformities that formed when sea level was extremely low or sediment supply was severely limited.

The oldest surficial sediments exposed in the Kingsville study area were deposited by several large late Pleistocene rivers and deltas (Brown and others, 1977). These meanderbelt sands and floodbasin muds graded seaward into barrier-strandplain sands that formed the wave-reworked shoreline during the sea-level highstand of the Sangamonian interglacial stage. The following early Wisconsinan glaciation was a time when sea level fell and major rivers and streams eroded valleys (Fisk, 1959; Behrens, 1963) as they merged, flowed across the coastal plain, and built deltas at the shelf margin. The late Wisconsinan interglacial stage began about 18,000 years ago, when a sudden rise in sea level and an abrupt reduction in sediment supply caused a rapid transgression. The former coastal plain was inundated, and the entrenched valleys began to aggrade first by deposition of fluvial-deltaic sediments and then by the deposition of bay-estuarine sediments as the valleys became flooded. Some of the rivers, such as the Rio Grande, transported enough sediment to fill their estuaries and to prograde onto the inner continental shelf.

Holocene sediments of the Rio Grande delta range in thickness from less than 1 ft (0.3 m) to nearly 100 ft (30.5 m) (Fulton, 1975). Thickness increases away from the feather edge, where it overlaps the late Pleistocene coastal plain deposits, and toward the river mouth, where subsidence was greatest and where the entrenched valley is deeper. Morphological and sedimentological evidence suggests that the Modern-Holocene Rio Grande delta was about 15 to 25 mi (24.1 to 40.2 km) seaward of its current position (Price, 1954; Morton and Winker, 1979). However, reductions in precipitation and sediment discharge associated with climatic changes caused delta abandonment and headland retreat as sea level approached its former (Sangamonian) elevation. Delta destruction was also accompanied by compactional subsidence, which contributed to the formation of Laguna Madre, Padre Island, and the adjacent wind-tidal flats about 2,000 years ago (Rusnak, 1960a; Morton and McGowen, 1980).

This last phase of transgression was characterized by brief pauses or slight reversals in sea-level rise that are manifested as relict beach deposits of the late Holocene deltas such as the Rio Grande. These former strandlines have arcuate shapes outlining the seaward limits of the Holocene deltas. They are distinguishable by unusually steep slopes (fig. 11) and patterns of coarse biogenic detritus and rock fragments on the inner shelf (Morton and Winker, 1979). Other relict shelf sediments in the Kingsville area are commonly indurated with carbonate cement and composed of crossbedded sandstone, micritic limestone, and shelly mudstone. These rocks have been variously interpreted as eolian, lacustrine, and lagoonal deposits that aggraded on the arid coastal plain before it was transgressed (Hayes, 1967; Thayer and others, 1974).

Shortly before sea level reached its present position, Padre Island began to form as sediment was supplied by updrift shoreline and shoreface erosion and by erosion of upper Pleistocene barrier-strandplain sands that had been exposed on the inner shelf. This segment of the shelf has

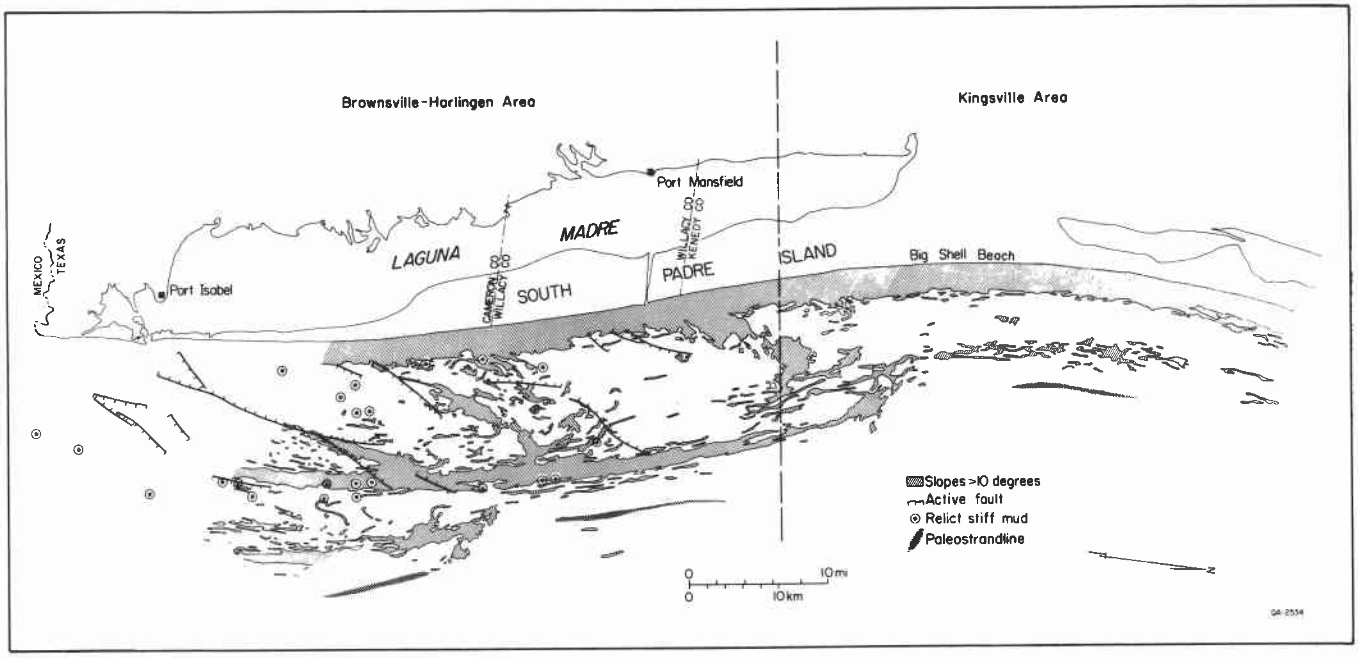


Figure 11. **Slope map of the inner shelf off South Padre Island showing the relationship among seafloor gradient, active faults, and paleostrandlines. Also shown is the distribution of relict stiff muds (from McGowen and Morton [1979]).**

continued to receive sediment transported from the upper and lower coasts by converging longshore currents. As a result, modern shelf sediments are thicker in the Kingsville area than in any other segment of the Texas shelf.

The warmer, drier climate of the last few thousand years has increased the activity of eolian systems that mobilized the late Pleistocene and Holocene surface sands and created extensive dune fields. The modern dunes cover much of the Kingsville area, obscuring the underlying Pleistocene sediments.

SEDIMENTS

Sediment Sources and Texture—Bay-Estuary-Lagoon System

Modern sediments in the bay-estuary-lagoon system of the Kingsville area are derived from several sources, including (1) suspended-load and bed-load materials of creeks, (2) erosional products from bay-margin shores, where upland areas include modern and Pleistocene barrier-strandplains and deltas, clay dunes, and eolian sand and loess, (3) Gulf sediments transported across barrier islands through washover channels, (4) sediments transported across the barriers by eolian processes, (5) nonterrestrial biogenic materials (carbonates), composed primarily of shells and serpulid reefs (Andrews, 1964) and associated debris, (6) other carbonate materials and grains, which include ooids and coated grains (Rusnak, 1960a, 1960b; Behrens, 1964; Frishman, 1969; Alaniz and Goodwin, 1974), and (7) spoil placed on submerged lands along dredged channels. Sediment textures include gravel, sand, and mud, the latter composed of silt and clay. Sand generally occurs along bay margins. Mud is more common in deeper bay-center areas and navigation channels. Gravel-sized sediments are composed of shell and rock fragments, which commonly occur mixed with sand and mud. Erosion, transportation, and deposition of sediments are directly related to active processes and corresponding levels of wave and current energy that occur in the bay systems. Erosion of the bay shorelines is largely determined by prevailing and dominant wind direction, fetch, orientation of the bay shoreline, and textural composition of the shore. For a more in-depth discussion of bay sedimentation, refer to McGowen and Morton (1979).

Sediment Sources, Texture, and Composition—Inner-Shelf System

Surficial sediments of the Texas inner shelf are derived from several primary processes, including (1) river deposition, (2) Gulf shoreline and shoreface erosion, and (3) redistribution of preexisting shelf sediments. During the past few thousand years, these processes have supplied sediment to the inner shelf near Kingsville. The influence of rivers on shelf sedimentation in this area has been indirect because the nearest rivers (Rio Grande and the Colorado) are more than 70 mi (112 km) and 100 mi (160 km) away, respectively. Despite the great distances, these rivers deposited most of the coarse-grained sediment found near the surface and some of the fine-grained sediment buried beneath the most recent shelf deposits.

Although it seems incongruous, the areas of greatest erosion of the Texas Gulf shoreline and shoreface are near the mouths of the Rio Grande and the Brazos and Colorado Rivers. Fluvial-deltaic deposits of the ancestral Rio Grande were major sources of shelf sediment in the Kingsville area shortly after sea level reached its present position several thousand years ago. However, the volume of sediment contributed directly by deposition and by shoreline and shoreface erosion has greatly decreased with time. This decrease in sediment was caused by retreat of the coastal promontories, which resulted in a straighter shoreline and an equilibrium profile for the shoreface and inner shelf.

The main processes contributing to shelf sedimentation near Kingsville today are suspension and redistribution of preexisting shoreline and shelf sediments during storms. Of secondary importance are minor amounts of suspended sediment from Laguna Madre transported onto the shelf through Brazos Santiago Pass, Mansfield Ship Channel, and washover areas along South Padre Island. Sediment introduced from Laguna Madre may include a suspended fluvial fraction passing through the lagoon system or suspended sediment derived from erosion of lagoon-margin and lagoon-center deposits. What portion the preexisting shelf or bay sediments contribute is impossible to determine because of continuous physical and biological mixing. Wind-driven shelf currents and wave activity cause mechanical mixing, whereas burrowing organisms create additional heterogeneity after sediments are deposited.

Sediments of the Texas inner shelf span three textural ranges—gravel, sand, and mud. The gravel-sized fraction, which is minor, is composed predominantly of shell but includes some rock fragments (Morton and Winker, 1979). Because shell dominates the gravel-sized fraction, the two classifications (size and composition) are used interchangeably. According to Morton and Winker (1979), shell fragments make up less than 1 percent of the shelf sediment north of Yarborough Pass; however, they are common in a broad band extending from Big Shell Beach (station 747, pl. VI) across the southern segment of the study area (station 562) and along a linear trend that is several miles wide between stations 765 and 964. Rock fragments also are abundant within the broad band of shelly sediments (stations 747 and 562) and at scattered sites offshore from Big Shell Beach. Together the shells and rock fragments constitute from 2 to 8 percent of the sediment volume at stations where the coarse fraction is abnormally high. Morton and Winker (1979) interpreted these trends as paleoshorelines that formed on the northern flank of the Holocene Rio Grande delta; the beaches were submerged and partially buried as sea level rose and the delta retreated landward.

Sand abundance decreases offshore within the Kingsville area; however, composition of the sand fraction does not vary substantially either alongshore or offshore. Major components of the sand fraction and their average percentages are quartz (87 percent), feldspar (6 percent), rock fragments (4 percent), and accessory minerals, including glauconite (2 percent). Black opaques account for nearly half of the heavy mineral populations; other heavy minerals in decreasing order of abundance are tourmaline (7 to 26 percent), hornblende (6 to 12 percent), zircon (5 to 12 percent), rutile (3 to 10 percent), and pyroxenes (1 to 16 percent). Chlorite and the micas (muscovite and biotite) account for about 6 and 3 percent, respectively. The heavy mineral assemblages and relative proportions of the minerals are similar to those of beach and river sands along the central Texas coast reported by Bullard (1942).

Silt-sized sediments usually have the same gross mineralogy as the sand fraction, whereas the clay fraction is composed mainly of three clay minerals: montmorillonite, illite, and kaolinite, in that order of abundance. Many studies have shown that the composition and relative abundance of clay minerals in the Texas submerged lands are similar to those in the source areas, indicating that neither subaqueous authigenic clay mineral formation nor diagenetic alteration is significant in these shallow marine sediments.

Surface Sediment Type and Distribution Patterns

Types, or textures, of submerged lands sediments range from clay to gravel, the latter consisting principally of shells. Four maps (pl. I) were prepared using grain-size analyses (app. A) to characterize the distribution of textures. The maps show (1) percentages of shell(gravel) - sand - mud, (2) percentages of sand - silt - clay, (3) percent sand, and (4) mean grain size. Map users should be aware that lines denoting the contacts of the various map units are interpretations based on the given data points. Other interpretations are possible in which the same data points are used but the position of boundary lines, or isoliths, is slightly altered.

Disagreement between the distribution of shell(gravel) - sand - mud mapped for this report and that mapped earlier by McGowen and Morton (1979) may be attributed to any of the following factors:

(1) Sediment textures were quantitatively determined for maps in this report, whereas they were visually described in the earlier report.

(2) Subsamples taken from the original whole sample for quantitative analyses may have varied slightly from the whole samples, which were visually described.

(3) Fewer samples were quantitatively analyzed than were visually described, which produced a smaller data base for this quantitative mapping, resulting in more extensive interpretation or extrapolation between data points.

Bay-Estuary-Lagoon System

Shell(Gravel) - Sand - Mud.—Three basic textural types are mapped on plate IA: mud, sand, and shell(gravel). Mud (silt and clay), muddy sand, and sand (pl. IA) are dominant in the bay-estuary-lagoon system. Mud principally occurs in deeper central-bay areas of Baffin and Alazan Bays, where suspended silt and clay-sized particles settle. Mud also occurs in Cayo del Grullo and Laguna Salada, but on plate IA it is not shown to be as widely distributed in Cayo del Grullo as it is depicted in a lithofacies map of surficial sediments by Alaniz and Goodwin (1974); this disagreement can be attributed to different textural classification schemes used in the two studies. Mud has a limited distribution in Laguna Madre, where bay-center sediments are dominated by muddy sand south of the Land-Cut Area and by sand and muddy sand north of the Land-Cut Area. Muddy sand and sandy mud are common in bay-margin areas of Baffin and Alazan Bays, and sandy mud occurs predominantly near the mouth of Baffin Bay. Sandy mud is a major sediment type in Cayo del Grullo and Laguna Salada, and it also occurs in a few samples in Laguna Madre north and south of Middle Ground (pl. IA). Sandy mud commonly intergrades with muddy sand, which in turn grades into sand that characterizes bay margins. Muddy sand and sandy mud are natural transitional units between areas that are predominantly sand and areas that are predominantly mud. However, in some areas, these sediment types are artificially produced by dredging activities. Near dredged-spoil-disposal areas, it is difficult to distinguish the contributions of natural from artificial sedimentary processes.

Sand is the dominant textural type in bay- and lagoon-margin areas. Along the margins of Padre Island at the north end of the study area, sand extends across shallow Laguna Madre to the mainland, reflecting the relatively high energy and abundant sand that characterize this area. Sand is derived from Padre Island on the east side of the lagoon and from Pleistocene strandplain, deltaic, and eolian deposits on the west side (McGowen and Morton, 1979). Ooids account for part of the sand fraction along the margins of the Baffin-Alazan Bay system and the mainland shore of Laguna Madre (Rusnak, 1960a, 1960b; Behrens, 1964; Frishman, 1969; Alaniz and Goodwin, 1974). Ooid sand is most abundant along wave-exposed shores that are oriented normal to the prevailing southeast winds (Rusnak, 1960b; Behrens, 1964). The abundance of the ooid sand decreases rapidly offshore (Rusnak, 1960b). Alaniz and Goodwin (1974) reported that ooids are a significant component of some bay-margin sands in Cayo del Grullo. In addition to ooids, shell material, foraminiferal tests, quartz, and feldspar are among other noteworthy constituents of the sand fraction in Cayo del Grullo (Alaniz and Goodwin, 1974).

Gravel-sized shell, shell fragments, and rock fragments constitute the third basic textural type mapped on plate IA. This unit is partly composed of biogenic sediments produced by biologic processes, such as the formation of shells and serpulid (polychaete worm) reefs, and partly composed of rock fragments from Pleistocene deposits that include well-cemented beach rock in some areas along the mainland shore. Shell and rock fragments accumulate in high-energy bay-margin environments, where spits and shell berms are constructed by storm waves. In submerged areas, many samples were taken of sediments containing mixtures of shell, sand, and mud, but frequently the ratio of shell to sand and mud was too low to affect sample classification. Mixtures of shell with sand and mud are more widely distributed than is pure shell in subaqueous areas of the bay system; however, relatively extensive serpulid reefs occur in Baffin Bay (Andrews, 1964) (pl. IA). Sand-sized shell particles apparently account for some of the sand fraction occurring near reefs and along bay-margin shell beaches and berms.

Sand - Silt - Clay.—On the sand - silt - clay map (pl. IB), which depicts the distribution of finer grained sediments (sand, silt, clay), gravel was omitted to provide a more detailed picture of the distribution of mud constituents—silt and clay.

In the mud fraction, silt is more abundant than clay. This relationship is shown by the wide distribution of clayey silt in deep bay-center areas of Baffin and Alazan Bays and in Cayo del Grullo. Although silty clay composes bay-floor sediments in some areas, the predominance of silt over clay in most muds in the bays and on the inner shelf is apparently an artifact of the textural analysis used (app. A).

In the Baffin-Alazan Bay system, bay-center silty clay and clayey silt grade shoreward into mixtures of sand, silt, and clay (in which no single sediment fraction exceeds 49 percent) and into silty sand, which in turn grade into sand that fringes the bay margins. These systematic trends are well displayed in Baffin and Alazan Bays and in much of Cayo del Grullo and Laguna Salada. In Laguna Madre south of Baffin Bay, clayey sand and mixtures of sand, silt, and clay commonly occur in deep lagoon-center areas, although clayey sand also occurs at several lagoon-margin sites (pl. IB). Sand, however, is the most abundant constituent in shallow lagoon margins. North of Baffin Bay, sand is the only sediment that was collected in Laguna Madre.

Distribution patterns of sand, silt, and clay in the Baffin-Alazan Bay system and in Laguna Madre depicted by Rusnak (1960a) are generally in agreement with those shown on plate IB. However, there are differences in the textures mapped in some areas. For example, Rusnak mapped the central part of Alazan Bay as clay instead of clayey silt, silty clay, and sand - silt - clay, as shown on plate IB. In addition, areas south of the Land-Cut Area mapped by Rusnak as silty clay with a border of clayey sand are mapped primarily as clayey sand on plate IB. These variations in textures probably result from differences in methods of textural analysis rather than from changes in textural composition of the sediments (app. A).

Percent Sand.—The sand-percent map (pl. IC) can be used to provide a more complete picture of the textural variations in the bay-estuary-lagoon system. The distribution of sand follows a systematic pattern, particularly in the Baffin-Alazan Bay system; sand percentage is high along bay margins but grades toward bay center to less than 20 percent in most areas. Surface sediments throughout most of the central bay area in Baffin Bay contain less than 5 percent sand.

In much of Laguna Madre, surface sediments contain intermediate to high percentages of sand (more than 50 percent), reflecting the influence of the sand-rich modern barrier islands on the east side of the lagoon and of Pleistocene sands on the western, mainland side (Brown and others, 1977). Only five samples collected in Laguna Madre contain sand percentages of less than 40 percent; three were collected between the mouth of Baffin Bay and the Land-Cut Area, and two were collected south of the Land-Cut (pl. IC). Sands from Padre Island are transported lagoonward by prevailing southeasterly winds—a process that has contributed substantial quantities of sand to the lagoon margin. Subaqueous lagoon sand grades toward the barrier island into extensive, sandy wind-tidal flats (pl. V).

Sand in the bay-estuary-lagoon system is predominantly quartz, but along the shores of Baffin and Alazan Bays, Cayo del Grullo, and the mainland shore of Laguna Madre near the mouth of Baffin Bay, ooids are important components of the sands (Rusnak, 1960a, 1960b; Behrens, 1964; Frishman, 1969; Alaniz and Goodwin, 1974). Also, sand-sized shell detritus composes a measurable proportion of the sand fraction in some areas, especially the coarser fraction (Rusnak, 1960b; Alaniz and Goodwin, 1974).

Mean Grain Size.—Mean grain size of the sand, silt, and clay fractions is expressed and mapped (pl. ID) in phi (ϕ) units. Phi units are logarithmic transformations of the Wentworth (1922) grade scale and are defined as the negative logarithm (base 2) of particle diameter (Krumbein, 1934). Thus, in the phi scale, larger numbers represent finer grain sizes. Because gravel was excluded in the determinations of mean grain size (app. A), mean phi size reported in appendix A and mapped on plate ID will be less than the true value for sediment samples with a measurable gravel component, such as the sample collected at station 140 in Laguna Madre (see pls. IA and VI).

Patterns of mean grain sizes in the bay-estuary-lagoon system generally follow those depicted on the other textural maps (particularly the shell(gravel) - sand - mud map [pl. IA], which was used as a guide). However, the mean-grain-size data, where available, provide a more detailed subdivision of sediments. The coarsest sediments range from medium to fine sand (1ϕ to 3ϕ), and in Laguna Madre they occur primarily in the northern part of the lagoon, in the southern end of The Hole, and along margins of the lagoon south of the Land-Cut Area. In the Baffin-Alazan Bay system, these coarser sediments (1ϕ to 3ϕ) occur (1) along the northern margin of Baffin Bay from Laguna Madre to the mouth of Alazan Bay, (2) along the margin of Alazan Bay and Cayo del Grullo on each side of Kleberg Point, and (3) along portions of the southern shore of Baffin Bay that extend into Laguna Salada (pl. ID). The distribution of these coarser sediments coincides largely with the distribution of ooids shown by Behrens (1964) and Dalrymple (1964). The ooids have median diameters of 0.25 mm (2ϕ) to 0.5 mm (1ϕ) (Rusnak, 1960b). Ooids collected near Kleberg Point in Baffin Bay by Frishman (1969) ranged primarily from 1.5ϕ to 2.25ϕ. Sediments in other bay-margin areas and in much of Laguna Madre between Middle Ground and the mouth of Baffin Bay, and locally in other parts of Laguna Madre, have mean grain sizes that are more commonly within the very fine sand range (3ϕ to 4ϕ).

The mean grain size of sediments generally becomes finer (greater phi sizes) toward the bay center in most areas of the Baffin-Alazan Bay system; mean phi exceeds 7 in the central parts of the bays. However, in central and southern Laguna Madre, mean grain size of sediments is typically less than 5ϕ, indicating that these sediments are much coarser than those in the central areas of the Baffin-Alazan Bay system. Locally, mean grain size is coarser on the flanks of serpulid reefs, where sediments are partly derived from detrital shell material.

Inner-Shelf System

Shell(Gravel) - Sand - Mud.—Except for 2 anomalous samples (583 and 601), only 4 of the 12 possible sediment types are represented on the shelf portion of plate IA because of extremely low percentages of shell in the sediments. Even though shelf sediments are composed mostly of sand and mud, the whole-sample classification, which includes shell (pl. IA), shows certain features that are not apparent on the other maps depicting sedimentologic characteristics. For example, the offshore increase in mud is accentuated, and the distinction between sand and mud is quantitatively defined. However, sand and mud can also be delineated on other maps because biogenic detritus is relatively insignificant in the Kingsville area.

Shell content of shelf sediments is so low that its use in the classification scheme mainly influences the sand-to-mud ratio. Only two of the shelf samples have sufficient quantities of the three sediment types to plot within the fields of shelly sand (601) or sandy, shelly mud (583). Hence, the distribution of shell cannot be determined from plate IA. A clearer representation of the shell(gravel) distribution was reported by Morton and Winker (1979).

Patterns of sediment distribution are relatively simple despite the complicated history of fluvial-deltaic-eolian sedimentation and eustatic sea-level changes that influenced the area during the late Quaternary. Dominantly sand-sized sediments occupy the nearshore zone along the beach and shoreface and extend offshore from 3 to 5 mi (1.8 to 3 km). Water depths average about 60 ft (18 m) at the outer limits of this broad sandy area. The greatest extent of sand, which occurs off central Padre Island south of Big Shell Beach, coincides with the area of concentrated shell and rock fragments. Overall, the highest concentration of sand parallels the coastline, but the trend of sandy sediments arcs gently seaward at the southern end of the map area.

Muddy fine sands lie seaward of the nearshore sand zone in a 2-mi-wide band that roughly parallels the sand trend. Sandy muds follow a similar pattern, except one small deposit found near Little Shell Beach (station 1014) in 48 ft (15 m) of water. Elsewhere, sandy muds are found in water depths ranging from 60 to 90 ft (18 to 27 m). The narrow band of sandy muds is largely inferred but suggests a rapid transition to muddy sediments containing little sand.

Mud is deposited along much of the seaward perimeter of the study area but extends landward as minor local reentrants of fine-grained sediment among other sediment types. A continuous area of mud is located offshore from Padre Island in water more than 60 ft (18 m) deep. Together, the muddy sediments cover a slightly smaller area than do the sandy sediments.

Sand - Silt - Clay.—Although subdivision of the shelf mud fraction into silt and clay provides a clearer definition of sediment size (pl. IB), a patchy pattern emerges because both modern and relict sediments are present. Despite its apparent complexity, the map shows a seaward increase in silt and clay. Where grain-size changes are more uniform, sand passes gradationally into silty sand, sandy silt, silt, and finally clayey silt, which is the finest grained sediment type on the inner shelf. The zone of silty sand and sand - silt - clay generally corresponds to the transition zone delineated on the other sediment maps.

Nearly equal amounts of sand and silt constitute sediments in the transition zone. These sediments, which are slightly coarser than adjacent muds, owe their distinctive characteristics to physical and biological processes that acted together to create a mixture of sand and mud. Burrowing organisms have been particularly effective in producing the more homogeneous sediments by reworking shoreface sand transported offshore during storms. Some of the storm deposits are incorporated into the underlying mud as backfill in burrows. Undisturbed storm deposits in the transition and offshore mud zones are preserved as graded sand layers within shelf mud (Morton, 1981).

Inner-shelf sediments of the Kingsville area may be locally more heterogeneous than either plate IA or IB suggests. Relict stiff muds mapped by McGowen and Morton (1979) occur at two stations (1105 and 1114) but apparently do not greatly influence the composition of less cohesive overlying sediments. The relict muds are located on the drainage divide that marks the northern boundary of the entrenched valley occupied by Baffin Bay.

Percent Sand.—Sand is a potential mineral resource as well as a useful indicator of transport processes that can be used to interpret the depositional history of an area. Sand constitutes from 0 to 99 percent of the inner-shelf sediments in the Kingsville area (pl. IC), depending largely on water depth and concomitant distance from the shoreline. Sand is generally least abundant (less than 10 percent) where water depths are greatest (greater than 72 ft [22 m]) and most abundant (greater than 80 percent) within 3 mi (5 km) of the shoreline, where water is less than 48 ft (14 m) deep.

The sand isoliths are approximately parallel to the shoreline and bathymetric contours. The isoliths display a basinward decrease in sand that is most pronounced in the middle range of sand concentrations (40 to 60 percent). Rapid reductions in sand percent correspond to the zone of physical and biological mixing that occurs along the seaward margin of the lower shoreface.

High dune ridges along central Padre Island prevent tidal exchange with, and storm runoff from, adjacent Laguna Madre. Therefore, these processes do not directly influence the distribution of sand on the inner shelf. The greater extent of sand in the southern part of the map area is related to erosion and landward retreat of the Holocene Rio Grande delta and to exposure of late Pleistocene sands on the seafloor (Morton and Price, 1987).

Mean Grain Size.—Inner-shelf sediments are characterized by average textures that range from 2.3ϕ to 7.1ϕ, or fine sand to fine silt (pl. ID). As with other textural properties, mean-grain-size values generally decrease offshore and parallel the shoreline and bathymetric contours. Sediments with fine sand and medium silt textures are only slightly more extensive than those of other grain sizes. Coarse silt and medium to fine silt are also abundant. The inner-shelf sediments with the finest textures have mean grain sizes between 6ϕ and 7ϕ (medium to fine silt). These sediments are coarser than the finest bay sediments, which have textures of fine silt and clay.

The simplicity of the textural patterns suggests a recent geologic history and a set of physical processes that are relatively uncomplicated. The inner shelf off Padre Island is far removed from riverine discharge, yet sedimentation rates in this interdeltaic setting have been great enough that most relict sediments are buried beneath recent deposits several tens of feet thick. As a result of the deposition, an equilibrium shelf and shoreface profile are maintained in the area. The seaward decrease in grain size across this part of the shelf corresponds to a decrease in wave and current energy.

Bathymetry and Sediment Distribution

Textural distribution of clastic sediments in the bay-estuary-lagoon system is controlled largely by wave and current energy levels that in turn are related to water depth. Sand concentrated along bay margins in the larger bays reflects the relatively high energy of these shallow margin environments, where breaking waves and littoral currents are common. Sand eroded from the shoreline is dispersed by littoral currents along the bay margin, where it remains because of diminishing current energy in deeper water. Thus, shallow bay margins are characterized by sand, whereas deeper bay centers are characterized by mud or silt and clay. Ooid sands are apparently most abundant along those shores of Baffin and Alazan Bays and Laguna Madre that are normal to the prevailing southeasterly winds; these shores coincide with the areas of highest wave intensity (Behrens, 1964).

This relationship between bathymetry and texture is apparent on all four textural maps, especially in the Baffin-Alazan Bay system. Factors besides bathymetry, such as lithology of bay margins, erosional and depositional patterns, wind and current directions, location of storm washover areas, and location of dredged-spoil deposits, also affect textural distribution in many areas. For example, sediments in Laguna Madre have a nearby source of sand in Padre Island, where lagoonward-migrating active dunes and hurricane washover channels are common. Thus, sediments in deeper parts of Laguna Madre are coarser than sediments in similar or shallower water depths in parts of Alazan Bay, Cayo del Grullo, and Laguna Salada (pls. IA and VI).

A comparison of the distribution of sand (pl. IC) with water depth (pl. V or VI) reveals that sediments with the highest percentages of sand are generally related to areas of shallow water, such as areas along the margins of the Baffin-Alazan Bay system. In this bay system, narrow belts of sand parallel the shores. The sands grade rather abruptly into muds that characterize the deeper central bay areas. In Laguna Madre, the relationship between sediment textures and bathymetry is less well defined. Sands occur alongshore in shallow water, but the sandy sediments also extend into deeper areas. Sand deposition along the lagoonward shore of Padre Island is related to eolian processes in which sand from the island is blown lagoonward by prevailing southeasterly winds, infilling the lagoon (Fisk, 1959; Hunter and Dickinson, 1970).

Distribution of terrigenous sediment on the inner shelf and in the bays is controlled largely by water depth and distance from the shoreline. However, the gentle broadening of the shelf to the northeast off Padre Island has little effect on the sediment pattern. Of greater importance is the presence of relict sand that crosses bathymetric contours in the southern part of the study area.

Sandy sediments are slightly more abundant than muddy sediments, and the transition zone between sand and mud, or zone of greatest sediment mixing, generally corresponds to the break in shelf gradient that occurs between water depths of 60 to 70 ft (18 to 21 m). This band of heterogeneous sand and mud delineates the depositional area of fine-grained sediments sorted from the beach and upper shoreface by wave action and associated littoral currents.

Data from the Gulf of Mexico and elsewhere suggest that the shoreface sands and interlaminated sands and muds of the transitional zone exhibit primary depositional structures. In contrast, the offshore muds deposited in deeper water are extensively bioturbated, and biogenic structures are more abundant than depositional structures. The systematic trend from nearshore sand to muddy sand and then to sandy mud and mud is well displayed along most of the shelf (pl. IA); mud generally becomes more abundant than sand beyond a depth of about 60 to 70 ft (18 to 21 m). To the south, however, offshore from the Land-Cut Area, sandy sediments extend seaward to the edge of the study area, where depths are greater than 90 ft (28 m). This arcuate trend of sandy sediment that extends to the southeast is related to erosion and landward retreat of the Holocene Rio Grande delta and exposure of late Pleistocene sands on the seafloor (Morton and Price, 1987).

GEOCHEMISTRY

Following is a discussion of the distribution of each element in sediments of the bay-estuary-lagoon and inner-shelf systems. In the section Textural and Geochemical Relationships (p. 34), the significance of trace metals in bay and shelf sediments, in terms of general distribution patterns and means and highest concentrations, is discussed.

Distribution of Selected Major and Trace Elements

Uniform standards were followed in contouring geochemical data (pls. II through IV), such as showing each map unit (a specific range of values) as one progresses from higher to lower or lower to higher values. Considerable confidence can be placed in the data where a cluster of points shows a trend toward higher or lower values. However, less confidence can be placed in a single anomalous value, represented by a "bull's-eye" pattern on the map. This bull's-eye effect, which can cover a relatively large area around the point, may or may not actually exist. Because the analyses are only semiquantitative, one should interpret the meaning or significance of any single value with caution.

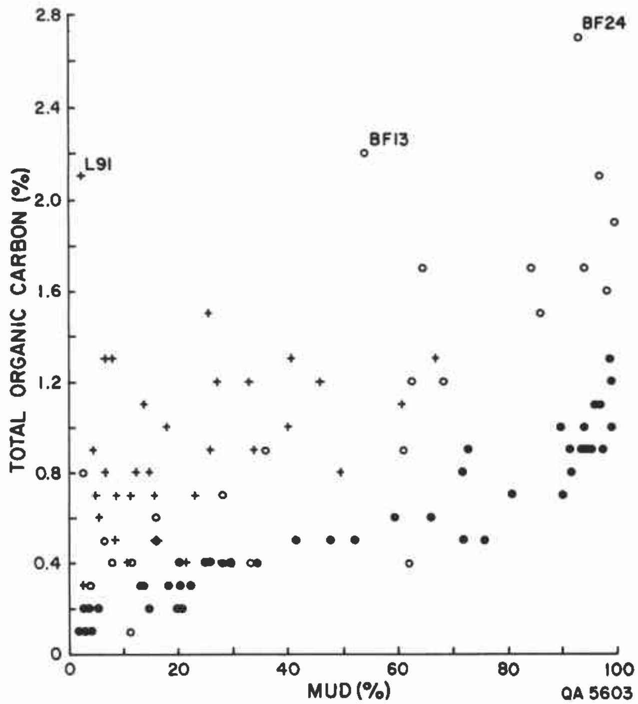
Map units for each element were selected after considering the semiquantitative nature of the values, the ranges of concentrations reported for the seven map areas (fig. 1), and the complexity of patterns representing the abundance of elements. Accordingly, on some maps the class intervals, or ranges of concentrations encompassed by each map unit, are equal (for example, iron, pl. IIIC), but on other maps the intervals increase at higher concentrations (for example, chromium, pl. IIIA). This increase at higher concentrations is deemed appropriate because the standard deviation of each reported value increases as the element concentration increases.

It should be reemphasized that two different analytical techniques were used to determine chemical element concentrations in sediments: (1) shelf sediment samples and bay sediment samples from the Baffin-Alazan Bay system and the northern tip of Laguna Madre were analyzed by the USGS using an emission spectrograph with computer analysis of the optical emission spectra and (2) samples from other areas of Laguna Madre and most sediment samples from the Intracoastal Waterway were analyzed by the Bureau of Economic Geology using an inductively coupled plasma-atomic emission spectrometer (ICP-AES). (See section on geochemistry in Data Acquisition and Analyses, p. 5, for more details about these methods). These methods of analysis are similar because both determine total concentrations of the selected elements in each sample. Because the analytical techniques are different, however, results are not exactly comparable. Therefore, on maps (pls. II through IV), scattergrams, and tables, results of the two analytical methods are distinguished from each other. Trace element distribution patterns and anomalies in some areas may be partly attributed to the different methods.

Total Organic Carbon

Bay sediments.—Distribution patterns defined by total organic carbon (TOC) concentrations in submerged land sediments (app. B; pl. IIA) are similar to those shown on textural maps (pl. I). Concentrations of TOC in bay-floor sediments (excluding channel sediments) range from 0.1 to 2.7 percent. Channel sediments collected from the Intracoastal Waterway north and south of the Land-Cut Area had the highest concentrations of TOC, a maximum of 5.7 percent (app. B).

Low values of TOC (less than 0.3 percent) generally correspond to sandy sediments (less than 20 percent mud) along bay margins, whereas



o Bay sediments (Baffin-Alazan Bay system); r = 0.841, n = 26
+ Bay sediments (Laguna Madre); r = 0.290, n = 36
● Shelf sediments; r = 0.953, n = 51

Figure 12. **Scattergram of total organic carbon and mud, Kingsville area. All analyses of TOC by Bureau of Economic Geology. (Numbers next to plotted point refer to sample station numbers—see figure 13 for explanation; r = correlation coefficient, n = number of samples used in regression analysis.)**

higher values of TOC (more than 1.2 percent) are generally associated with bay-center muds (greater than 80 percent mud) (fig. 12). This relationship between TOC and texture, which has been reported in other studies, is consistent throughout most of the bay-estuary-lagoon system, although variations occur in sands of Laguna Madre because of abundant marine grasses, which are sources of TOC.

Distribution of TOC in the Baffin-Alazan Bay system follows systematic trends, with highest concentrations (greater than 2 percent) occurring along the bay axes in deeper muddy areas and lowest concentrations occurring alongshore in sandy sediments. The highest concentration of TOC in bay-floor sediments occurs at stations 17 and 24 in Baffin Bay (pls. IIA and VI). Each sample collected at these stations has a TOC concentration of 2.7 percent; sediments from station 24 contain 93 percent mud. Textural data are not available for station 17, but visual descriptions of the sediment show that it is principally mud (McGowen and Morton, 1979). In Cayo del Grullo, TOC concentrations range from 1.7 percent in bay-center muds to 0.3 percent in bay-margin sands. Similar concentrations of TOC in surficial sediments of Cayo del Grullo were measured by Alaniz and Goodwin (1974); they reported an average value of 1.77 percent in muds and 0.46 percent in bay-margin sands.

The mean concentration of TOC is lower in Laguna Madre compared with that in the Baffin Bay system, mostly because the overall composition of sediment in Laguna Madre is coarser. Still, the average concentration of TOC relative to the amount of mud in the sandier sediment (sediments that contain less than 50 percent mud) is higher in Laguna Madre than in the Baffin Bay system (fig. 12). This trend toward higher than normal concentrations of TOC in sands is exemplified by Laguna Madre station 91 (pls. IIA and VI), where the sediment sample collected is composed of 98 percent sand and the TOC concentration is relatively high at 2.1 percent (fig. 12). Marine grasses that grow in the sandy sediments of Laguna Madre have contributed to the TOC concentrations and have elevated TOC values relative to the mud content. The high concentrations of TOC in the Intracoastal Waterway, which extends down Laguna Madre, probably are caused by marine-grass-derived organic detritus that settles in the 12-ft-deep (3.7-m) channel. Highest concentrations of TOC in the Kingsville area were measured in sediment samples collected from the Intracoastal Waterway (app. B). The maximum value of 5.7 percent occurs at station 6 at the northern edge of the study area (pl. VI). Ten of the 28 Intracoastal Waterway sediment samples that were analyzed for TOC had concentrations of at least 3 percent.

Shelf sediments.—The general relationship between TOC values and sediment size in bay sediments noted in this (fig. 12) and other studies also applies to the inner shelf, where highest values of TOC (app. B; pl. IIA) approximately coincide with high mud concentrations, and lowest values of TOC are associated with shoreface sands. Accordingly, TOC increases seaward in trends approximately parallel to shore that are similar to the shelf sediment patterns (pl. I). Concentrations of TOC in shelf sediments from the Kingsville area range from 0.1 to 1.4 percent; most samples, however, contain less than 0.8 percent TOC. These concentrations (fig. 12) are considerably lower than those measured in sediments from adjacent bays, where upland runoff and biological productivity are substantially greater.

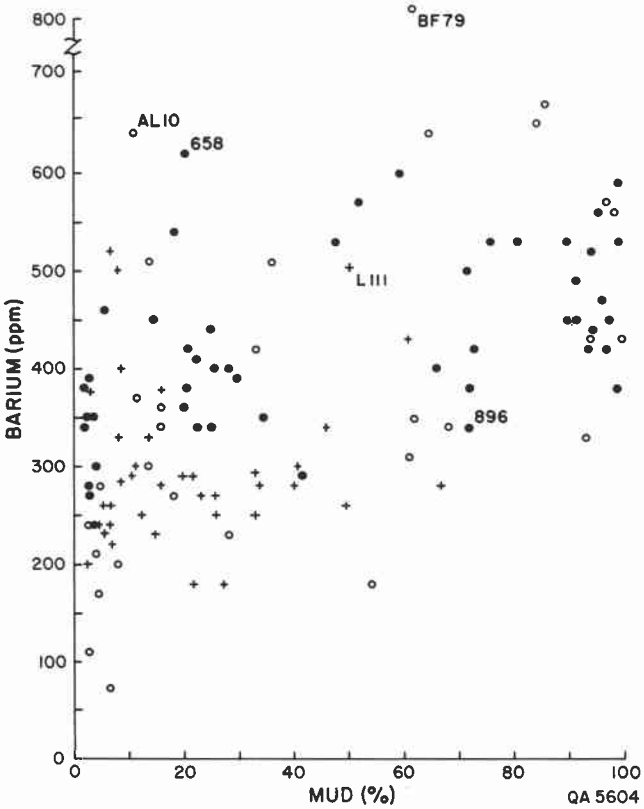
Local areas with intermediate TOC levels (0.4 to 1.2 percent) occur at isolated stations and as small patches within the band of shoreface sand. The highest concentrations of TOC on the inner shelf occur at individual stations along the seaward perimeter of the study area. The highest measured TOC value (station 670, pls. IIA and VI) was from a clayey silt with about 5 percent sand and 95 percent mud. These textures are typical of many other shelf samples, and therefore that particular TOC value is anomalously high compared with surrounding sediments. The patchy pattern of TOC values is complex as a result of the minor variations in sediment types and corresponding variations in TOC concentration. However, transects from the shoreline normally exhibit increases in TOC in an offshore direction.

Barium

Bay sediments.—Concentrations of barium (Ba) in sediments of the bay-estuary-lagoon system range from less than 100 to 820 ppm; average values are approximately 400 ppm in the Baffin-Alazan Bay system and 300 ppm in Laguna Madre (pl. IIB). Highest concentrations of barium occur in sediments of Laguna Salada, where there is a maximum concentration of 820 ppm near Riviera Beach. In Baffin and Alazan Bays, maximum concentrations are 650 and 640 ppm, respectively, and occur in the inland halves of the bays. Trends in high barium concentrations in sediments of Laguna Salada appear to continue into Baffin Bay, suggesting that the barium may be transported from Laguna Salada into Baffin Bay. The highest barium concentration in Cayo del Grullo is 640 ppm.

Barium concentrations are lower in Laguna Madre, where a high of 520 ppm was measured in a sediment sample collected from a station near the lagoon's mainland shore about 5 mi (8 km) south of the mouth of Baffin Bay (pl. IIB). However, only three samples from Laguna Madre contain a barium concentration exceeding 400 ppm, and each was collected just north of Middle Ground (pl. IIB). Most samples collected in other areas of Laguna Madre contain between 200 and 300 ppm barium.

Bivariate correlation analysis shows a low positive association between barium and mud in the Baffin-Alazan Bay system (fig. 13). Anomalously high occurrences of barium in the bays are possibly related to drilling activities and



o Bay sediments (Baffin-Alazan Bay system); Ba analyses by USGS; r = 0.491, n = 26
+ Bay sediments (Laguna Madre); Ba analyses by Bureau of Economic Geology; r = 0.072, n = 40
● Shelf sediments; Ba analyses by USGS; r = 0.540, n = 51

Figure 13. **Scattergram of barium and mud. (Letter and number combinations shown next to plotted points on this and other scattergrams are sample station numbers for sediments that plot significantly above or below the general trend set by other bay sediments: BF = Baffin Bay, AL = Alazan Bay, and L = Laguna Madre. Numbers without prefixes represent shelf sample stations whose sediments plot significantly above or below the general trend set by other shelf sediments. In the bay system, geochemical analyses by the Bureau of Economic Geology were of sediments collected from Laguna Madre; analyses by the USGS were primarily of the Baffin-Alazan Bay system (fig. 4). See plate VI and appendix B for station listings; r = correlation coefficient, n = number of samples used in regression analysis.**

the associated use of barite ($BaSO_4$) in drilling muds. Holmes (1974) reported a positive correlation between locations of oil and gas wells and high concentrations of barium in Corpus Christi Bay.

Shelf sediments.—Surface sediments of the inner shelf contain barium in quantities ranging from 240 to 620 ppm (app. B; pl. IIB). Maximum concentrations of barium in shelf sediments are lower than those for sediments in adjacent bays. The lowest amounts of barium occur nearshore usually within 1 mi (1.6 km) of the beach, whereas highest amounts occur farther offshore but in irregularly shaped patches rather than in systematic trends. Comparison of maps showing well sites and barium abundance suggests that some patches of high barium may be related to drilling activities on the inner shelf, whereas others are unrelated to well sites. Moreover, some well sites plot within areas of low barium concentration. Most samples contain between 300 and 500 ppm barium. This background level extends from the shoreline to the offshore limit of the study area and represents the norm against which the areas of higher and lower concentrations are contrasted.

Boron

Bay sediments.—Because concentrations of boron (B) were measured only in sediments collected from the Baffin-Alazan Bay system and the northern tip of Laguna Madre, discussion of boron concentrations and distribution patterns is restricted to those areas (pl. IIC). Concentrations of boron in Baffin and Alazan Bays range from less than 20 ppm to a high of 94 ppm. The highs occur along bay axes in relatively deep, muddy areas. The lows are more common along the shallow bay margins, where sands are predominant. In Cayo del Grullo and Laguna Salada the maximum boron concentrations are 80 ppm and 70 ppm, respectively; the highs occur in sediments collected near bay centers (pl. IIC). Higher concentrations of boron (more than 60 ppm) are usually associated with higher percentages of mud (more than 60 percent) (fig. 14).

The highest concentration of boron in the Kingsville area is 170 ppm and was found in sediments collected from the Intracoastal Waterway in the northern tip of Laguna Madre at station 4 (pl. VI). Although the textural composition of sediments collected from the Intracoastal Waterway was not analyzed, TOC was. TOC and mud generally exhibit a close positive association, as shown for Baffin and Alazan Bays in figure 12. Also, White and others (1983) reported a positive correlation between boron and TOC. Therefore, the 3.6 percent concentration of TOC in sediments collected from

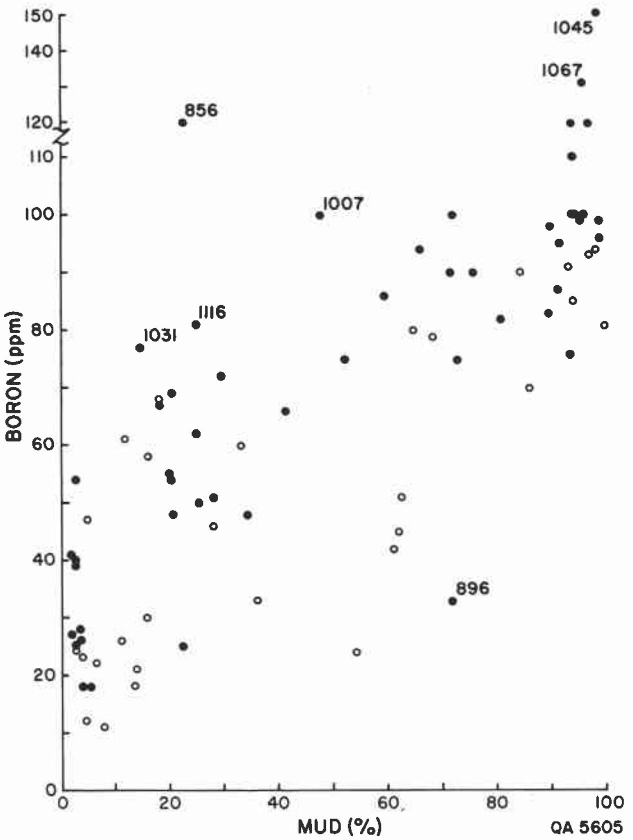


Figure 14. **Scattergram of boron and mud. All analyses of boron by USGS. (Letters and numbers shown next to plotted points are sample station numbers—see figure 13 for explanation.)**

Intracoastal Waterway station 4, which is among the highest in the study area, may be associated with the high boron at this station.

Shelf sediments.—Boron concentrations in shelf sediments (app. B; pl. IIC) range from 15 to 150 ppm, a range slightly greater than that of nearby bay sediments. However, more samples at the high end of the range are found offshore. The correlation coefficient between boron and mud (fig. 14) is similar for both shelf and bay areas, except that boron concentrations on the shelf are slightly higher than in the bays, even where mud concentrations are similar. The relation of boron to mud in shelf sediments generally corresponds to the upper limits established by comparable data from bay sediments (fig. 14).

Boron generally increases offshore but its complex pattern only vaguely resembles the pattern exhibited by sediment textures (pl. I). Lowest boron concentrations occur where sand is abundant, especially along the shoreface and extending into deeper water at the southern end of the map area. An exception to this pattern is the nearshore reentrant of higher boron concentrations near Big Shell Beach. The class interval having the greatest number of samples is in the mid-high range of 80 to 120 ppm. Each lower class interval contains about an equal number of samples.

Calcium

Bay sediments.—Concentrations of calcium (Ca) in bay-estuary-lagoon sediments have a mean concentration of approximately 4.5 percent (45,000 ppm). Maximum concentration of calcium is 28 percent in sediments from Laguna Madre and 23 percent in sediments from the Baffin-Alazan Bay system (pl. IID). Highest concentrations of calcium occur along the shores of the Baffin-Alazan Bay system and along the mainland shore of Laguna Madre near the mouth of Baffin Bay. These areas coincide mostly with the distribution of ooid sands mapped by Behrens (1964) and Dalrymple (1964). Serpulid reefs also occur along these shores (Andrews, 1964) and undoubtedly contribute to the high calcium content.

In Laguna Madre south of the Land-Cut Area, calcium content in sediments from two lagoon-center stations is relatively high at 13 to 15 percent; these sediments have a shell content of almost 10 percent. There is a close positive association between high calcium and shell(gravel) content in sediments of the bay-estuary-lagoon system. For example, at eight stations in which calcium content ranges from 10 to 23 percent, shell(gravel) content ranges from 8 to 20 percent (table 4).

Table 4. Comparison of the concentrations of calcium and shell in sediments from selected sampling stations in Alazan Bay (AL), Baffin Bay (BF), and Laguna Madre (L).

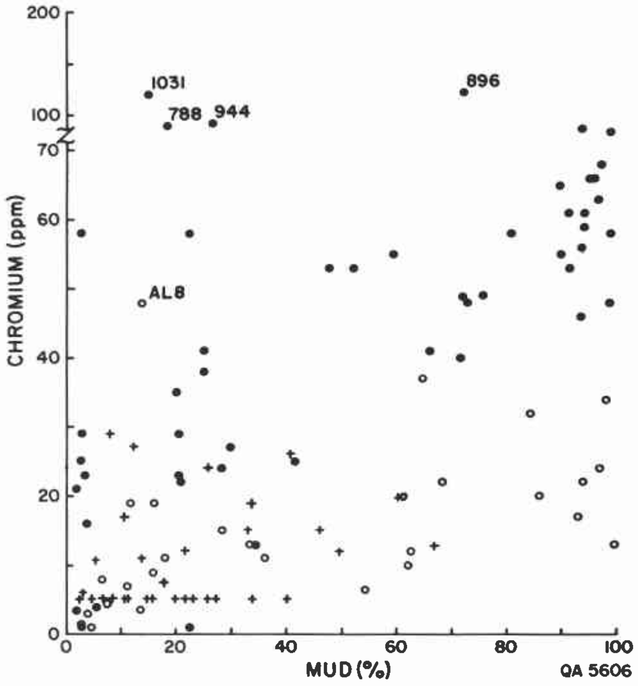
Station Number	Calcium (%)	Shell (%)
AL 25	23	8
BF 54	17	15
L 101	14	17
L 102	20	20
L 109	10	13
L 140A	16	6
L 150	15	10
L 156	13	9

Contrary to expectations, the sample station with the lowest shell content (8 percent) in table 4 contains the highest calcium content (23 percent). Sediments from this particular location (station 25 in Alazan Bay [pl. VI]) contain ooids, which may account for the apparent contradiction. Ooids are also a source of calcium in sediments collected at Baffin Bay station 20, where the calcium concentration is 11 percent and the shell content is only 2 percent.

In areas where quartz sand is predominant, such as along the lagoon margins of Padre Island north of the Land-Cut Area, calcium concentrations are less than 1.5 percent. Low concentrations of calcium also occur in bay-center areas of the Baffin-Alazan Bay system (pl. IID).

Shelf sediments.—Although concentrations of calcium in shelf sediments range from 0.4 to 4.7 percent, most samples contain between 1 and 3 percent (pl. IID). Highest calcium concentrations occur at isolated sample sites that also have abundant shell fragments. An exception is the relatively high calcium concentration at station 892, where sediments are composed of mud with very little shell.

Calcium concentrations generally increase offshore, a direction that reflects finer grain sizes and deeper water. Calcium is less abundant on the shelf than in adjacent bays, probably because shelf sediments contain less shell material than do bay sediments.



o Bay sediments (Baffin-Alazan Bay system); Cr analyses by USGS; r = 0.435, n = 26
+ Bay sediments (Laguna Madre); Cr analyses by Bureau of Economic Geology; r = 0.452, n = 29
• Shelf sediments; Cr analyses by USGS; r = 0.507, n = 51

***Figure 15.* Scattergram of chromium and mud. (Letters and numbers shown next to plotted points are sample station numbers—see figure 13 for explanation.)**

Chromium

Bay sediments.—Concentrations of chromium (Cr) in bay-floor sediments range from less than 1 to 56 ppm (pl. IIIA). The average chromium value is about 16 ppm. In the Baffin-Alazan Bay system, highest concentrations of chromium (generally more than 20 ppm but reaching a high of 48 ppm near the head of Alazan Bay) occur in bay-center areas, and lowest concentrations (less than 20) occur along the bay margins. Highest concentrations in Laguna Madre occur near Middle Ground and in lagoon-center sediments south of the Land-Cut Area (pl. IIIA).

In the Baffin-Alazan Bay system, highest concentrations of chromium occur parallel to the bay axes and are generally associated with mud that resides in the deeper bay segments, whereas lower concentrations commonly occur in sands along bay margins. This general, although low, positive correlation with mud helps isolate anomalous sediments such as the one collected at Alazan Bay station 8 (fig. 15). The correlation coefficient for Laguna Madre sediments (shown in figure 15) is similar to that of the Baffin-Alazan Bay system. (Concentrations of less than 5 ppm were not considered in correlation-coefficient calculations because 5 ppm is the minimum level of detection for chromium by the ICP-AES used by the Bureau of Economic Geology.) Most Laguna Madre sediments are high in sand and contain less than 5 ppm chromium (fig. 15; pl. IIIA). Sediments collected from the Intracoastal Waterway, which extends the length of Laguna Madre, commonly contain more mud and also have higher concentrations of chromium (app. B; pl. IIIA).

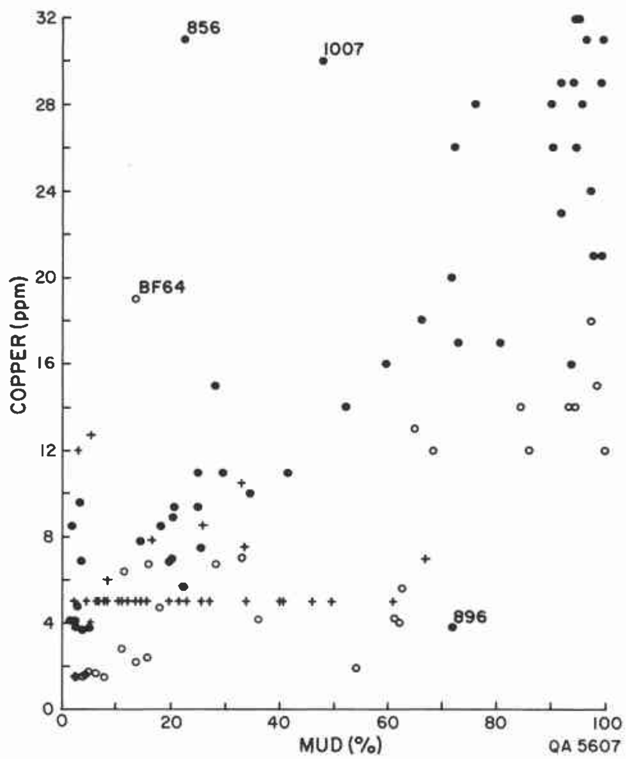
Shelf sediments.—Chromium concentrations in shelf sediments (app. B; pl. IIIA) are highly variable, and their distribution pattern is complex. As a result, chromium abundance correlates poorly with either grain size or water depth. A plot of chromium versus mud (fig. 15) shows a correlation that corresponds to the upper limit established by data from adjacent bays. Shelf sediments commonly contain more chromium than do bay sediments, and higher chromium values are found in large areas on the shelf rather than in the bays. Some shelf samples with exceptionally high chromium content, especially given the percent mud, occur along the shoreface of Padre Island. Although chromium concentrations range from 3 to 120 ppm, values between 40 and 70 ppm are most common. Values above 70 ppm occur at a few individual sample sites. Chromium generally increases gulfward (pl. IIIA); however, reentrants of higher than average concentrations occur in the vicinity of Big Shell Beach and Little Shell Beach.

Copper

Bay sediments.—Concentrations of copper in sediments collected from bay, estuary, and lagoon areas (excluding channels) range from less than 2 to 19 ppm. Average concentrations range from approximately 8 ppm in the Baffin-Alazan Bay system to a lower, but undetermined, value in Laguna Madre (the Laguna Madre average cannot be determined because most samples contain copper concentrations that are below the minimum level of detection [5 ppm] by the ICP-AES) (pl. IIIB). The highest concentrations of copper in the bay-estuary-lagoon system occur in sediments south of the Land-Cut Area. Sediments from three stations in the Intracoastal Waterway in this area contain from 25 to 44 ppm copper (pl. IIIB). The highest concentration in lagoon-floor sediments (13 ppm) occurs nearby at Laguna Madre station 140A (pl. VI).

Highest concentrations of copper (more than 10 ppm) generally occur in bay-center muds and lowest concentrations (less than 5 ppm) in sandier bay-margin areas, although there are exceptions. Some sediments with a relatively low mud content (less than 40 percent) contain above-normal copper concentrations (more than 10 ppm) (fig. 16). Nevertheless, there is a positive association between copper and grain size for most sediments, as shown in figure 16. The substantial differences in correlation coefficients (r) reported in figure 16 for the Baffin-Alazan Bay system and for Laguna Madre are probably related more to differences in chemical analytical methods used in the two areas than to variations in copper-sediment relationships (see the section Data Acquisition and Analyses, p. 3).

Shelf sediments.—Concentrations of copper in shelf sediments range from 3.7 to 32 ppm (app. B; pl. IIIB). Copper values generally increase systematically offshore. Lowest concentrations occur nearshore, where sand is predominant, whereas highest concentrations of copper are generally associated with fine-grained sediments that cover broad areas (pl. VI). A reentrant of higher than average concentrations occurs near Big Shell Beach. Copper concentrations in shelf sediments (1) have higher correlations with percent mud than do bay sediments (fig. 16), (2) are slightly greater than concentrations in adjacent bays, and (3) correspond to the upper limit of bay concentrations. They also exhibit a more steeply sloped plot than do bay-sediment concentrations that have comparable quantities of mud.

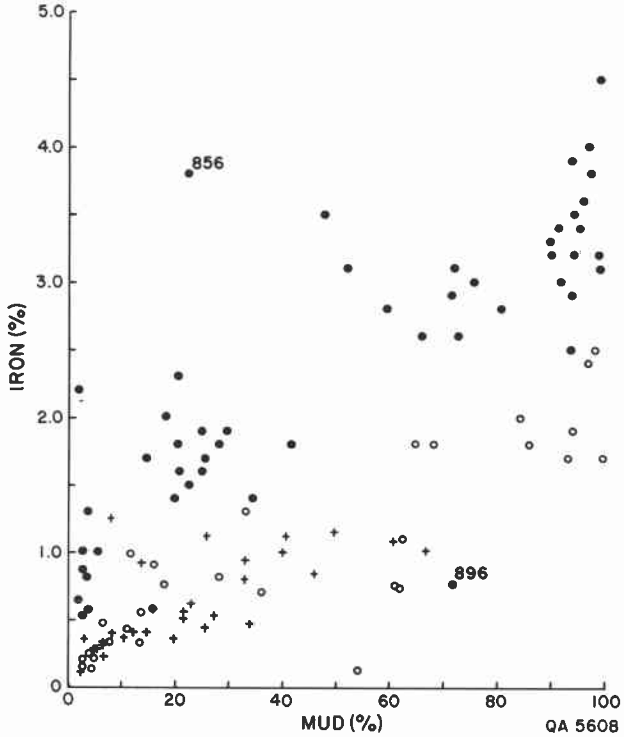


o Bay sediments (Baffin-Alazan Bay system); Cu analyses by USGS; r = 0.686, n = 26

+ Bay sediments (Laguna Madre); Cu analyses by Bureau of Economic Geology; r = 0.259, n = 15

• Shelf sediments; Cu analyses by USGS; r = 0.828, n = 51

Figure 16. **Scattergram of copper and mud. Plots along the 5 ppm line represent copper concentrations of less than 5 ppm, which was generally the minimum level of detection in samples analyzed by the Bureau of Economic Geology (see footnote, p. 6). (Letters and numbers shown next to plotted points are sample station numbers—see figure 13 for explanation.)**



o Bay sediments (Baffin-Alazan Bay system); Fe analyses by USGS; r = 0.850, n = 26
+ Bay sediments (Laguna Madre); Fe analyses by Bureau of Economic Geology; r = 0.744, n = 40
• Shelf sediments; Fe analyses by USGS; r = 0.822, n = 51

***Figure 17.* Scattergram of iron and mud. (Letters and numbers shown next to plotted points are sample station numbers—see figure 13 for explanation.)**

Iron

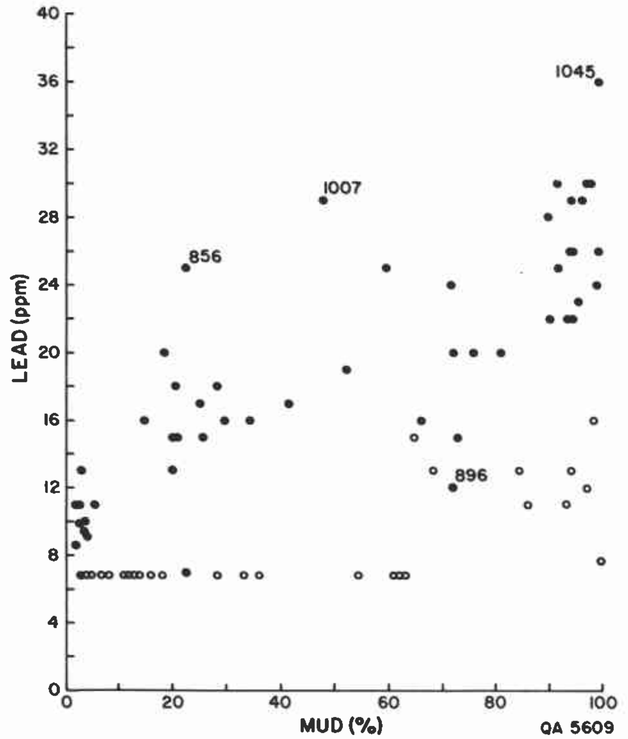
Bay sediments.—Concentrations of iron (Fe) in bay sediments range from 0.1 percent (1,000 ppm) to 2.5 percent (25,000 ppm); the highest values (excluding navigation-channel sediments) occur in the Baffin-Alazan Bay system, where the mean concentration is about 1 percent (pl. IIIC). Sediments in Laguna Madre, with a mean of about 0.6 percent, contain the lowest concentrations of iron, primarily because of the sandy sediments (which are typically low in iron) that characterize the lagoon. Highest concentrations of iron occur in channel-floor sediments collected from the Intracoastal Waterway; the maximum value measured (3 percent) is in sediments south of the Land-Cut Area. Eight sediment samples collected from the Intracoastal Waterway have iron concentrations of more than 2.5 percent (pl. IIIC). Although channel sediments were not analyzed for texture, visual descriptions of the sediments indicate that those with high iron content along the northern and southern sections of the Intracoastal Waterway are primarily muds, and those with low iron content along the central reaches of the channel (between Middle Ground and the southern end of the Land-Cut Area) are principally sands.

As with the trace metals chromium and copper, highest iron concentrations are associated with fine-grained sediments; therefore, iron has a high positive correlation with mud (fig. 17). Samples with more than 75 percent mud generally contain more than 1.5 percent iron, and samples with less than 25 percent mud generally contain less than 1.0 percent iron (fig. 17). Along bay margins and in other sand-rich environments, iron concentrations are generally less than 0.5 percent.

Shelf sediments.—The abundance of iron in shelf sediments (pl. IIIC) ranges from 0.5 to 4.5 percent and systematically increases in an offshore direction. As in the bays, maximum values coincide with fine-grained sediments (fig. 17); conversely, lowest values occur along the shoreface where sand is abundant. Patterns of iron abundance are simple, and concentrations are uniformly distributed across the entire range except for the few highest values (greater than 4 percent) that occur at isolated sample stations. These maximum values of iron exceed those for sediments in the adjacent bays, and iron is more concentrated in shelf sediments than in bay sediments having comparable amounts of mud (fig. 17).

Lead

Bay sediments.—Sediments from most of Laguna Madre were analyzed using the ICP-AES, which due to dilution factors did not detect a level of lead (Pb) lower than 40 ppm. Therefore, the distribution of lead was mapped only in the Baffin-Alazan Bay system and in the northern tip of Laguna Madre, where sediments were analyzed by the USGS (pl. IIID). In these areas, lead concentrations range from less than 6.8 ppm (minimum level of detection) to a high of 20 ppm in the Intracoastal Waterway. The highest concentration of lead measured in bay-floor sediments was 16 ppm from a station near the head of Baffin Bay (pl. IIID). Lower values of lead typically occur in sandy areas along bay margins; higher concentrations commonly occur



o Bay sediments (Baffin-Alazan Bay system); r = 0.719, n = 26
● Shelf sediments; r = 0.814, n = 51

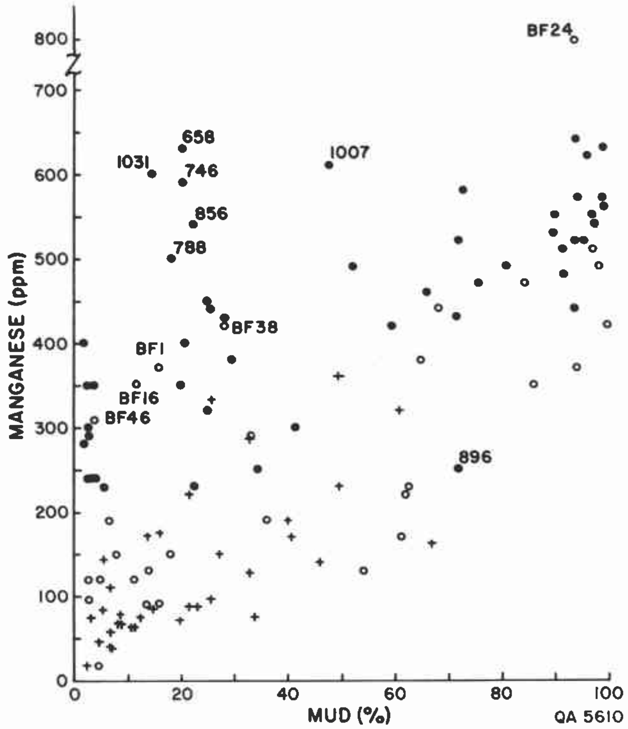
Figure 18. **Scattergram of lead and mud. All analyses of lead by USGS. The line plotted below 8 ppm represents sediments with lead concentrations of less than 6.8 ppm, the minimum level of detection (see footnote, p. 6). (Letters and numbers shown next to plotted points are sample station numbers—see figure 13 for explanation.)**

in deeper muddy areas. There is a positive correlation between lead and mud, as shown in the scattergram in figure 18.

Shelf sediments.—Lead in surface sediments of the inner shelf ranges only from about 7 to 36 ppm (pl. IIID); nevertheless, patterns emerge within this limited range. Lowest concentrations occur nearshore, especially along the beach and upper shoreface. This association possibly reflects the coarser sediment textures. Lead abundance increases nearly systematically offshore in bands almost parallel to the coast. Lead concentrations greater than 25 ppm occur in patches and as isolated samples associated with fine-grained sediments. Highest values of lead occur where the sediments are composed of at least 80 percent mud (fig. 18).

Manganese

Bay sediments.—Concentrations of manganese (Mn) in bay- and lagoon-floor sediments range from less than 20 ppm in Laguna Madre to 820 ppm in Baffin Bay (pl. IVA). Average manganese concentrations range from approximately 130 ppm in Laguna Madre to 300 ppm in the Baffin-Alazan Bay system. Sediments collected from the Intracoastal Waterway contain the highest concentrations of manganese; seven samples have concentrations exceeding 600 ppm, with one sample (from station 47 located near the southern end of the study area) exceeding 900 ppm (app. B; pl. IVA). High concentrations are commonly associated with muddy sediments and low concentrations with sandy sediments; the correlation coefficient between manganese and percent mud is approximately 0.7 in the Baffin-Alazan Bay system and 0.5 in Laguna Madre (fig. 19). This positive association helps

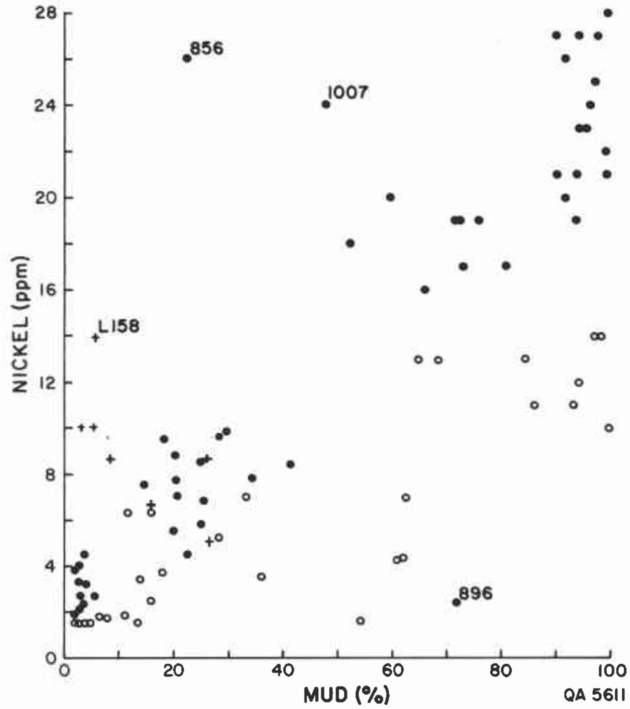


o Bay sediments (Baffin-Alazan Bay system); Mn analyses by USGS; r = 0.665, n = 26
+ Bay sediments (Laguna Madre); Mn analyses by Bureau of Economic Geology; r = 0.515, n = 40
● Shelf sediments; Mn analyses by USGS; r = 0.635, n = 51

Figure 19. **Scattergram of manganese and mud. (Letters and numbers shown next to plotted points are sample station numbers—see figure 13 for explanation.)**

differentiate samples that contain anomalous concentrations of manganese with respect to mud content; the most obvious anomaly occurs at Baffin Bay station 24 (fig. 19). Sands typically contain less than 200 ppm manganese, and muds typically contain more than 300 ppm (fig. 19), but there are exceptions to these general associations. For example, sands located along much of the southern margin of Baffin Bay contain more than 300 ppm manganese. These sandy sediments, containing less than 30 percent mud (Baffin Bay stations 1, 16, 38, and 46), plot along a linear trend significantly above the trend set by other sediments (fig. 19).

Shelf sediments.—Surface sediments on the inner shelf contain from 230 to 640 ppm manganese; however, most samples contain from 400 to 550 ppm (pl. IVA). This average, or background level, which extends from the shoreline to the offshore limit of the study area, serves to contrast the areas of higher and lower values of manganese. Overall, there is a weak trend toward higher amounts in a seaward direction, but some exceptions occur. For example, reentrants of intermediate concentrations project landward near Big Shell Beach. Furthermore, some concentrations of 600 ppm or greater are scattered at isolated sample sites, including stations 658, 716, 784, and 1,001 (pl. VI). Most of these sediments contain at least 90 percent mud. In the Kingsville area, manganese abundance is generally greater in shelf sediments than in bay sediments (fig. 19).



o Bay sediments (Baffin-Alazan Bay system); Ni analyses by USGS; r = 0.845, n = 26
+ Bay sediments (Laguna Madre); Ni analyses by Bureau of Economic Geology; r = 0.383, n = 15
• Shelf sediments; Ni analyses by USGS; r = 0.873, n = 51

Figure 20. **Scattergram of nickel and mud. Nickel concentrations reported as less than 20 ppm (app. B) are not plotted. (Letters and numbers shown next to plotted points are sample station numbers—see figure 13 for explanation.)**

Nickel

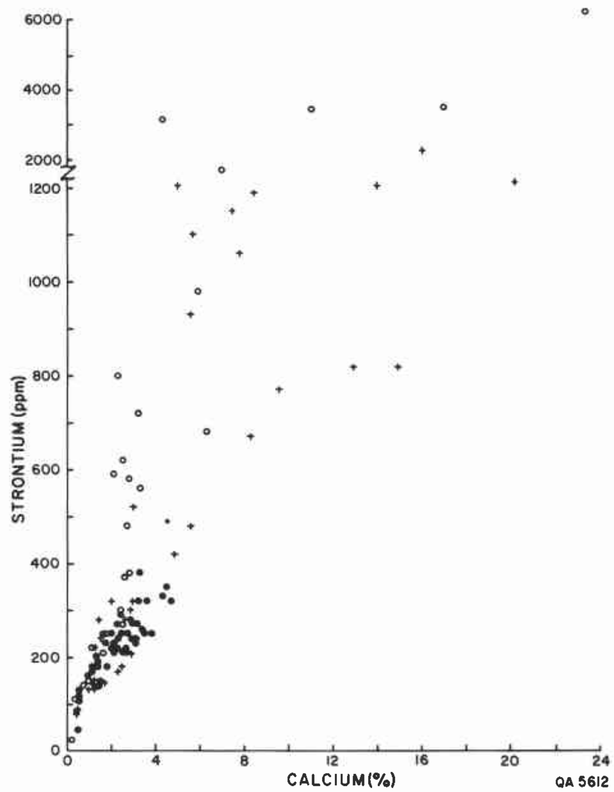
Bay sediments.—Concentrations of nickel (Ni) in bay- and lagoon-floor sediments range from less than 2 ppm to about 20 ppm, the highest concentration occurring in Laguna Madre sediments south of the Land-Cut Area (pl. IVB). Sediments collected from the Intracoastal Waterway, however, contain the highest concentrations overall. Six samples have nickel concentrations exceeding 30 ppm, and sediment from Intracoastal Waterway station 79, located west of Middle Ground, has the highest concentration at 37 ppm. In the Baffin-Alazan Bay system, the maximum concentration is 14 ppm, and the average is 6.6 ppm. The average concentration in Laguna Madre sediments could not be accurately determined because the minimum level of detection for most sediments analyzed with the ICP-AES was 20 ppm. For this reason also, the distribution of nickel in the central part of Laguna Madre was not mapped on plate IVB. There is a positive association between nickel and mud in the Baffin-Alazan Bay system, as shown by a correlation coefficient of 0.845 (fig. 20).

Shelf sediments.—Concentrations of nickel in shelf sediments range only from 1.9 to 30 ppm; nevertheless, distinct patterns emerge within this limited range (pl. IVB). The clearest pattern is a systematic increase in an offshore direction; nearshore sand-rich sediments contain the lowest amounts of nickel, whereas mud contains proportionally more nickel. Also, the distribution of the various concentration levels is fairly uniform except for values of greater than 25 ppm, which commonly occur in smaller patches associated with a few sample sites. These maximum concentrations generally exceed those found in sediments of the adjacent bays. Furthermore, shelf sediments generally have more nickel than do bay sediments if the relationship with sediment texture is considered (fig. 20). The only sample with abundant nickel and little mud (from station 856) also contains anomalously high concentrations of other trace elements.

Strontium

Bay sediments.—Strontium (Sr) concentrations in bay sediments range from less than 50 ppm to 6,500 ppm. High values are commonly less than 2,000 ppm. Exceptions are for sediments collected at four bay-margin stations in the Baffin-Alazan Bay system where strontium concentrations exceed 3,000 ppm, and at Alazan Bay station 25, located about 1.2 mi (2 km) northeast of Kleberg Point (pls. IVC and VI), where concentrations reach a high of 6,500 ppm. Mean concentrations of strontium range from about 500 ppm in Laguna Madre to approximately 1,050 ppm in the Baffin-Alazan Bay system. The highest concentration of strontium measured in sediments from Laguna Madre is 1,900 ppm at station 103, located near the mainland shore south of Baffin Bay. Sediments from a nearby station in the Intracoastal Waterway (station 81) contain 2,300 ppm strontium—an unusually high concentration for channel sediments (pl. IVC). Another area in which strontium concentrations are relatively high (more than 1,000 ppm) is in Laguna Madre south of the Land-Cut Area.

The distribution of sediments high in strontium corresponds closely to that of sediments high in calcium (pl. IID). There is a high statistical correlation between these two elements, as demonstrated both in other studies (for example, Holmes, 1974) and in this study (correlation coefficient of approximately 0.90, fig. 21). Similar to calcium distribution patterns, high concentrations of strontium occur along shorelines where ooid sands are present (Behrens, 1964; Dalrymple, 1964). In addition, serpulid reefs occur along some of these shores (Andrews, 1964) and undoubtedly have contributed to high strontium content in sediments in these areas. Strontium-to-calcium ratios can vary depending on (among other variables) the type of shell contained in the sample analyzed. Some shells are composed mostly of calcite, whereas many other shells and worm tubes (serpulid worm tubes and marine gastropods, for example) are composed of aragonite, which has a higher strontium-to-calcium ratio than calcite (Odum, 1957; Galtsoff, 1964). Frishman (1969), in a study of the geochemistry of ooids in Baffin Bay, found three petrographically distinct types of coatings in ooids. The coatings differed in the amount of strontium carbonate and magnesium carbonate that they contained, which could affect the strontium-to-calcium ratios in ooid sands.



o Bay sediments (Baffin-Alazan Bay system); analyses by USGS; r = 0.933, n = 26

+ Bay sediments (Laguna Madre); analyses by Bureau of Economic Geology; r = 0.856, n = 40

• Shelf sediments; analyses by USGS; r = 0.876, n = 51

***Figure 21.* Scattergram of strontium and calcium (r = correlation coefficient, n = number of samples). There is a high positive correlation between these two elements in both bay and shelf sediments.**

Shelf sediments.—Strontium concentrations range from less than 45 to 380 ppm; however, most shelf sediments contain between 200 and 300 ppm (pl. IVC). The two extremes are anomalous and usually occur as isolated samples or small patches; the highest concentrations come from shelly material. Although most samples occur within a limited range, they still show a general increase offshore. Strontium abundance is fairly uniform and is substantially lower in sediments from the inner shelf than in most sediments from adjacent bays. The greater abundance of shell material in bay sediments than in shelf sediments probably accounts for the difference between strontium concentrations measured in the two areas. This explanation is supported by the positive correlation between strontium and calcium and the lower strontium-calcium ratios for shelf sediments (fig. 21).

Zinc

Bay sediments.—Concentrations of zinc (Zn) in bay sediments (excluding navigation channels) range from less than 10 ppm to 82 ppm (pl. IVD). Average concentrations are 27 ppm in the Baffin-Alazan Bay system and 26 ppm in Laguna Madre. Sediment samples from the Intracoastal Waterway contain the highest concentrations of zinc, with five exceeding 90 ppm. However, duplicate analyses of two Intracoastal Waterway samples with concentrations exceeding 140 ppm (station numbers 53 and 92, app. B) yielded concentrations of less than 100 ppm (78 and 99 ppm, respectively), indicating possible contamination during the analytical process. Another Intracoastal Waterway sample (85) with a reported concentration of 212 ppm is also suspect.

In the Baffin-Alazan Bay system, highest concentrations occur in the bay-center muds, where zinc typically ranges from 35 to 50 ppm. An exception occurs at station 7 near the southern edge of the mouth of Baffin Bay, where zinc reaches a high of 82 ppm. Sediments from this particular site were analyzed using a different method (ICP-AES) than was used for other samples in the Baffin-Alazan Bay system. Still, this high concentration of zinc is anomalous with respect to nearby Laguna Madre sediments that were analyzed by the same method (ICP-AES). The positive association between zinc content and percent mud shown in figure 22 helps isolate sample stations with anomalous concentrations of zinc. Several stations plot above the trend set by most of the samples.

Shelf sediments.—Surface sediments from the inner shelf contain concentrations ranging from less than 15 ppm to 96 ppm zinc (pl. IVD). Highest concentrations are usually limited in areal extent. The maximum values of zinc fall within the range of concentrations found in sediments of adjacent bays. Zinc concentrations generally increase in an offshore direction. Lowest concentrations occur where sand is abundant, and highest concentrations coincide with fine-grained sediments (fig. 22). Landward and seaward projections of high and low zinc concentrations near Big Shell Beach produce a pattern that is similar to those of other trace elements. The relation between muddy texture and zinc abundance noted in the bays also holds true for the inner shelf of the Kingsville area (fig. 22).

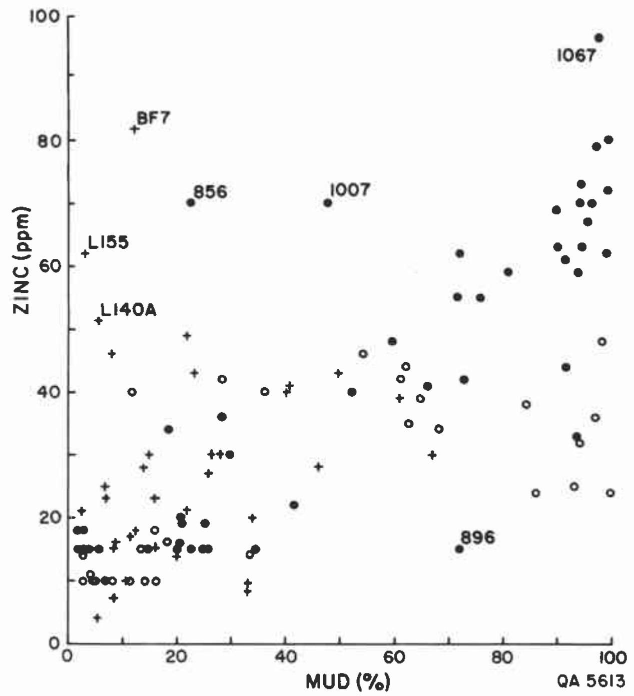


***Figure 22.* Scattergram of zinc and mud. (Numbers next to plotted points refer to sample station number—see figure 13 for explanation.)**

TEXTURAL AND GEOCHEMICAL RELATIONSHIPS

The bay-estuary-lagoon and inner-shelf systems are dynamic environments encompassing complex physical, chemical, and biological interactions. In the past three decades since the classic study by Krauskopf (1956), many studies have analyzed the concentration, speciation, migration pathways, physicochemical conditions, and diagenetic changes of major, minor, and trace elements occurring in water and in sediments of fresh, estuarine, and marine systems. Many of these studies used selective extraction techniques to determine the proportion of a particular trace metal or element that is (1) dissolved, (2) contained in mineral crystal lattices,

(3) precipitated as hydroxides, carbonates, or sulfides, (4) adsorbed on or complexed with clay minerals, organic matter, or hydrous oxides of iron and manganese (Förstner and others, 1978), or (5) concentrated through biological processes in flora (Parker, 1962) or fauna (Berryhill, 1975). Conflicting evidence and conclusions about trace element behavior in estuaries, notably with respect to solid-solution exchange, have led to considerable disagreement (Aston, 1978; Förstner and Wittman, 1981).

Geochemical analyses of sediments for the Submerged Lands of Texas Project provided the total concentration of selected chemical elements in the sediments (which in this study included interstitial water and contained flora and fauna). Although speciation, or phase of occurrence, of the different measured elements is not determinable from the analyses, definite tendencies and relationships can be described by comparing total element concentrations with each other and with sediment texture and TOC.

The correlation between decreasing grain size and increasing trace metal concentrations in sediments of submerged lands—shown on the maps and figures discussed earlier in this section—is in agreement with several other studies (for example, Turekian, 1965; Shimp and others, 1970; Thorne and Nickless, 1981). The importance of considering trace element concentrations in terms of sediment grain sizes has been pointed out by several researchers, including de Groot and others (1976). Without a standard such as grain size, comparison of trace element levels at one or more localities is meaningless. Suter (1980), in attempting to determine seasonal variations of selected trace metals in sediments of the Corpus Christi Ship Channel Inner Harbor, suggested that much of the variation in trace metal concentrations found in previous studies was probably the result of differences in grain size rather than of seasonal differences in trace metal concentrations.

Several variables appear to account for the higher concentrations of trace metals in fine-grained sediments: (1) the mineralogy of the sediment, which generally affects grain size (de Groot and others, 1976); (2) the large surface area of the clays on which trace metals can be adsorbed (coarser materials such as sand and shell that have lower surface areas tend to dilute the concentration of trace metals) (Williams and others, 1978); and (3) the tendency of organic matter to be associated with the fine-grained fraction (organic matter can adsorb or form complexes with trace metals) (Rashid, 1974; Nissenbaum and Swaine, 1976; Sholkovitz, 1976). The association of organic matter and fine-grained sediments with each other and with trace metals requires the use of selective extraction techniques to determine the fraction of trace metal held by each. Also, many of the trace metals can be adsorbed or scavenged by hydrous oxides of manganese and iron (Goldberg, 1954; Krauskopf, 1956; Jenne, 1968). Förstner and others (1978), citing Guy and Chakrabarti (1975), presented a generalized sequence of trace metal sorption capabilities of different solids: MnO_2 > humic acid > hydrous iron oxides > clay minerals.

To analyze the trends and significance of selected trace, minor, and major element concentrations in the sediments of the Kingsville area, three principal methods were used: (1) visually comparing the mapped distribution of sediments, as defined by grain-size analyses (pl. I), with the mapped distribution of element concentrations (pls. II through IV); (2) plotting trace metal concentrations against percent mud (sediments less than 63μm in size) (figs. 13 through 20 and 22), percent clay (less than 3.9μm), percent TOC, or parts-per-million oxides of manganese; and (3) computing and mapping the distribution of the ratio of trace element concentrations to percent clay, percent TOC, and percent mud. The third method, although relatively effective in normalizing trace element concentrations with respect to grain size and TOC, was found to be less desirable for reporting results than were methods 1 and 2. In method 2, the most commonly used measure of grain size is percent mud (less than 63μm). This is primarily because percent mud shows a close correlation with trace element concentrations and also because it was measured in more sediment samples than was percent clay or mean phi.

The significance of trace metal concentrations in the Kingsville area can be assessed by comparing mean and highest values with average concentrations measured in sedimentary shales, nearshore sediments, and other sediments apparently unaffected by human contributions (table 5). These latter concentrations are thought to represent baseline values that are derived from natural sources and therefore exclude anthropogenic sources. Anthropogenic sources have greatly increased the concentrations of certain trace metals in sediments in many areas (Förstner and others, 1978), including Texas (Holmes, 1974; Warshaw, 1976; Suter, 1980). Also included in table 5 for comparison are some high concentrations of trace metals measured in estuarine sediments (Warshaw, 1976).

Table 5. Comparison of trace element concentrations in sediments (mud) of the Kingsville area with those in uncontaminated sediments (baseline levels) and contaminated estuarine sediments along the Texas coast. Values in parts per million.†

	Kingsville Area[1]				Worldwide Baseline Levels					Contaminated Sediments
	Bay sediments* (muds) mean	Bay sediments* (muds) high**	Shelf sediments (muds) mean	Shelf sediments (muds) high**	Shale[2]	Nearshore sediment[3]	Clays and shales[4]	15th-16th-century sediment in Rhine estuary[5]	Modern marine argillaceous sediment[6]	Example of high estuarine sediment value, Texas coast[7]
Barium	520	820	489	620	580	750	800			910
Boron	86	94	102	150	100		100		90	
Chromium	23	48	61	120	90	100	100	63	66-72	134
Copper	14	18	26	32	45	48	57	21	37	1,510
Iron	20,000	25,000	33,500	45,000	47,200		33,300			
Lead	12	16	26	36	20	20	20	31	21	340
Manganese	490	820	542	640	850	850	670			1,400
Nickel	12	14	23	30	68	55	95	33	40	160
Zinc	32	48	65	96	95	95	80	93		4,900

†Chemical analysis for bay (Baffin-Alazan Bay system only) and shelf sediments by USGS—see Data Acquisition and Analyses (p. 3).
[1]Appendix B; muds = sediments > 75% mud (< 63 microns in particle size)
[2]Turekian and Wedepohl (1961)
[3]Wedepohl (1960)
[4]Vinogradov (1962)
[5]de Groot and others (1976)
[6]Potter and others (1963)
[7]Warshaw (1976)
*Includes only those sediments from the Baffin-Alazan Bay system (analyzed by USGS)
**Highest recorded value—not limited to muds

Average trace element concentrations in muds of the Kingsville area are comparable to or lower than baseline levels for all elements (table 5). However, the highest concentrations of four elements exceed baseline values: barium, having a high bay concentration of 820 ppm; boron, having a high shelf concentration of 150 ppm; chromium, which reaches a high of 120 ppm in shelf sediments; and lead, having a high of 36 ppm in shelf sediments. Concentrations of chromium and zinc locally exceed screening levels for dredged-sediment disposal established in 1974 by the U.S. Environmental Protection Agency (EPA) (table 6). (It should be noted that numerical values such as those listed in table 6 are no longer used by the EPA.)

Concentrations of trace metals in many sediment samples may not appear excessively high, or even above background levels, until they are plotted against percent mud in a scattergram. This normalization with percent mud helps to identify sediments that contain higher than normal trace element concentrations relative to the amount of mud they contain.

Sediment samples that plot outside the norm can be seen in scattergrams of barium, boron, chromium, copper, iron, lead, manganese, nickel, and zinc (figs. 13 through 20 and 22). Although it is possible that some sediment samples plot above normal because of contamination during the sampling or analytical phases of the study or because of natural factors, some are probably abnormal

Table 6. Heavy-metal screening levels proposed by the U.S. Environmental Protection Agency (1974) for dredged-sediment disposal in EPA Region VI (includes Kingsville area).

Metal	Sediment concentration in mg/kg dry weight (ppm air dried)
Arsenic	5
Cadmium	2
Chromium (total)	100
Copper	50
Lead	50
Mercury	1
Nickel	50
Zinc	75

because of anthropogenic contributions of trace elements to the system. For example, high barium concentrations in Laguna Salada may be associated with barite, which is used in drilling muds. In determining which samples are above normal in relation to the amount of mud they contain, it is important to compare bay and shelf sediments with other bay and shelf sediments; bay and shelf sediments commonly follow different trends, partly because different analytical methods were used to analyze samples from the two areas (for example, Laguna Madre and the shelf).

In bay-estuary-lagoon systems, sediment distribution patterns of various trace metals follow similar trends. Some of the highest concentrations of chromium (pl. IIIA), copper (pl. IIIB), nickel (pl. IVB), and zinc (pl. IVD), for example, occur along the bay axes of the Baffin-Alazan Bay system. In Laguna Madre, concentrations are generally highest south of the Land-Cut Area, but local highs also occur near Middle Ground. Although trace metal distribution patterns generally mimic sediment textural patterns (highs associated principally with muds), trace metal concentrations in some sediments are anomalously high with respect to associated mud content (for example, copper [Cu], fig. 16; nickel [Ni], fig. 20; and zinc [Zn], fig. 22). The highest concentrations of several elements occur in sediments of the Intracoastal Waterway. Quantitative textural analyses were not conducted on channel sediments, but visual descriptions of sediment textures indicate that high concentrations of trace metals are generally confined to muds (table 7).

On the inner shelf, distributions of various trace metals also follow similar patterns, especially those of copper, iron, lead, manganese, nickel, and zinc. Highest concentrations occur along the outer margins of the study area and extend shoreward on each side of a low that extends from nearshore gulfward toward the center of the map area (pls. IIIB through IIID, IVA, IVB, and IVD). Why this zone of sediment is characterized by low trace metal concentrations is not apparent because it does not seem to be associated with a coarsening of sediment textures, as might be expected. Because sediment samples analyzed for trace metals were not necessarily the same samples analyzed for texture, it is possible that existing textural data did not detect a seaward coarsening of sediments that may occur along a narrow belt. Along the southern margin of the study area, lower concentrations of trace metals are associated with an arcuate zone of coarser sediments that extends southeastward from Big Shell Beach to the seaward edge of the study area. This arcuate trend of sandy sediments (pl. I), marked by low trace metal concentrations, is apparently related to the seafloor exposure of upper Pleistocene sands following the erosion and landward retreat of the Holocene Rio Grande delta.

Table 7. Comparison of sediment textures and selected trace metal concentrations of sediments from the Intracoastal Waterway (ICWW) in the Kingsville area.

ICWW Station Numbers	Sediment Type (visual description)	Cr (ppm)	Cu (ppm)	Ni (ppm)	Zn (ppm)
1	mud	34	21	20	43
4	mud	24	15	15	47
47	mud	19	43	11	226
49	muddy sand	<4	8	<10	95
51	mud	133	32	84	224
53	mud	18	25	12	197
57	mud	12	<5	<20	23
59	sandy mud	<5	<5	<20	26
61	muddy sand	<5	<5	<20	28
63	sand	<5	<5	<20	23
65	muddy sand	<5	<5	<20	21
67	mud	<5	<5	36	36
69	muddy sand	<5	<5	34	34
71	sandy mud	<5	<5	33	25
73	muddy sand	<5	<5	<20	25
75	mud	74	<5	32	49
76	sandy mud	15	<5	<20	36
79	mud	<5	<5	37	82
81	muddy shell	<5	<5	<20	37
82	mud	<5	13	35	90
85	mud	39	14	17	212
89	mud	74	20	38	363
92	mud	34	27	14	141

Anomalously high concentrations of chromium occur in shelf sediments near Padre Island's Little Shell Beach. This anomalous zone of chromium-enriched sediment is offshore from an abandoned military bombing and gunnery target, which may have been the source of some of the chromium. In the Port Lavaca area, high chromium concentrations also have a close geographic association with an abandoned bombing and gunnery range and other military facilities located on Matagorda Island, suggesting that at least some of the chromium may be anthropogenic (White and others, 1989).

To further examine trace metal levels and distribution patterns, bay and shelf sediments were compared with those in other submerged lands areas (Corpus Christi, Galveston-Houston, Brownsville-Harlingen, Beaumont-Port Arthur, Bay City-Freeport, and Port Lavaca [White and others, 1983, 1985, 1986, 1987, 1988, and 1989, respectively]) (fig. 1). The following paragraphs discuss similar comparisons made in the Kingsville area; however, the different methods of spectrochemical analysis used must be considered. The mapped distributions of elements in bay sediments from the Beaumont-Port Arthur, Bay City-Freeport, and Port Lavaca areas are based primarily on chemical analyses by the Bureau of Economic Geology using an ICP-AES. Shelf sediments from all areas and bay sediments used for comparison in the Kingsville (Baffin-Alazan Bay system), Brownsville-Harlingen, Corpus Christi, and Galveston-Houston areas were analyzed by the USGS using computer-assisted spectrographic methods.

In the Corpus Christi area (White and others, 1983), a comparison of trace element concentrations in bay and shelf sediments showed some consistent trends for many of the trace elements. Scattergrams of percent mud versus boron, copper, iron, nickel, lead, and to some degree chromium, showed that the scattering of both shelf and bay sediment data reflects linear trends; however, shelf sediments consistently were coincident with, and just above the upper scatter boundary of, bay sediments. These trends indicated that for a given amount of mud, shelf sediments had higher trace metal concentrations than did bay sediments. A similar trace element relationship occurred with mean phi, percent clay, and TOC, as demonstrated by the scattergram of copper. That zinc concentrations in bay and shelf sediments did not show a pattern similar to other trace metals, but rather one in which bay sediments typically had higher concentrations with respect to mud content, was attributed to anthropogenic zinc in bay sediments (Holmes and others, 1974).

A comparison of trace element concentrations in sediments from the bay-estuary-lagoon system and the inner shelf in the Kingsville area shows that most of the elements, including boron, chromium, copper, iron, lead, and manganese, follow a trend that is similar to that of most elements in the Corpus Christi area. In scattergrams where these elements are plotted against percent mud, shelf sediments generally plot above the cluster of values representing bay sediments (figs. 14 through 19). Accordingly, the mean concentrations of these elements in shelf muds (sediments composed of 75 percent or more silt or clay) are higher than the concentrations in bay muds (excluding sediments from navigation channels). Unlike zinc in the Corpus Christi area, which in bay sediments exceeds that in shelf sediments, zinc in the Kingsville area follows the trend of the other elements by being more abundant in shelf sediments than in bay sediments. Holmes and others (1974) reported that high concentrations of zinc in the Corpus Christi Bay were anthropogenic and derived from the Corpus Christi Ship Channel and Inner Harbor.

Higher concentrations of trace metals in bay sediments than in shelf sediments indicate that the difference possibly may relate to anthropogenic enrichment and that in the Kingsville area anthropogenic enrichment in bay sediments has not occurred because trace metal concentrations are generally lower there than on the inner shelf. This conclusion assumes, perhaps incorrectly, that under natural conditions, shelf muds contain trace metal concentrations that are comparable to or slightly greater than those of bay sediments. Studies indicate that average concentrations of five trace metals (boron, chromium, copper, nickel, and zinc) are higher in marine shales than in fresh-water shales (Keith and Degans, 1959; Potter and others, 1963) but trace metal concentrations in brackish-water shales are not significantly different from those found in marine shales (Keith and Degans, 1959).

Comparisons of trace element levels in sediments from Kingsville, Brownsville-Harlingen, Corpus Christi, Port Lavaca, Bay City-Freeport, Galveston-Houston, and Beaumont-Port Arthur areas (fig. 1) show some interesting relationships (table 8). Element concentrations in some areas differ significantly from others. In the bay-estuary-lagoon systems, the mean concentration of barium in sediments (muds) in the Corpus Christi area is higher than that in all other areas and exceeds by a factor of almost three that in the Brownsville-Harlingen area, which has the lowest mean. Except for the Corpus Christi area, barium concentrations are highest in the Kingsville and Beaumont-Port Arthur areas, where mean values are almost 2 times the value in the Brownsville-Harlingen area. Chromium has the highest mean concentration in the Bay City-Freeport, Galveston-Houston, and Port Lavaca areas, where the mean concentrations are more than 2 times higher than the lowest concentration occurring in the Kingsville area. The mean concentration of copper is highest in the Galveston-Houston area; it is 2.7 times higher than in the Port Lavaca area, where the concentration is lowest. Brownsville-Harlingen and

Table 8. Comparison of mean concentrations of selected elements in bay and inner-shelf muds (sediments composed of more than 75 percent silt and clay) in the Brownsville-Harlingen, Kingsville, Corpus Christi, Port Lavaca, Bay City-Freeport, Galveston-Houston, and Beaumont-Port Arthur area submerged lands. Values in parts per million.*

		Brownsville-Harlingen area	Kingsville area[a]	Corpus Christi area	Port Lavaca area	Bay City-Freeport area	Galveston-Houston area[b]	Beaumont-Port Arthur area[c]
Barium	Bay	272 (1.0)	520 (1.9)	800 (2.9)**	468 (1.7)	345 (1.3)	410 (1.5)	493 (1.8)
	Shelf	355 (1.0)	489 (1.4)	478 (1.3)	485 (1.4)	479 (1.3)	538 (1.5)	724 (2.0)
Boron	Bay	82 (1.1)	86 (1.1)	75 (1.0)	— —	— —	79 (1.1)	— —
	Shelf	89 (1.3)	102 (1.5)	94 (1.3)	91 (1.3)	92 (1.3)	70 (1.0)	82 (1.2)
Chromium	Bay	25 (1.1)	23 (1.0)	26 (1.1)	45 (2.0)	57 (2.5)	56 (2.4)	30 (1.3)
	Shelf	33 (1.0)	61 (1.8)	59 (1.8)	54 (1.6)	60 (1.8)	45 (1.4)	54 (1.6)
Copper	Bay	20 (2.0)	14 (1.4)	15 (1.5)	10 (1.0)	11 (1.1)	27 (2.7)	20 (2.0)
	Shelf	26[d] (1.4)	26 (1.4)	24 (1.3)	23 (1.3)	26 (1.4)	18 (1.0)	22 (1.2)
Iron	Bay	15,000 (1.0)	20,000 (1.3)	23,400 (1.6)	29,300 (2.0)	30,900 (2.1)	24,000 (1.6)	30,600 (2.0)
	Shelf	30,000 (1.0)	33,500 (1.1)	31,900 (1.1)	32,300 (1.1)	35,900 (1.2)	30,000 (1.0)	37,500 (1.3)
Lead	Bay	18 (1.5)	12 (1.0)	17 (1.4)	— —	— —	34 (2.8)	— —
	Shelf	19 (1.0)	26 (1.4)	25 (1.3)	23 (1.2)	24 (1.3)	19 (1.0)	24 (1.3)
Manganese	Bay	557 (1.4)	490 (1.2)	535 (1.4)	394 (1.0)	481 (1.2)	475 (1.2)	486 (1.2)
	Shelf	623 (1.2)	542 (1.1)	560 (1.0)	516 (1.0)	561 (1.0)	783 (1.5)	1,007 (2.0)
Nickel	Bay	14 (1.2)	12 (1.0)	15 (1.3)	24 (2.0)	28 (2.3)	22 (1.8)	17 (1.4)
	Shelf	17 (1.0)	23 (1.4)	22 (1.3)	22 (1.3)	26 (1.5)	28 (1.6)	32 (1.9)
Zinc	Bay	52 (1.6)	32 (1.0)	93 (2.9)	79 (2.5)	76 (2.4)	62 (1.9)	108 (3.4)
	Shelf	86 (1.6)	65 (1.2)	60 (1.1)	54 (1.0)	71 (1.3)	53 (1.0)	67 (1.3)

*Data from USGS except for bay sediments in the Beaumont-Port Arthur, Bay City-Freeport, and Port Lavaca areas, which were analyzed by the Bureau of Economic Geology using ICP-AES—see Data Acquisition and Analyses section (p. 3).

**Numbers in parentheses are "enrichment factors," in which the lowest mean for each element is used as the standard against which the means from other areas are compared; for example, the mean concentration of barium in bay muds in the Corpus Christi area is 2.9 times the mean concentration of barium in bay muds in the Brownsville-Harlingen area.

[a]Excludes sediments from Laguna Madre.

[b]Excludes sediments from Houston Ship Channel/Buffalo Bayou.

[c]Excludes sediments from Sabine, Neches, and Port Arthur canals and river systems.

[d]Based in part on estimates from line of regression with mud percent.

—Not analyzed.

Beaumont-Port Arthur have mean copper concentrations that are 2 times higher than in the Port Lavaca area. (Reported concentrations of copper in bay sediments of the Port Lavaca and Bay City-Freeport areas may be below true values because the concentration reported for one of several standards used was low.) The mean concentration of iron is highest in the Bay City-Freeport, Beaumont-Port Arthur, and Port Lavaca areas, where it is about 2 times that occurring in the Brownsville-Harlingen area. Where lead was measured (table 8), the highest mean concentration is in the Galveston-Houston area. There it is almost 3 times the mean in the Kingsville area and about 2 times the mean in both the Corpus Christi and Brownsville-Harlingen areas. The highest mean concentration of nickel occurs in muds of the Bay City-Freeport area and is 2.3 times the lowest mean, which occurs in the Kingsville area. Zinc is highest in the Beaumont-Port Arthur and Corpus Christi areas, where the mean concentrations in mud are almost 3 times that in the Kingsville area. Manganese is the only element shown in table 8 for which mean concentration in bay muds does not vary significantly among all localities; the highest mean concentrations occur in the Brownsville-Harlingen and Corpus Christi areas, which are about 1.4 times the lowest mean that occurs in the Port Lavaca area. Boron, which was not measured in all areas, had a similar mean in areas where it was measured, although it is slightly higher in the Kingsville area.

In a comparison of semiquantitative chemical analyses of sediments from Corpus Christi Bay with those from the Baffin-Alazan Bay system, Holmes (1974) reported that nickel and zirconium were the only elements found to have higher concentrations in the Baffin Bay sediments. He found that several elements, including boron and lead, had higher concentrations in the Corpus Christi Bay sediments, which he attributed to anthropogenic sources by noting that boron is found in detergents, and lead is associated with urban and industrial activities. Holmes reported that the higher nickel in Baffin Bay appeared to be associated with organics, as shown by a high statistical correlation ($r = 0.80$) between organic content and nickel concentrations. In this study of submerged lands, nickel and boron were found to have higher concentrations in Corpus Christi Bay sediments (muds) than in Baffin Bay sediments (muds). A higher mean concentration for boron, however, exists in the Kingsville area (table 8) because the mean concentration in the Corpus Christi area includes sediments not only from Corpus Christi Bay but from other bays, where boron concentrations are lower. McGowen and others (1979) attributed high values of boron to the discharge of oil field brine. Holmes (1974) reported a strong to moderate correlation between iron and transitional metals in Baffin Bay sediments. In this study a very high statistical correlation was found between iron and nickel ($r = 0.98$) and between iron and boron ($r = 0.96$) and nickel and boron ($r = 0.97$) in Baffin Bay.

In summary, in bay-estuary-lagoon system muds (sediments with greater than 75 percent silt and clay), the areas having the highest mean concentrations of the various elements are (1) Kingsville, boron; (2) Corpus Christi, barium; (3) Bay City-Freeport, chromium, iron, and nickel; (4) Galveston-Houston, copper and lead; and (5) Beaumont-Port Arthur, zinc. (Note that if Corpus Christi and Nueces Bays are the only bays considered in the Corpus Christi area [that is, excluding Laguna Madre and other bays in the map area], then the mean concentration of zinc in the Corpus Christi area is 119 ppm [White, 1985], which exceeds that in the Beaumont-Port Arthur area.) Some variations in trace metal content can be attributed to the different analytical methods used. For example, iron concentrations are highest in those areas where sediments were analyzed by ICP-AES: Bay City-Freeport, Beaumont-Port Arthur, and Port Lavaca.

Concentrations of trace elements in muds from the inner shelf were determined using the same analytical method in all areas; accordingly, comparison of trace elements in shelf areas should be more meaningful than comparisons of trace elements in the bay-estuary-lagoon systems. Barium concentrations in shelf muds are highest in the Beaumont-Port Arthur and Galveston-Houston areas, where the respective means are 2 and 1.5 times higher than in the Brownsville-Harlingen area, where the lowest mean occurs (table 8). Mean concentrations of barium in the other areas are from 1.3 to 1.4 times the mean in the Brownsville-Harlingen area. The highest mean for boron on the inner shelf occurs in the Kingsville area, where it is 1.5 times the lowest mean, which occurs in the Galveston-Houston area. In the other five map areas (fig. 1), mean boron concentrations do not vary greatly, ranging between 1.2 and 1.3 times the low in the Galveston-Houston area. Mean chromium concentrations are highest in the Kingsville, Bay City-Freeport, and Corpus Christi areas, where they are about 1.8 times the lowest mean in the Brownsville-Harlingen area. The Beaumont-Port Arthur and Port Lavaca areas each have mean chromium concentrations that are 1.6 times the lowest mean; the mean chromium concentration in the Galveston-Houston area is 1.4 times the lowest mean in the Brownsville-Harlingen area. (Chromium is higher in sands than in muds in some shelf sediments, such as those in the Brownsville-Harlingen and Port Lavaca areas.) Copper, which has similar mean concentrations in most areas, is lowest in muds on the Galveston-Houston inner shelf, where the mean is 18 ppm. Other areas have mean concentrations that are 1.2 to 1.4 times higher than the mean in the Galveston-Houston area. The highest means of copper (26 ppm) occur in the Brownsville-Harlingen, Kingsville, and Bay City-Freeport areas. Iron concentrations do not differ greatly from area to area; the highest mean concentration occurs in the Beaumont-Port Arthur area, which is 1.3 times the lowest mean in both the Brownsville-Harlingen and Galveston-Houston areas. Mean concentration of lead is highest on the Kingsville shelf and is 1.4 times the lowest mean in the Brownsville-Harlingen and Galveston-Houston areas. Means for manganese and nickel are highest in the Beaumont-Port Arthur area, where the concentrations are almost twice the lowest means in the Port Lavaca and Brownsville-Harlingen areas, respectively. Zinc concentration is highest in the Brownsville-Harlingen area, where the mean value is 1.6 times the lowest mean, which occurs in the Galveston-Houston area (table 8).

In summary, in inner continental shelf muds, the areas with highest mean concentrations of the various elements are (1) Brownsville-Harlingen, zinc; (2) Kingsville, boron, chromium, and lead; (3) Beaumont-Port Arthur, barium, iron, manganese, and nickel; and (4) Brownsville-Harlingen, Kingsville, and Bay City-Freeport, copper. Only three elements—barium, manganese, and nickel—have mean concentrations that vary from one area to another by factors equal to or exceeding 1.9. The Beaumont-Port Arthur area (table 8) contains the highest concentrations of these three elements.

Differences in trace metal concentrations in bay and shelf sediments in the Kingsville, Brownsville-Harlingen, Corpus Christi, Galveston-Houston, Bay City-Freeport, and Beaumont-Port Arthur areas (fig. 1) may be the result of many variables other than anthropogenic contributions, including different mineralogical sources and provinces. Heavy minerals associated with Gulf sediments in the Corpus Christi area, for example, are derived in part from rivers along the northeastern part of the coast (Bullard, 1942). Among the rivers providing these heavy minerals, with which the trace metals may be associated, is the Colorado River. Its drainage area includes extensive igneous and metamorphic terranes and associated mineralized zones. In the Beaumont-Port Arthur and Galveston-Houston areas, sources of sediments include the Brazos, Mississippi, Trinity, Colorado, Neches, and Sabine Rivers. Other possible causes of differences in trace metal levels in shelf sediments compared with bay sediments (and in the respective coastal areas) include differences in clay mineralogy, organic content, water circulation pattern, and physicochemical conditions affecting precipitation and adsorption of trace metals.

Inner-shelf sediments in the Kingsville area contain relatively high mean concentrations of boron, chromium, copper, and lead, which are as high as or slightly higher than the mean concentrations in other coastal areas (see table 8). The Kingsville area is the least urbanized and industrialized of any along the Texas coast, and there are no tidal inlets or storm washover areas that connect (for any length of time) to bay and lagoon waters. Elsewhere, for example, in the Corpus Christi area (White and others, 1983), some of the highest concentrations of many elements mapped (barium, chromium, copper, iron, lead, manganese, and nickel) occurred in reentrants in shelf sediments near storm washover passes and tidal inlets. The association of the reentrants with washover areas, which sometimes become temporary tidal passes, suggests that the reentrants are formed by sediments deposited by either storm floods or ebb tides or both. If the reentrants are related to ebb currents, perhaps flocculation (of inorganic and organic particulates loaded with trace metals), adsorption, precipitation of minerals, or all these processes occur as storm-related, brackish bay waters discharge through the passes/washovers and contact the different physicochemical marine-water environments. For example, iron and manganese, which can sequester trace metals as hydrous oxides (Jenne, 1968), behave nonconservatively (interactively) in some estuaries when crossing from the physicochemical conditions of fresher water to that of marine water. Some studies suggest that dissolved iron and manganese decrease exponentially with increasing salinity, indicating large-scale removal of these two elements upon entering the estuarine zone from rivers (Windom, 1975). Ebb currents may also transport heavy minerals (bearing trace metals from nearshore areas) gulfward, thereby contributing to the higher levels of trace metals in the entrants.

Although the Kingsville area has no tidal passes and minimal urban and industrial activities, trace metals on the shelf might be transported from other regions. The Kingsville area is the site of a zone of annual net convergence (at approximately 27 degrees north latitude) of longshore currents and littoral drift (Lohse, 1952). Maps of trace element distribution for the other map areas along the coast indicate that trace element reentrants are associated with tidal passes and that lobes of sediment containing higher than normal trace element concentrations extend gulfward from the mouths of the Colorado and Brazos Rivers and from the mouth of the Rio Grande. Higher concentrations are expected at the river mouths because the rivers are a source of trace elements from both natural and anthropogenic sources.

Holmes (1982) proposed that estuarine and bay systems along the northern Texas coast, for example, Matagorda Bay, are staging areas from which fine-grained sediments (and associated trace metals) are transported southward onto the Outer Continental Shelf during and following frontal passage. A slightly modified version of this hypothesis may help explain trace metal levels in the Kingsville area inner shelf. The high trace metal concentrations and fine-grained sediments (muds) offshore may be linked to the discharge of rivers and bay waters that were elevated by fresh-water inflows and wind tides in conjunction with storm passage. During these events, highly turbid channel and bay waters (and associated trace metals, including those from anthropogenic sources) apparently move through tidal passes or out from the mouths of rivers and onto the inner shelf and southwestward. In the marine environment, much of the suspended silts, clays, organic matter, and associated trace metals flocculate or precipitate and might be transported southward along the coast and deposited. The highest concentrations of most of the elements in the Kingsville area are associated with the silts and clays (muds) on the gulfward margin of the study area. These finer sediments also contain organic carbon concentrations that are among the highest along the inner shelf (table 9); the presence of TOC, in conjunction with the clay—both of which can sequester trace metals—may account for the relatively high levels of the different elements in these shelf sediments.

Table 9. Comparison of the mean concentration of total organic carbon in muds of the inner continental shelf in the seven map areas shown in figure 1.

Map area	TOC (ppm)
Brownsville-Harlingen	0.86
Kingsville	0.94
Corpus Christi	0.84
Port Lavaca	0.94
Bay City-Freeport	1.02
Galveston-Houston	0.91
Beaumont-Port Arthur	0.92

BENTHIC MACROINVERTEBRATES

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INTRODUCTION

This study provides information on benthic macroinvertebrate populations in the State-owned submerged lands of the Kingsville area. This inventory focused on (1) identification and enumeration of the macrofauna, (2) identification and delineation of characteristic faunal assemblages, and (3) correlation of distributions with abundances, including an investigation of sediment and faunal relationships.

Although several studies of the macrobenthos have been conducted in the State-owned submerged lands of the Kingsville area, only the more relevant ones—those that examine all macrofauna rather than specific groups of organisms—will be discussed here.

Three broad-based surveys have been conducted on the inner shelf of the Kingsville area. Hill and others (1982), Holland and others (1976), and Flint and Rabalais (1981) conducted benthic studies primarily on the South Texas Outer Continental Shelf (OCS); only two stations in the surveys of Holland and others (1976) and Flint and Rabalais (1981) were located within State-owned submerged lands of the Kingsville area. Several of the nearshore stations of Hill and others (1982) were located within State-owned submerged lands.

Hill and others (1982) took 264 benthic samples from an area that extended from Matagorda Peninsula in the north to the Rio Grande in the south and seaward to about the 656-ft (200-m) isobath. The 67-ft (20-m) isobath was the general inshore boundary. Approximately eight samples were taken from the nearshore bottom in the Kingsville area. Hill and others (1982) found that numbers of species and individuals were highest on the inner shelf in the general area of the ancestral Brazos-Colorado and Rio Grande deltas. Numbers of species and individuals decreased as water depth increased.

Flint and Rabalais (1981) reported 6 station groupings, including a transition group, from results of ordination analyses of infaunal species at 25 collection sites (depths of 33 to 426 ft [10 to 130 m]) on the South Texas OCS. Two station groupings (shallow and mid-shelf) occurred on the inner shelf in the Kingsville area. The highest numbers of species and individuals were located in the shallow-water group. Species diversity was also high in the shallow-water group. Equitability increased with distance from shore. Deposit-feeding polychaetes (polychaetes that feed on organic detritus on or in the sediment) were the dominant infaunal group throughout the shelf. According to Flint and Rabalais (1981), water depth was the main variable affecting infaunal and epifaunal community groupings. Other important environmental variables were nutrient availability, bottom-water variability, and sediment differences, including sand-to-mud ratios, sediment grain size, and silt percentages.

Holland and others (1976) delineated three infaunal assemblages from cluster analysis of data from the South Texas OCS. The assemblages were distributed according to depth and modified by the influence of sandy sediments. The shallow-water assemblages occurred in muddy sand substrates and had high numbers of species and individuals. Numerical dominance by some species resulted in low equitability. Deep-water assemblages were located in muddy sand and silty clay substrates. The deep-water environment was more stable than the shallow-water habitat, resulting in higher diversity and equitability but fewer species than the shallow-water assemblage. Sedentary deposit feeders were abundant in the nearshore environment, but they were generally replaced by burrowing detrital feeders farther offshore.

More benthic studies have been conducted in the bay-estuary-lagoon system than on the inner shelf. Baffin and Alazan Bays probably have been studied the most often (Breuer, 1957; Parker, 1959; Mackin, 1971; Martin, 1979). Benthic studies also have been conducted in Laguna Madre (Simmons, 1957; Parker, 1959).

Breuer (1957) and Simmons (1957) emphasized commercially important fish and invertebrates in

Table 10. Abundance of the major taxonomic groups, Kingsville area.

	Number of stations examined	All species	All individuals	Polychaete species	Polychaete individuals	Molluscan species	Molluscan individuals	Crustacean species	Crustacean individuals
Laguna Madre*	41	143	7,258	72	2,846	45	3,649	26	763
Baffin Bay	29	91	3,581	38	700	28	973	25	1,908
Alazan Bay	10	37	699	16	129	12	262	9	308
Inner Shelf	81	259	12,668	125	8,733	78	1,410	56	2,525
Totals**	161	342	24,206	156	12,408	113	6,294	73	5,504

*Includes five stations in the Intracoastal Waterway.

**Because some species occur in both the bay-estuary-lagoon system and on the inner shelf, species totals are not true totals.

their study of the ecology of Baffin and Alazan Bays and upper Laguna Madre. They also presented a synoptic list of many other invertebrates and briefly discussed their abundance and distribution.

For the Kingsville area, Parker (1959) utilized data from published reports and from American Petroleum Institute (API) collections to delineate a deep-hypersaline assemblage in Baffin and Alazan Bays and an enclosed hypersaline-lagoon assemblage for most of Laguna Madre. Nearly all characteristic species in Parker's assemblages were mollusks; polychaetes were not included in his species lists. The API collections were taken during an extended drought with accompanying low river runoff and record-high salinities in the bays (Parker, 1955). Open Gulf organisms extended into the upper parts of the bays, and many organisms adapted to lower salinities were killed.

Mackin (1971) collected benthic samples from five stations in Baffin Bay (including Laguna Salada) and five stations in Alazan Bay from August 1970 through June 1971. Samples were also taken from serpulid reefs in Baffin Bay. Mackin found 41 species in Baffin Bay and 30 species in Alazan Bay. In addition, 43 species (primarily polychaetes and crustaceans) were taken from serpulid reef rocks in Baffin Bay.

Martin (1979) studied the feeding habits of the black drum (*Pogonias cromis*) in Alazan Bay and Laguna Salada to determine first the food organisms of the black drum and then the distribution and abundance of the principal food organisms. Martin took benthic samples at 76 stations in Alazan Bay and at 43 stations in Laguna Salada. Bivalve mollusks, especially *Mulinia lateralis* and *Anomalocardia auberiana,* were the most frequently encountered species in both areas. Other abundant species included the bivalves *Amygdalum papyrium, Tagelus plebeius,* and *Tellina texana,* the polychaetes *Nereis succinea* and *Diopatra cuprea,* and the crustaceans *Harrieta faxoni* and *Erichsonella attenuata.*

Other benthic studies have shown that species number and content change seasonally (Maurer and others, 1979; Flint and Rabalais, 1981). Although this study does not examine seasonal fluctuations in benthic populations, its greater sample density further resolves the areal distribution of the organisms and assemblages and allows better understanding of the diversity of the bay-estuary-lagoon system and inner shelf. Other differences between this study and others include dissimilar sampling techniques and temporal and climatic changes.

DISTRIBUTION IN THE KINGSVILLE AREA

Three hundred sixty-two macroinvertebrate species (25,256 individuals) were found in the 161 samples examined in the Kingsville map area. Polychaetes are the most numerous species, followed by mollusks and crustaceans (table 10). Numbers of all live species per station on the inner shelf range from 5 to 71 species (pl. V). The highest number of species generally occurs at stations from 1 to 5 mi (1.6 to 8.1 km) offshore, which average 38.6 species per station; stations from 6 to 11 mi (9.7 to 17.7 km) offshore average 17.4 species per station. In the bay-estuary-lagoon system, species numbers per station range from 1 to 52 total species. The highest number of species (52 total species) occurs at 2 stations in Laguna

Table 11. Most abundant molluscan species, Kingsville area.

LAGUNA MADRE		
Gastropoda	Number of individuals	Percent of all (2,404) gastropod individuals
Caecum pulchellum	1,870	77.8
Cerithium lutosum	89	3.7
Bittium varium	75	3.1
Acteocina canaliculata	69	2.9
Crepidula convexa	58	2.4
Bivalvia	Number of Individuals	Percent of all (1,245) bivalve individuals
Nuculana acuta	266	21.4
Tellina texana	188	15.1
Mulinia lateralis	183	14.7
Lyonsia hyalina floridana	161	12.9

BAFFIN BAY		
Gastropoda	Number of individuals	Percent of all (372) gastropod individuals
Sayella cf. *S. livida*	64	17.2
Acteon punctostriatus	61	16.4
Caecum pulchellum	53	14.2
Crepidula convexa	48	12.9
Acteocina canaliculata	48	12.9
Bivalvia	Number of individuals	Percent of all (601) bivalve individuals
Mulinia lateralis	213	35.4
Tagelus plebeius	163	27.1
Brachidontes exustus	82	13.6
Amygdalum papyrium	73	12.1

ALAZAN BAY		
Gastropoda	Number of individuals	Percent of all (47) gastropod individuals
Acteocina canaliculata	15	31.9
Mitrella lunata	13	27.7
Acteon punctostriatus	12	25.5
Bivalvia	Number of individuals	Percent of all (215) bivalve individuals
Mulinia lateralis	86	40.0
Brachidontes exustus	73	34.0
Mysella planulata	27	12.6

INNER SHELF		
Gastropoda	Number of individuals	Percent of all (394) gastropod individuals
Natica pusilla	140	35.5
Terebra protexta	50	12.6
Vitrinella floridana	33	8.4
Turbonilla (Strioturbonilla) sp. B	19	4.8
Bivalvia	Number of individuals	Percent of all (1,016) bivalve individuals
Abra aequalis	511	50.3
Linga amiantus	110	10.8
Parvilucina multilineata	102	10.0
Tellina versicolor	46	4.5

Madre. Distributions of the polychaetes, mollusks, crustaceans, and other phyla are discussed individually in the following sections; distributions are related to bathymetry and sediment type. Records are for live-collected animals except as noted.

Mollusca

One hundred thirteen species of live mollusks were collected from the Kingsville area: the polyplacophoran *Ischnochiton papillosus,* 61 gastropods, 48 bivalves, and 3 scaphopods. Although 261 total species (live and dead species) are listed in appendix C, including the polyplacophoran, 159 gastropods, 98 bivalves, and 3 scaphopods, only those species collected live are considered in this report. Table 11 lists the most abundant mollusks of each system.

Bay-Estuary-Lagoon System

Laguna Madre.—Forty-five species of mollusks—26 gastropods, 18 bivalves, and the polyplacophoran *Ischnochiton papillosus*—were collected in Laguna Madre. The gastropod *Caecum pulchellum* is the most abundant mollusk. Almost 80 percent of the total number of individuals of *C. pulchellum* found in Laguna Madre occur in the grassflats at station 108 (pl. VI).

The four most abundant bivalve species are found primarily at stations south of the Land-Cut Area and in muddy-sand substrates (50 to

80 percent sand). *Nuculana acuta,* the most abundant bivalve, does not occur at any station north of the Land-Cut Area.

Numbers of molluscan species at stations in Laguna Madre range from 0 to 19. Station 157, located south of the Land-Cut Area, has the highest number of species (19), and station 108 has the highest number of individuals (1,831).

Most molluscan species that are abundant in Laguna Madre in the Kingsville area also are abundant in Laguna Madre in the Brownsville area (White and others, 1986). *Cerithium lutosum* is the only species that is abundant in the Kingsville area and almost totally absent from the Brownsville area. White and others (1986) found only dead shell of *C. lutosum* in the Brownsville area; however, Cornelius (1975) found a few live *C. lutosum* = [*Cerithium variable*] in the Brownsville area. *Cerithium lutosum* is abundant in Laguna Madre in the Corpus Christi area (Williamson, 1979; White and others, 1983).

Baffin Bay (including Cayo del Grullo and Laguna Salada).—Twenty-eight molluscan species (973 individuals) were found in Baffin Bay. Bivalve species compose more than 60 percent of all individuals. *Mulinia lateralis* and *Tagelus plebeius,* the two most abundant bivalves, account for almost 40 percent of all individuals. *Mulinia* occurs at 26 of 29 stations and ranges in abundance from 1 to 31 individuals per station. *Tagelus plebeius* is found at only 6 stations and ranges from 2 to 142 individuals (station 80) per station.

Grassflat stations have more molluscan species, especially gastropods, than those without marine grasses. Stations with grassflats average almost 11 species per station, whereas stations without grassflats average only about 4 species per station.

Parker (1959) found eight molluscan species, including six bivalves, in the Baffin-Alazan Bay system. Most bivalves were found as shell associated with plant debris along the bay margin. *Mulinia lateralis* was the only live mollusk species found by Parker.

Dalrymple (1964) found dense populations of *Mulinia lateralis* and *Anomalocardia auberiana* in many parts of Baffin Bay, including the heads of the tributary bays and near the mouth of Baffin Bay proper. Dalrymple concluded that because *Mulinia* and *Anomalocardia* can live where salinities fluctuate widely, they are able to colonize most of the Baffin Bay complex. However, Dalrymple also found that the distribution of bivalve populations varied strikingly from place to place and from year to year. One area may have live bivalves in abundance, whereas a nearby area, apparently identical ecologically, will have no live bivalves. Also, a given area will be densely populated one year and barren the next. Dalrymple (1964) suggested that the distribution of *Mulinia* and *Anomalocardia* may depend upon the vagaries of local current conditions and their effect on larval movement.

Breuer (1957) and Mackin (1971) reported that both *Mulinia lateralis* and *Anomalocardia auberiana* were common in Baffin and Alazan Bays. *Anomalocardia* reached maximum numbers in the late fall, winter, and early spring, when water temperatures were low (Mackin, 1971).

In this study, *Mulinia* and *Anomalocardia* are both abundant as dead shell, but only *Mulinia* is common alive. Only three live individuals of *Anomalocardia* were found.

Alazan Bay.—Twelve species of mollusks, 6 gastropods and 6 bivalves, were collected from Alazan Bay. Bivalve species compose more than 80 percent of all molluscan individuals collected. The three most abundant bivalves, *Mulinia lateralis, Brachidontes exustus,* and *Mysella planulata,* constitute 71 percent of all mollusks that were sampled. *Mulinia* occurs at 9 of the 10 stations and ranges in abundance from 1 to 19 individuals per station. *Mulinia* and *Anomalocardia auberiana* are abundant as dead shell in most samples. However, *A. auberiana* was not found alive in Alazan Bay.

Numbers of species and individuals at stations in Alazan Bay are generally low. Stations 8 and 13 have the highest number of molluscan species (9 each) and individuals.

Martin (1979) found 7 species of mollusks in 79 samples collected in Alazan Bay. *Mulinia lateralis* and *Anomalocardia auberiana* were the most abundant species, occurring at 59 (934 individuals) and 17 (1,141 individuals) stations, respectively. *Mulinia* occurred throughout Alazan Bay and, according to Martin (1979), seemed to prefer sandy-mud substrates in the bay's shallow areas. *Anomalocardia* was most abundant in sandy substrates.

Inner Shelf

Forty-three gastropods, 32 bivalves, and 3 scaphopod species were found on the inner shelf. A total of 1,410 individuals were counted, of which 68 percent are bivalves. Numbers of molluscan species per station range from 0 to 16. Six stations had no live mollusks.

Natica pusilla, the most abundant gastropod collected on the inner shelf, constitutes 35.5 percent of all gastropod individuals (table 11) and occurs at 51 percent of the stations. *Natica pusilla* is found typically in sediments of 80 to 100 percent sand. The next most abundant gastropod, *Terebra protexta,* commonly occurs in slightly muddier sediments of 60 to 80 percent sand.

Abra aequalis is by far the most abundant mollusk on the inner shelf (table 11). Ninety percent of the total number of individuals of *Abra* occur at nearshore stations in sediments of 80 to 100 percent sand. *Abra* was also the dominant mollusk on the inner shelf in the Corpus Christi area, accounting for 75 percent of all molluscan individuals (White and others, 1983). Where *Abra* is dominant, such as in the Corpus Christi, Brownsville, and Kingsville areas, high numbers of individuals occur at only one or two stations. In the Corpus Christi and Brownsville areas, more than 50 percent of all individuals of *Abra* occurred at a single station in each area (White and others, 1983, 1986). Sixty-eight percent of the individuals in the Kingsville area occur at only two stations (stations 746 and 813).

Polychaeta

One hundred fifty-six species numbering 12,408 individuals were included in the 161 samples from the Kingsville area. *Magelona* cf. *M. phyllisae* is by far the most abundant species on the inner shelf, and *Prionospio heterobranchia* is most abundant in the bay-estuary-lagoon system. All polychaete species in the Kingsville area are listed in appendix C.

Bay-Estuary-Lagoon System

Laguna Madre.—Although 72 species (2,846 individuals) were taken from the 41 stations, 4 species account for almost 50 percent of the total number of individuals (table 12). Numbers of species per station range from 2 species at stations 77 and 135 to 26 species at station 160.

Prionospio heterobranchia is the dominant polychaete in the grassflats of Laguna Madre in the Kingsville area, as well as in Laguna Madre in the Corpus Christi and Brownsville areas (White and others, 1983, 1986). In the Kingsville area, *P. heterobranchia* occurs at 15 stations (37 percent), ranging from 1 to 96 individuals per station. *Chone duneri* is the most widespread species, occurring in 61 percent of the samples (25 stations).

The most abundant species in the Kingsville area (table 12) are also abundant in lower Laguna Madre in the Brownsville area (White and others, 1986) and in upper Laguna Madre in the Corpus Christi area (White and others, 1983). However, several of the polychaetes that are dominant in the Corpus Christi area, including *Asychis elongatus* = [*Branchioasychis americana*], *Platynereis dumerilii,* and *Capitella capitata,* are not as dominant in the Kingsville area.

Table 12. Most abundant polychaete species, Kingsville area.

LAGUNA MADRE	Number of individuals	Percent of all (2,846) individuals
Prionospio heterobranchia	391	13.7
Mediomastus californiensis	388	13.6
Chone duneri	367	12.9
Melinna maculata	267	9.4
Typosyllis (Langerhansia) sp.	223	7.8
Exogone dispar	158	5.6
Streblospio benedicti	112	3.9

BAFFIN BAY	Number of individuals	Percent of all (700) individuals
Prionospio heterobranchia	186	26.6
Typosyllis (Langerhansia) sp.	94	13.4
Mediomastus californiensis	84	12.0
Exogone dispar	51	7.3
Nereis succinea	46	6.6

ALAZAN BAY	Number of individuals	Percent of all (129) individuals
Pista quadrilobata	33	25.6
Capitella capitata	25	19.4
Mediomastus californiensis	16	12.4
Paraprionospio pinnata	16	12.4

INNER SHELF	Number of individuals	Percent of all (8,733) individuals
Magelona cf. *M. phyllisae*	2,120	24.3
Paraprionospio pinnata	1,005	11.5
Lumbrineris verrilli	912	10.4
Aricidea taylori	403	4.6
Apoprionospio pygmaea	380	4.4
Owenia fusiformis	283	3.2

Baffin Bay (including Cayo del Grullo and Laguna Salada).—Thirty-eight species (700 individuals) were found at the 29 stations examined in Baffin Bay. Grassflat stations near the mouth of Baffin Bay have the highest numbers of species and individuals. Stations with marine grasses average 9.6 species per station, whereas stations without grasses average only 2.6 species per station. The highest number of species (17) occurs at station 4; stations 22 and 61 have no polychaetes. The four most abundant polychaetes (table 12) occur primarily at stations with marine grasses. *Prionospio heterobranchia,* the most abundant species, is found only at stations with marine grasses.

Mackin (1971) found 14 polychaete species in benthic samples taken at 5 stations in Baffin Bay and 5 stations in Alazan Bay. Samples were collected monthly from August 1970 through June 1971. *Streblospio benedicti,* the dominant polychaete, was abundant only during May and June 1971; more than 95 percent of the total number of individuals of *S. benedicti* were collected then. *Streblospio benedicti* was also the most abundant polychaete in benthic samples collected from Baffin Bay (Laguna Salada) by Martin (1979). In this study, *Streblospio benedicti* is not abundant, because only 20 individuals were found in Baffin Bay and 7 in Alazan Bay.

Alazan Bay.—Although 16 species were identified in Alazan Bay, only 4 species account for 70 percent of the total (table 12). All but one individual of *Pista quadrilobata,* the most abundant polychaete, occurs at station 20. Other abundant species, including *Capitella capitata* and *Mediomastus californiensis,* also occur at only two stations. Most stations have less than five species. The highest number of species (nine) occurs at station 13, a bay-margin, grassflat station.

Martin (1979) found two polychaete species, *Nereis succinea* and *Diopatra cuprea,* in the benthos from Alazan Bay. *Nereis succinea* was the most widespread species, occurring at 25 of 76 stations (33 percent). *Diopatra cuprea* was found at only four stations.

Inner Shelf

One hundred twenty-five species (8,733 individuals) were found in the 81 inner-shelf samples. This diversity is greater than the 89 species from the 73 stations on the Corpus Christi inner shelf (White and others, 1983) but less than the 150 species from the 113 stations on the Brownsville inner shelf (White and others, 1986). Numbers of species per station range from 2 at station 845 to 43 at stations 610 and 944.

The most abundant species (table 12) are *Magelona* cf. *M. phyllisae*, which occurs at 51 stations (63 percent of those sampled), and *Paraprionospio*, which occurs at 67 stations (83 percent). *Magelona* cf. *M. phyllisae* is found primarily in sediments of 60 to 80 percent sand; *P. pinnata* occurs most often in sediments of 0 to 20 percent sand. Both species are the most abundant polychaetes on the inner shelf in the Galveston-Houston (White and others, 1985), Brownsville-Harlingen (White and others, 1986), and Bay City-Freeport areas (White and others, 1988).

Crustacea

Seventy-three crustacean species (5,504 individuals) were identified from the bays and inner shelf in the study area. Amphipoda, represented by 29 species, is the most abundant order. *Ampelisca abdita* and *A. agassizi,* each with more than 25 percent of the total number of individuals, are the most abundant crustaceans. *Ampelisca abdita* occurs only in the bay-estuary-lagoon system, and *A. agassizi* is found only on the inner shelf. Appendix C shows the distribution of the Crustacea.

Bay-Estuary-Lagoon System

Laguna Madre.—Laguna Madre has more species (26) than Baffin or Alazan Bays. Station 69 has the highest number of crustacean species (13). Twenty-one of the 41 stations (51 percent of the species sampled) have less than 4 species, and 10 stations (20 percent) have no crustaceans.

Oxyurostylis salinoi and *Ampelisca abdita,* with more than 50 percent of the total number of individuals, are the most abundant species (table 13). *Oxyurostylis salinoi* occurs at 16 stations and is most abundant at stations 66, 67, 69, and 75 in the northern part of the map area. *Ampelisca abdita* is most abundant at stations 145 and 158 in the southern part of the map area.

Baffin Bay (including Cayo del Grullo and Laguna Salada).—Twenty-five species (1,908 individuals) were found at 29 stations in Baffin Bay; however, only three species compose 87 percent of the total number of individuals (table 13). Most species occur at stations with marine grasses. Stations with marine grasses average 8.3 species per station, whereas stations without grasses average only 1.8 species per station.

Ampelisca abdita is by far the most abundant species, with nearly 65 percent of all individuals. Eighty-nine percent of all individuals of *A. abdita* occur at stations 47 and 69. *Ampelisca abdita* was the most abundant benthic species collected by Mackin (1971) in Baffin Bay.

Table 13. Most abundant crustacean species, Kingsville area.

LAGUNA MADRE	Number of individuals	Percent of all (763) individuals
Oxyurostylis salinoi	250	32.8
Ampelisca abdita	152	19.9
Harrieta faxoni	63	8.3

BAFFIN BAY	Number of individuals	Percent of all (1,908) individuals
Ampelisca abdita	1,238	64.9
Grandidierella bonnieroides	277	14.5
Harrieta faxoni	145	7.6

ALAZAN BAY	Number of individuals	Percent of all (308) individuals
Ampelisca abdita	102	33.1
Grandidierella bonnieroides	85	27.6
Harrieta faxoni	61	19.8

INNER SHELF	Number of individuals	Percent of all (2,525) individuals
Ampelisca agassizi	1,642	65.0
Ampelisca verrilli	153	6.1
Trichophoxus floridanus	149	5.9
Platyschnopus sp.	110	4.4

Alazan Bay.—Only 9 crustacean species were found in Alazan Bay, with station 8 having the highest number of species (7) and individuals (193). Only 3 stations have more than three species; 5 of 10 stations have no crustaceans. *Ampelisca abdita,* the most abundant species, is found at three stations; however, 97 percent of the total number of individuals occur at station 8.

Gammarus mucronatus was the most abundant crustacean that Martin (1979) found in Alazan Bay. Other abundant species included *Corophium acherusicum, Harrieta faxoni,* and *Erichsonella attenuata.* Both *C. acherusicum* and *Ampelisca abdita* were abundant in samples collected by Mackin (1971) in Alazan Bay.

Inner Shelf

Although 2,525 individuals representing 56 species were collected on the inner shelf, only 1 species, *Ampelisca agassizi,* accounts for 65 percent of the total number of individuals. *Ampelisca agassizi* and *A. verrilli,* the two most abundant species, occur in different substrates. *Ampelisca agassizi* is most abundant in muddy substrates of 0 to 20 percent sand, and *A. verrilli* occurs primarily in muddy sand substrates of 60 to 80 percent sand. Two other abundant species, *Trichophoxus floridanus* and *Platyschnopus* sp., are found almost entirely in sandy substrates of 80 to 100 percent sand.

Numbers of species per station range from 1 species at 20 different stations to 11 species at station 792. Sixty-three percent of the stations have fewer than five crustacean species; 54 percent of the stations have fewer than five molluscan species; and only 2 percent of the stations have fewer than five polychaete species.

Other Phyla

Eleven phyla besides the Annelida, Mollusca, and Arthropoda occur in the Kingsville area. They are Cnidaria, Platyhelminthes, Nemertinea, Aschelminthes, Chaetognatha, Bryozoa, Phoronida, Sipunculida, Echinodermata, Hemichordata, and Chordata (app. C). Many phyla are so little known or so difficult to identify that most identifications for these groups are not to species level.

The two most abundant phyla sampled, Cnidaria and Nemertinea, occur primarily on the inner shelf, although most phyla are found both in the bay-estuary-lagoon system and on the inner shelf. Species in the phylum Cnidaria, the most abundant of the other phyla (app. C) on the inner shelf, occur at 36 percent of the stations. In Laguna Madre, the sipunculid *Phascolion strombi* is by far the most abundant of the other phyla, although it occurs at only four stations. All four stations are located south of the Land-Cut Area.

BATHYMETRY AND INVERTEBRATE DISTRIBUTION

Analysis of the bathymetric distribution of invertebrates on the inner continental shelf shows that the average number of species per station is greatest in a depth range of 42 to 60 ft (12.8 to 18.3 m) (fig. 23). Species averages per station for mollusks and polychaetes are highest in a depth range of 48 to 60 ft (14.6 to 18.3 m). Crustaceans are more abundant at shallower

Table 14. Distribution by depth of macroinvertebrate species on the inner shelf.

Groups	Depth range ft (m)	Average number of species per station	Depth range ft (m)	Average number of species per station	Depth range ft (m)	Average number of species per station
Polychaeta	24-48 (7.3-14.6)	12.9	48-72 (14.6-21.9)	23.8	72-96 (21.9-29.3)	10.8
Mollusca	24-48 (7.3-14.6)	4.7	48-72 (14.6-21.9)	7.5	72-96 (21.9-29.3)	2.3
Crustacea	24-48 (7.3-14.6)	6.5	48-72 (14.6-21.9)	4.5	72-96 (21.9-29.3)	2.1
Other groups	24-48 (7.3-14.6)	3.4	48-72 (14.6-21.9)	2.5	72-96 (21.9-29.3)	1.4
All groups	24-48 (7.3-14.6)	28.5	48-72 (14.6-21.9)	38.2	72-96 (21.9-29.3)	16.6

depths of 24 to 30 ft (7.3 to 9.1 m) (fig. 23). All groups exhibit a decrease in the average number of species per station beyond a depth of 72 to 78 ft (21.9 to 23.8 m) (table 14). Substrates at stations with water depths of 42 to 60 ft (12.8 to 18.3 m) are sandier (average 68.3 percent sand) than those at stations in water depths greater than 60 ft (18.3 m) (average 28.8 percent sand).

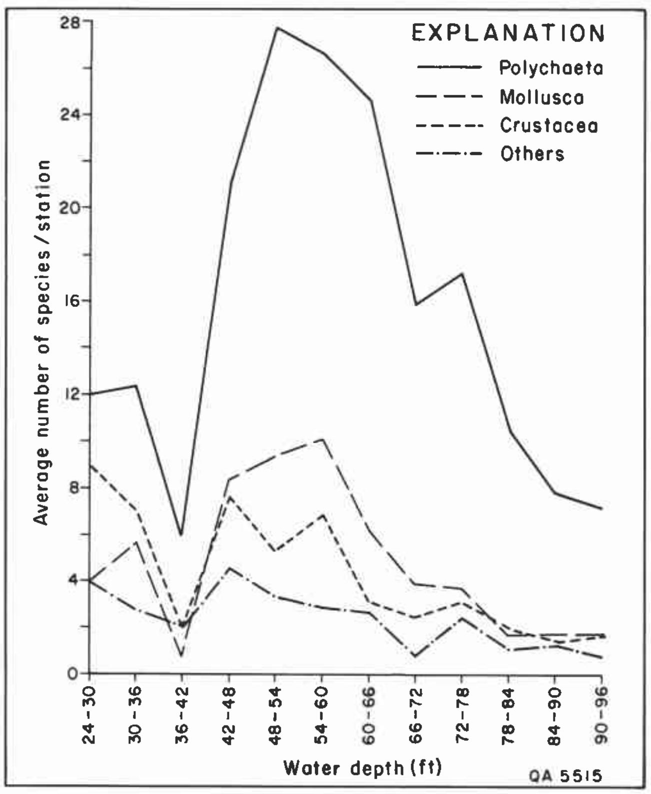


Figure 23. **Distribution by depth of the average number of live species per station of the major groups of macroinvertebrates.**

The average number of individuals per station for the polychaetes and mollusks is highest at stations with water depths of 48 to 60 ft (14.6 to 18.3 m). Numbers of crustacean individuals are generally low and fairly uniform at all depths except at stations with water depths of 84 to 96 ft (25.6 to 29.3 m) where the amphipod *Ampelisca agassizi* is abundant.

Some of the physical parameters that are related to water depth and that affect invertebrate distributions are (1) sediment distribution and other environmental conditions related to sediment type, such as the distribution of TOC (discussed in the following section); (2) degree of turbidity (Parker, 1960); (3) changes in bottom water temperature (Hill and others, 1982); and (4) oxygen concentration levels (Hill and others, 1982).

Because of the overall shallowness of the bay-estuary-lagoon system, depth is not as important an influence on invertebrate distribution there as it is on the inner shelf. Other elements, such as sediment type (although obviously related to bathymetry) and salinity, are probably greater determinants of invertebrate distribution in the bay-estuary-lagoon system.

SEDIMENT TYPE AND INVERTEBRATE DISTRIBUTION

Sediment type is a primary influence on benthic macroinvertebrate distribution (Sanders, 1958; Purdy, 1964). Many of the morphologic and physiologic adaptations of organisms relate to sediment properties. Probably one of the most drastic changes that occur in benthic communities is the alteration of substrate, which results in the replacement of one community by another (Johnson, 1971). Dredging, filling, and erecting structures may cause changes in sediment and sedimentation patterns. On the inner shelf and especially in the shallow bays of the Kingsville area, extreme fluctuations in temperature and salinity are common and may be more significant to invertebrate distribution than is substrate. However, the type of substrate and other environmental parameters related to sediment distribution all affect invertebrate distribution.

The relationship between TOC and sediment texture (fig. 12) influences the distribution of benthic macroinvertebrates. An ecologically important attribute of an invertebrate is its manner of feeding. Many benthic species are either deposit feeders or suspension feeders. Deposit feeders feed on bottom deposits of organic detritus and associated microorganisms, and suspension feeders feed on microorganisms in surrounding waters. Because fine-grained sediments generally contain more organic matter than do coarse-grained deposits, the proportion of deposit feeders composing the bottom fauna will increase as the substrate texture becomes finer (Purdy, 1964). Deposit feeders are thus most often found in bay-center muds and deeper, muddy stations on the inner shelf; suspension feeders are more abundant in bay-margin sands and shallow, sandy stations on the inner shelf.

Animal-sediment associations have been discussed in previous benthic studies of the Kingsville area. Parker (1959) listed dominant sediment types inhabited by macroinvertebrate assemblages in Laguna Madre and Baffin and Alazan Bays. On the South Texas inner shelf and Outer Continental Shelf (OCS), Hill and others (1982) studied the correlation between sand-to-mud ratios and various biological parameters. Holland and others (1976) described macroinfaunal distribution from the South Texas OCS on the basis of sediment type and bathymetry.

Parker (1959) delineated an enclosed, hypersaline-lagoon assemblage in Laguna Madre north of the Land-Cut Area and an open, shallow hypersaline-bay assemblage in most of Laguna Madre south of the Land-Cut Area. Dominant substrates north of the Land-Cut Area were sand and clayey sand; to the south, sand and shelly sand were dominant. According to Parker, extreme fluctuations of physical conditions, including salinity and temperature, were the main influences on the composition of biological assemblages in Laguna Madre.

All factors studied by Hill and others (1982) correlated most closely with sand-to-mud ratios. A series of regression analyses showed that number of species and individuals and biomass increased

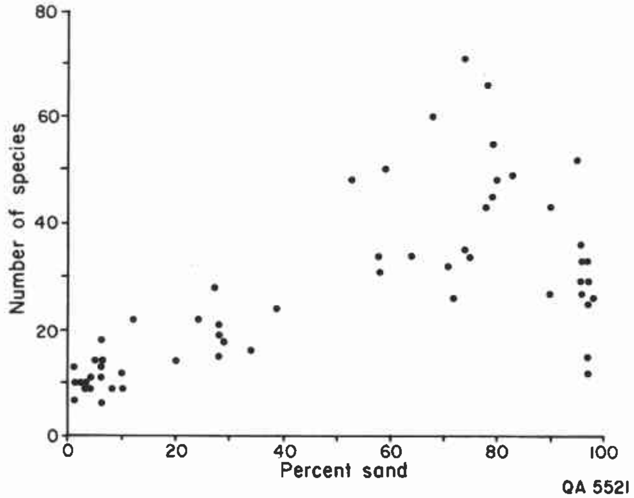


Figure 24. **Scattergram of total number of species and percent sand on the inner shelf. Correlation coefficient (r) = 0.70, number of samples (n) = 57.**

with increasing sand-to-mud ratios. The largest increase occurred where the sand-to-mud ratios exceeded 1.00. Water depth was the only other physical variable that correlated with a significant increase in variation. Hill and others (1982) emphasized that other physical variables related to water depth, such as bottom-water temperature and dissolved oxygen (not measured), could also influence the zonation of the benthos.

Shallow-water stations ranging from 32.8 to 80.6 ft (10 to 27 m) deep that were included in the Holland and others (1976) study had substrates of muddy sand. Sediments at deep stations (213 to 440 ft [65 to 134 m]) were silty clay, and mid-depth station sediments represented a transition zone that ranges from sandy mud to silty clay. Numbers of macroinfaunal species and individuals were highest at stations in the shallow-water cluster. Polychaetes dominated the muddy sand assemblage.

Scattergrams and histograms show the relationship between number of species and sediment type on the inner shelf and in the bay-estuary-lagoon system. Numbers of all species (figs. 24, 28, and 32) and number of species within each major taxonomic group—mollusks, polychaetes, and crustaceans—are plotted against percent sand (figs. 25 through 27 and 29 through 32). Histograms also depict faunal distribution versus sediment type along two inner-shelf transects for all species (fig. 33) and for each of the major taxonomic groups (figs. 34 through 36).

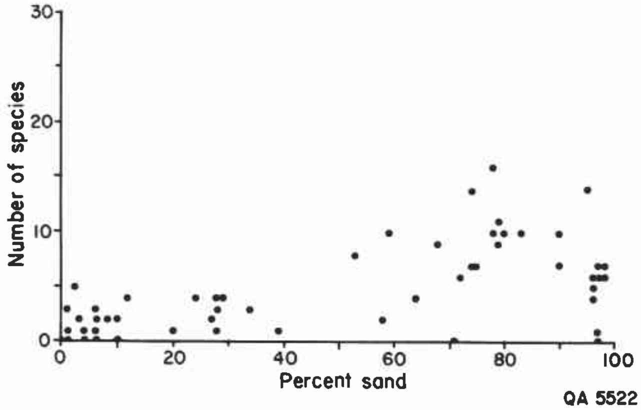


Figure 25. **Scattergram of mollusks and percent sand on the inner shelf. Correlation coefficient (r) = 0.57, number of samples (n) = 52.**

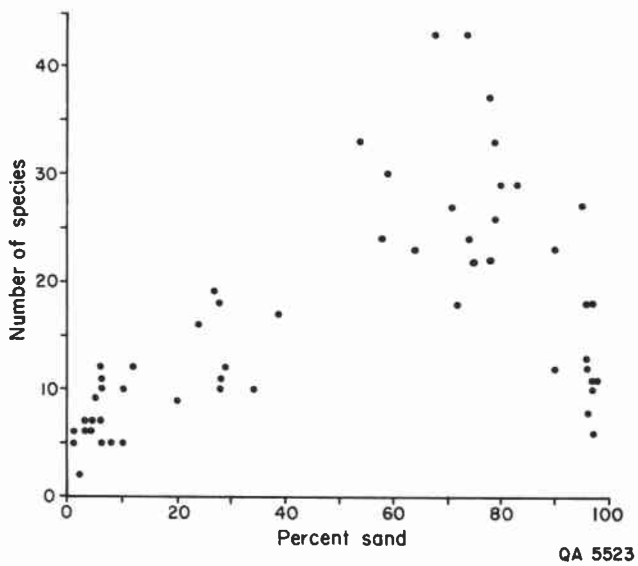


Figure 26. **Scattergram of polychaetes and percent sand on the inner shelf. Correlation coefficient (r) = 0.62, number of samples (n) = 54.**

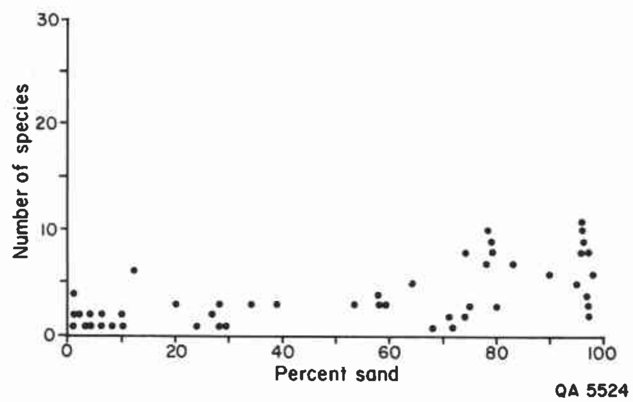


Figure 27. **Scattergram of crustaceans and percent sand on the inner shelf. Correlation coefficient (r) = 0.64, number of samples (n) = 49.**

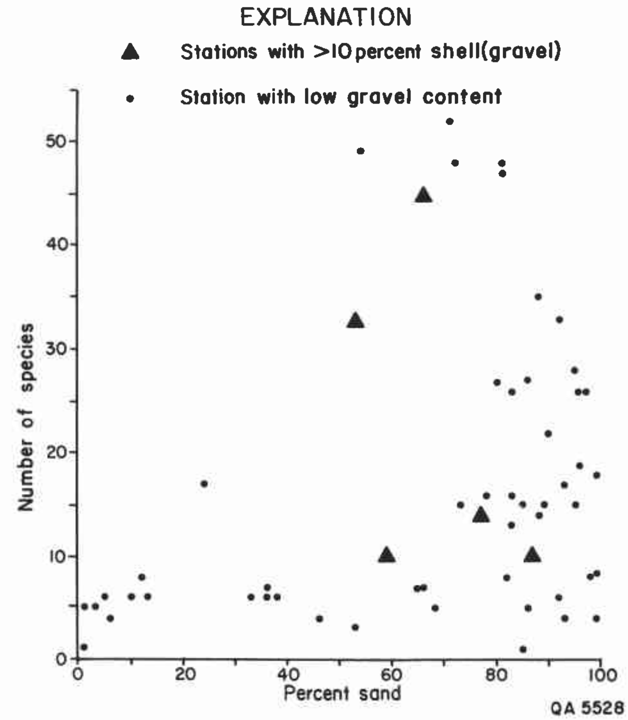


Figure 28. **Scattergram of total species and percent sand in the bays. Correlation coefficient (r) = 0.33, number of samples (n) = 56.**

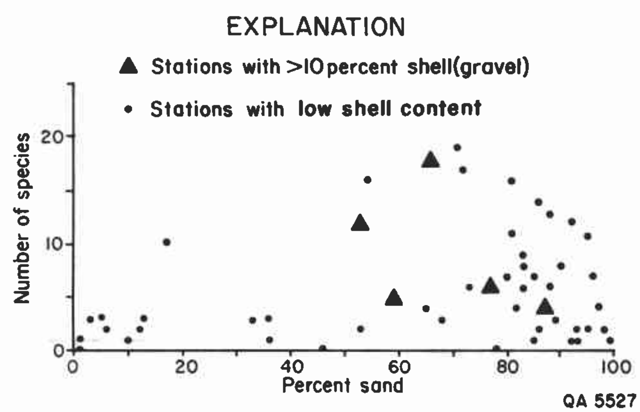


Figure 29. **Scattergram of mollusks and percent sand in the bays. Correlation coefficient (r) = 0.24, number of samples (n) = 51.**

On the inner shelf, correlation coefficients for all species and for mollusks, polychaetes, and crustaceans are positive, although numbers of species vary widely in both muddy and sandy sediments. The highest number of species per station for all species, mollusks, and crustaceans generally occurs in muddy sand and sandy sediments of 50 to 100 percent sand (figs. 24, 25,

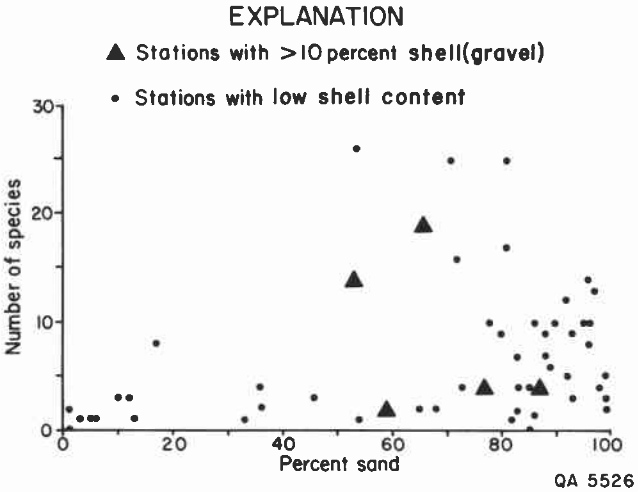


Figure 30. **Scattergram of polychaetes and percent sand in the bays. Correlation coefficient (r) = 0.30, number of samples (n) = 54.**

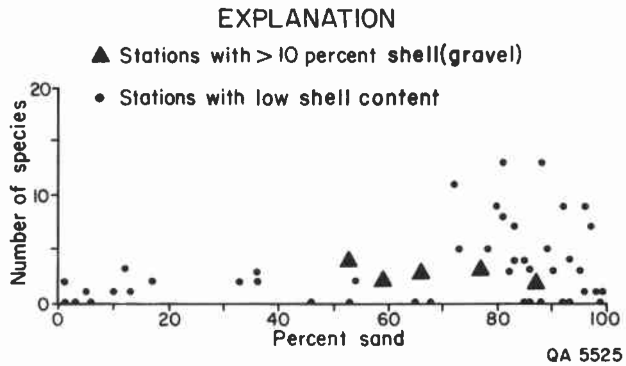


Figure 31. **Scattergram of crustaceans and percent sand in the bays. Correlation coefficient (r) = 0.33, number of samples (n) = 50.**

and 27). Numbers of polychaete species and the average numbers of polychaete species per station are highest in sediments of 40 to 80 percent sand (figs. 26 and 32). The optimum range for all species and for mollusks, polychaetes, and crustaceans is approximately 50 to 95 percent sand (figs. 24 through 27).

The primary cause of the high number of species (species richness) in predominantly muddy sand (60 to 80 percent sand) and sandy (80 to 100 percent sand) substrates is probably structural complexity or heterogeneity of the substrate. Coarse and heterogeneous sediments in sublittoral samples are generally more structurally complex and seem to have higher diversities than fine and homogeneous sediments (Gray, 1974). Boesch (1972) and Gray (1974) noted that fauna on sandy bottoms are generally more diverse than those on muddy bottoms because of the greater variety of microhabitats. Although species number does not necessarily correlate with diversity (Gray, 1974), numbers of both epifaunal and infaunal species in the Irish Sea were highest in the coarsest sediments or gravel, followed by muddy sand, sand, and mud, respectively (Craig and Jones, 1966).

Substrates of muddy sand may be able to support benthic communities that are trophically more diverse than substrates with homogeneous muds or sands. The optimal substrate for both deposit and suspension feeders may be muddy sands or predominantly sandy substrates having an integral but smaller percentage of silt and clay. Substrates with large amounts of clay and organic matter have reduced capillary circulation and increased chances of having anaerobic conditions (Purdy, 1964). Most suspension-feeding species cannot tolerate large amounts of silt and clay, whereas deposit feeders have special feeding and respiratory adaptations to do so (Johnson, 1971). Even small increases in the silt-clay content of substrates may clog interstitial spaces and slow oxygen diffusion to sediment depths (Coull, 1985). Sediments that consist predominantly of silts and clays indicate feeble currents that allow the fine particles to settle out; therefore, less food remains in the water column for suspension feeders (Sanders, 1958). On the other hand, substrates with moderate amounts of silt and clay lend a certain rigidity to sandy substrates, allowing the tunnels of burrowers (deposit feeders) to remain open (Harry, 1976).

Biological interactions related to sediment distribution may also affect molluscan distribution. Suspension feeders may be unable to coexist with deposit feeders in muddy bottoms because of sediment instability produced by deposit feeders. Such instability, termed trophic group amensalism (Rhoads and Young, 1970), inhibits suspension feeders and sessile epifauna by clogging filtering mechanisms, resuspending and burying larvae, and discouraging the settlement of larvae of suspension feeders and adults of sessile epifauna (Rhoads and Young, 1970). The reworked muddy surface is limiting to suspension feeders when the surface becomes mobile (Rhoads and Young, 1970).

Histograms of two inner-shelf transects perpendicular to the shoreline reflect the systematic decrease in sand offshore, especially in the

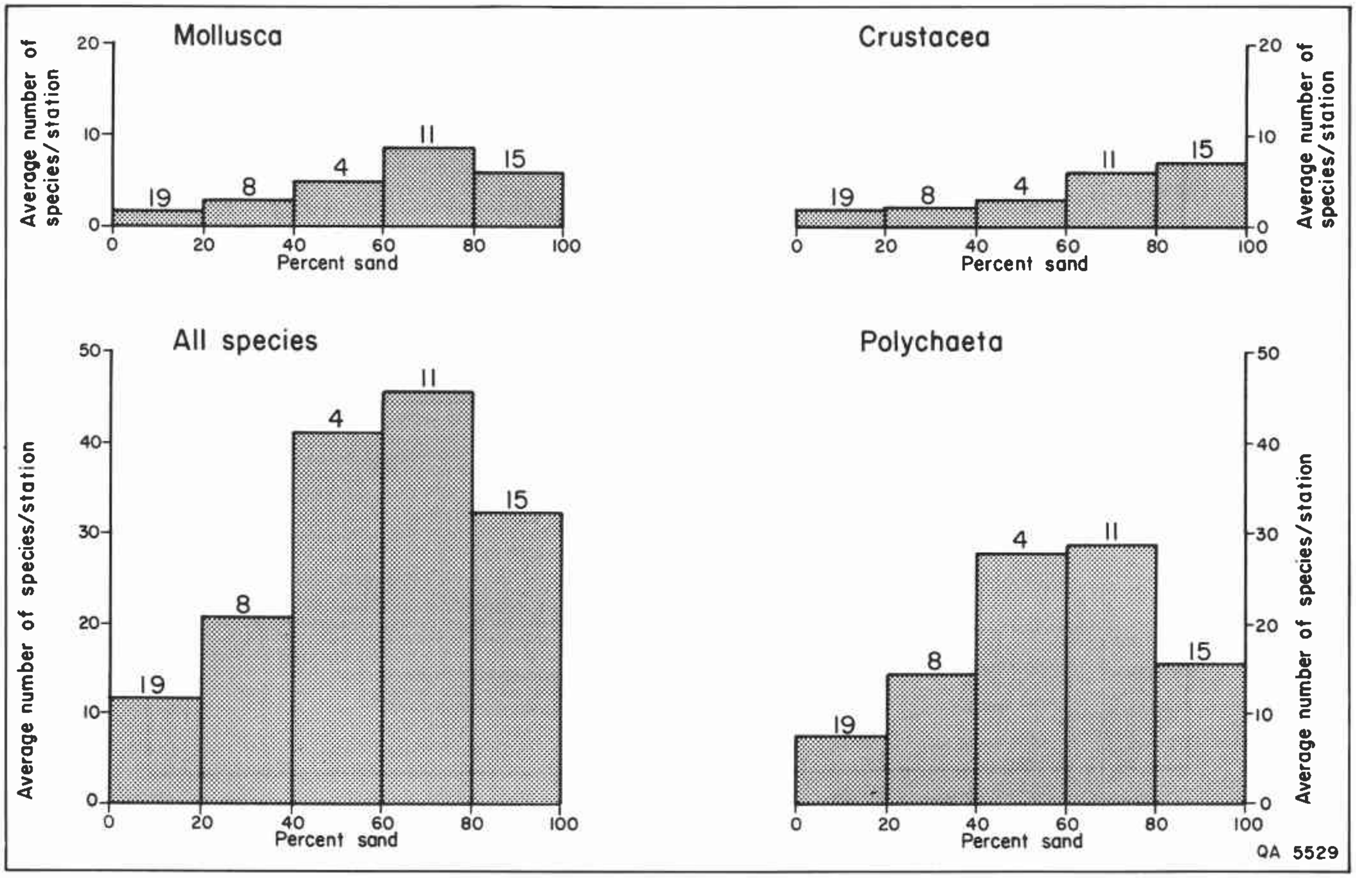


Figure 32. **Average number of molluscan, crustacean, and polychaete species and of all species per station versus percent sand on the inner shelf. Numbers above bars are number of stations within that sediment type.**

northern two-thirds of the map area (figs. 33 through 36; pl. VI). The transect with stations 936 to 946 is in the central part of the map area, and the transect with stations 1109 to 1118 is in the northern part of the map area (pl. VI). Bands of sands, muddy sands, sandy muds, and muds are oriented subparallel to the shoreline (McGowen and Morton, 1979; pl. I). Sands generally extend 3 to 5 mi (4.8 to 8.0 km) offshore, except at the southern edge of the map area, where sandy sediments are more than 9 mi (14.4 km) offshore (pl. IA). Sandy muds and muds occur from 4 to 11 mi (6.4 to 17.7 km) offshore. Bands of muddy sands and sandy muds are comparatively narrow and together average slightly more than 5 mi (8.0 km) wide (pl. IA).

Numbers of species and individuals are generally highest at stations 1 to 5 mi (1.6 to 8.0 km) offshore in substrates of sand and muddy sand (97 to 59 percent sand) (figs. 33 through 36). The only exceptions are the large numbers of crustacean individuals at stations 938, 1109, and 1110, which are found 9 to 11 mi (14.4 to 17.7 km) offshore within muddy substrates (fig. 36).

Total numbers of species and diversity indices shown on plate V also reflect sediment-faunal relationships. Stations with the highest number of species are slightly sandier on average than those with fewer species. For example, stations with 20 or more species (48 stations or 59 percent of the total number of stations) average 70.6 percent sand, whereas stations with fewer than 20 species (33 stations or 41 percent of the total number of stations) average 12.1 percent sand. Also, stations with very high diversity values (greater than 2.500) have sandier substrates (average 71.3 percent sand) than those stations with diversity values of less than 2.500 (average 27.5 percent sand) (see following section for discussion of total species diversity).

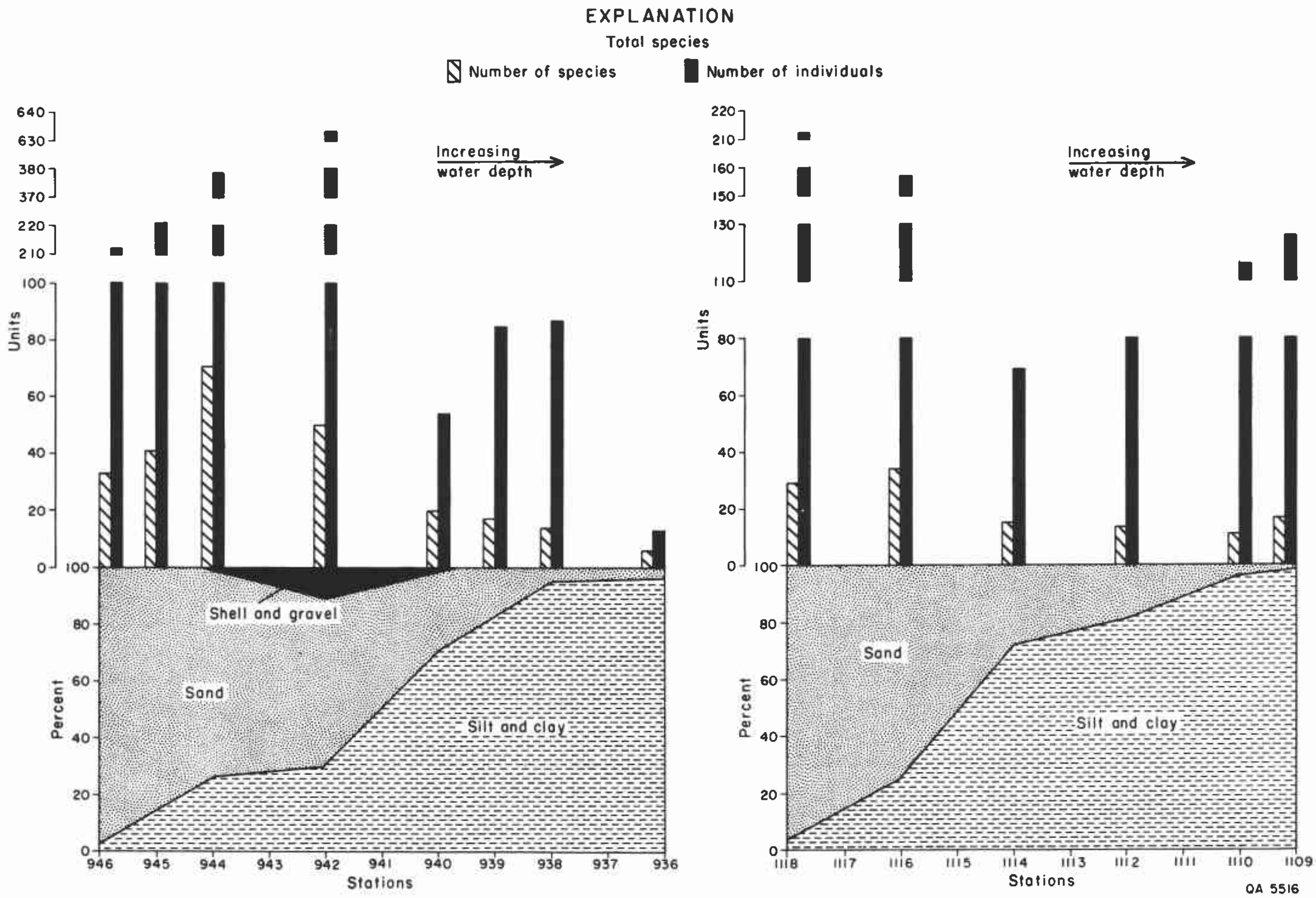


Figure 33. **Total species distribution along two inner-shelf transects. Stations without data were not analyzed.**

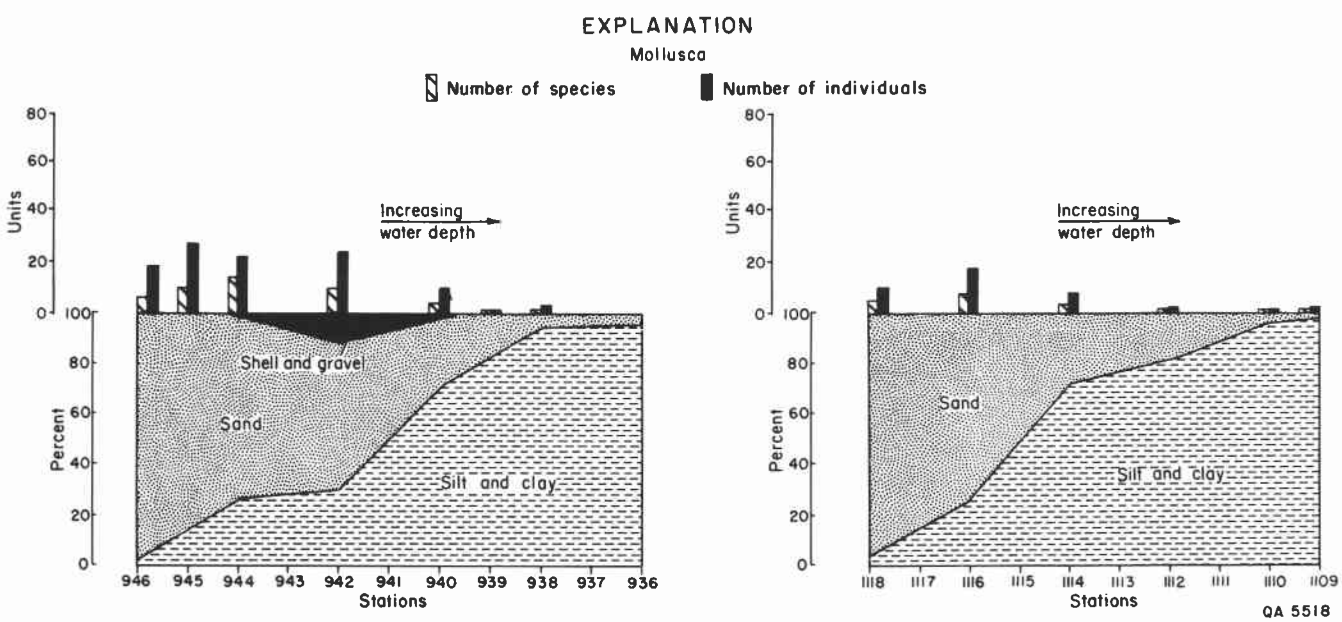


Figure 34. **Molluscan distribution along two inner-shelf transects. No live mollusks were present at station 936; other stations without data were not analyzed.**

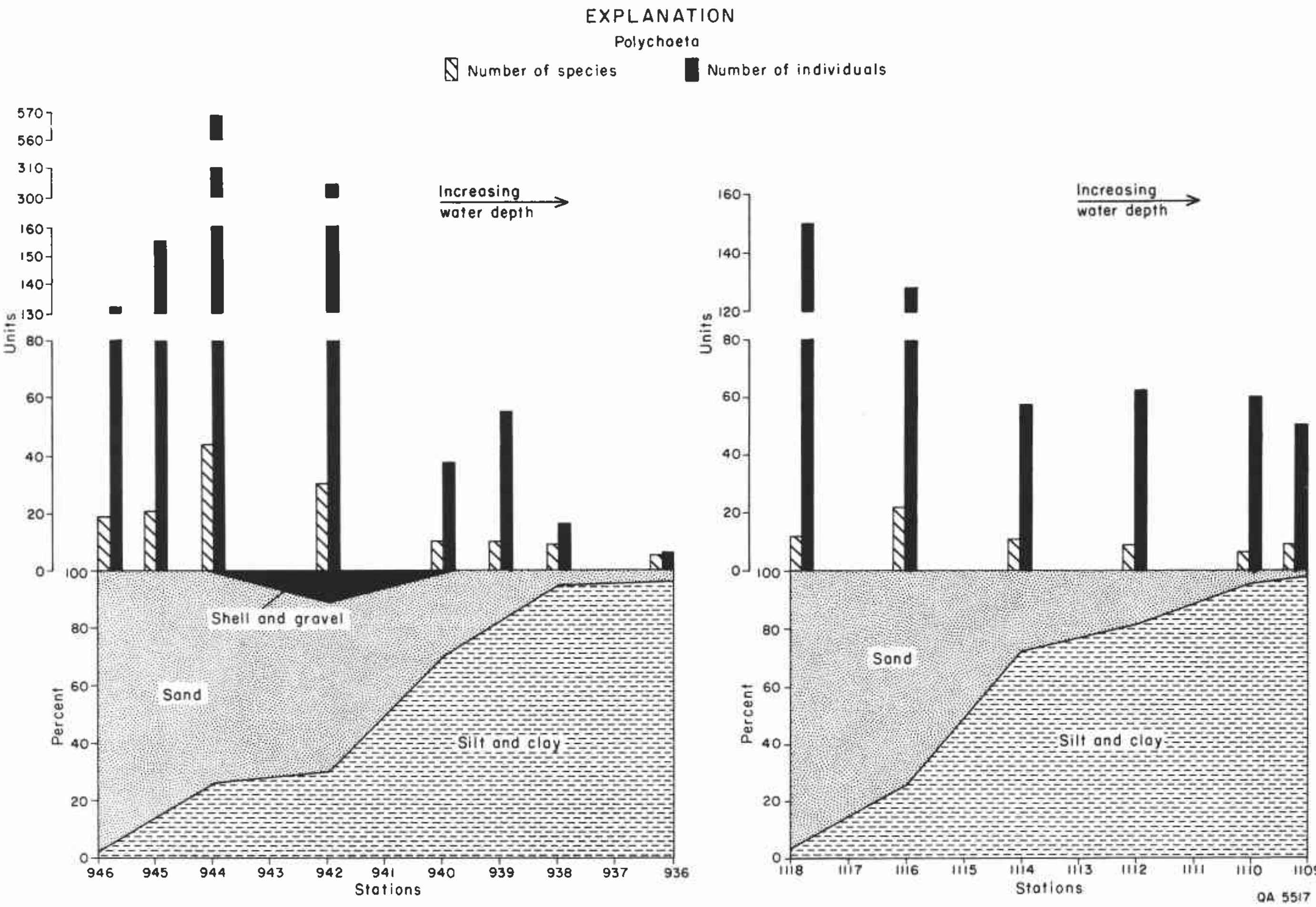


Figure 35. **Polychaete distribution along two inner-shelf transects. Stations without data were not analyzed.**

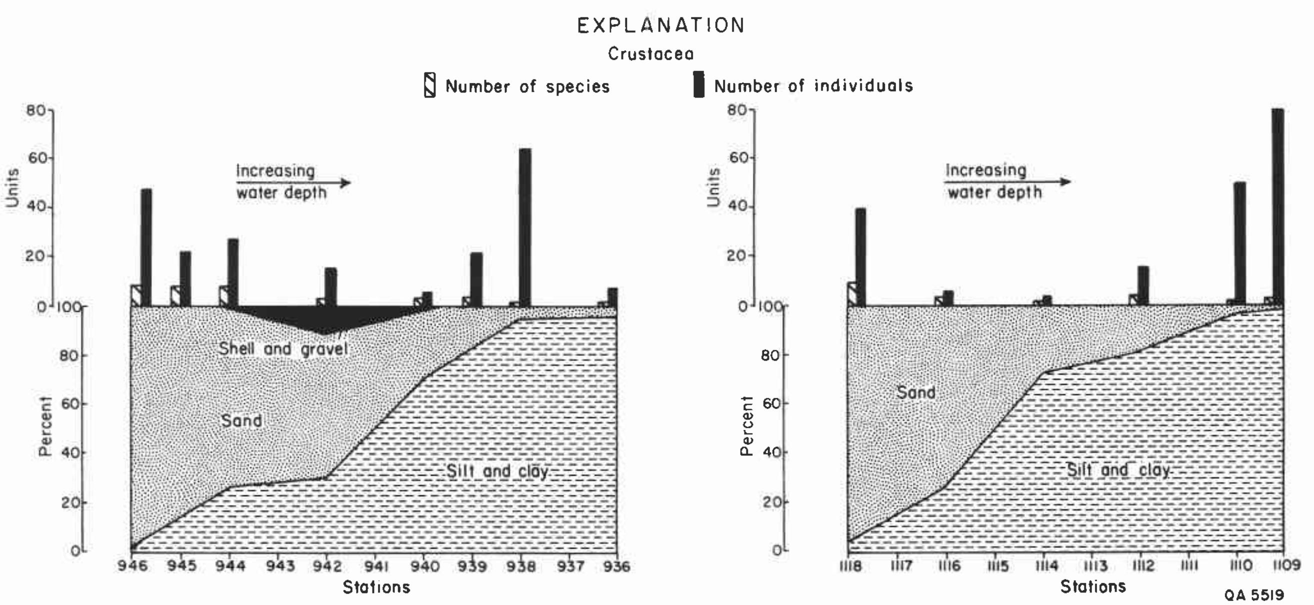


Figure 36. **Crustacean distribution along two inner-shelf transects. Stations without data were not analyzed.**

In the bay-estuary-lagoon system, scattergrams comparing species number with percent sand show a broad scatter in both muddy and sandy sediments (figs. 28 through 31). However, sediment-faunal relationships for total species, mollusks, polychaetes, and crustaceans are similar to those occurring on the inner shelf; that is, the highest number of species per station generally occurs in muddy sand and sandy sediments of 50 to 100 percent sand (figs. 28 through 31). Other environmental factors, such as salinity, temperature, turbidity, and the presence of seagrasses and serpulid reefs, may be more important than sediment in determining species distribution.

Many assemblages depicted on the Distribution of Wetlands and Benthic Macroinvertebrates Map (pl. V) also reflect the dependency of benthic invertebrate species on particular substrates. The assemblages often closely follow sediment trends. (A discussion of sediment and assemblage relationships is included in Macroinvertebrate Assemblages, p. 58.)

TOTAL SPECIES DIVERSITY

An important biological aspect of an animal community is its diversity. Species diversity is usually considered to be synonymous with species richness; that is, the greater the number of species in a sample, the greater the diversity of the sample. Another common understanding of species diversity, species dominance, involves the numerical (percentage) composition of the various species present in the sample: the more nearly the constituent species are represented by equal numbers of individuals, the more diverse the fauna. Species dominance is a measure of how equally or unequally the species divide the sample, and the number of species involved is immaterial (Sanders, 1968).

To describe a population quantitatively, various diversity indices have been used. The Shannon-Weaver diversity index (H′) was chosen for this report. This function has the attribute of being influenced by both species richness (the number of species present) and species dominance (how evenly the individuals are distributed among the constituent species). In this formula,

$$H' = -\sum_{r=1}^{s} p_r \log_2 p_r$$

where s = total number of species, and p = observed proportion of individuals that belong to the r^{th} species (r = 1, 2, . . ., s) (Sanders, 1968).

By definition, higher diversity indices correspond to higher species diversity. Interpretations of the diversity index have included its use as a measure of stress upon the organisms (Boesch, 1972; Holland and others, 1973) and as an indication of pollution in a system (Bechtel and Copeland, 1970). Caution should be used in making such interpretations from the diversity index (McIntosh, 1967) because it is easy to read into the numbers meanings that are not there. This misinterpretation is due to the inherent design of the Shannon-Weaver formula, which is affected by both species number and species dominance. Therefore, a single diversity number may be misleading. For example, the equation will give the same H′ value for any sample with only one species, regardless of the number of individuals present. Also, because of the influence of dominance, it is possible that the sample with the highest diversity index does not contain the greatest number of species.

To avoid misinterpreting specific values of the diversity index, the numerical values for diversity were subjectively grouped in this study into low (H′ = 0.000–1.499), medium (H′ = 1.500–1.999), high (H′ = 2.000–2.499), and very high (H′ = 2.500 and greater) diversity. These groupings are color coded on the Distribution of Wetlands and Benthic Macroinvertebrates Map (pl. V). In the text, any mention of "high diversity" or other grouping refers to that particular subjective classification.

Bay-Estuary-Lagoon System

Of the three bays in the study area, Laguna Madre has the highest median diversity and Alazan Bay the lowest (fig. 37). More than 60 percent of the diversity values in Laguna Madre are high or very high, whereas only 38 percent in Baffin Bay and 30 percent in Alazan Bay are high or very high. Highest diversities in Baffin Bay occur at grassflat stations near Laguna Madre. The highest diversity in Alazan Bay also occurs at a grassflat station (station 13).

Diversity values in Laguna Madre are generally lowest at stations located in the middle of the lagoon from just south of the Baffin Bay mouth to stations in The Hole near the Land-Cut Area. Highest values occur at grassflat stations south of the Land-Cut Area and at grassflat stations north of the mouth of Baffin Bay. A

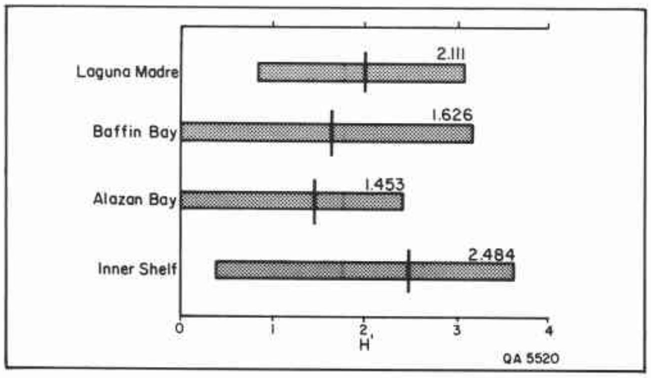


Figure 37. **Range and median values of diversity (H′) of macroinvertebrates in the bays and on the inner shelf.**

significant part of Laguna Madre contains grassflats, which contribute to the high diversity of the system.

Inner Shelf

Diversity on the inner shelf is generally high to very high. Only 35 percent of the stations (28 of the 81 examined) have indices below 2.000; 48 percent (39 stations) of the stations examined have indices above 2.500, and 17 percent (14 stations) have indices above 3.000. The median value of 2.484 is higher than the median value for the inner shelf in any area except the Brownsville-Harlingen area (2.933) (White and others, 1986).

Stations with very high diversity (greater than 2.500) tend to have sandier substrates than those stations with low or medium diversity (less than 2.000). The average percent sand at stations with very high diversity is 71.3, whereas the average for stations with low to medium diversity is 11.0. All stations with low diversity (less than 1.500) occur in sediments of less than 20 percent sand (pl. V and pl. IC).

Hill and others (1982) used the Shannon-Weaver diversity index to determine diversity of the macrobenthos on the South Texas Outer Continental Shelf (OCS). Their study area extended from Matagorda Peninsula in the north to the Rio Grande in the south and seaward to about the 656-ft (200-m) isobath. The 66-ft (20-m) isobath was the general inshore boundary. Several stations were within the State-owned submerged lands in the Kingsville area.

Hill and others (1982) found that the highest diversity values (greater than 2.750) were concentrated mainly within the southern one-third of their study area and were associated with coarse-grained substrates. Diversity values at nearshore stations in the Kingsville area were less than 1.75. Hill and others (1982) found that diversity on the South Texas OCS generally decreased with increasing water depth. They pointed out that regional patterns of diversity on the South Texas OCS did not agree completely with what has been found elsewhere. Diversity on other shelves generally increased in a seaward direction, away from the more variable and rigorous environments of the inner-shelf and coastal waters. Hill and others (1982) thought that greater sediment variability might explain higher diversity at shallow stations on the South Texas OCS than at deeper stations having relatively homogenous fine-grained substrates. Increases in structural (sediment) variability would increase habitat diversity and would probably result in greater numbers of species.

Holland and others (1976) found that the greatest number of species and individuals occurred at relatively shallow stations (49 and 82 ft [15 and 25 m]) rather than at deeper stations (131 to 410 ft [40 to 125 m]) in the Kingsville area. Infaunal equitability was highest at the deeper stations. High equitability at deep stations and high numbers of species at nearshore, relatively shallow stations produced similar diversities at both shallow- and deep-water stations.

MACROINVERTEBRATE ASSEMBLAGES

Computer Procedures

Cluster analysis (numerical classification) was used to delineate benthic communities in all bays and on the inner shelf. The use of cluster analysis in community ecology has the advantages of allowing objective analysis, simplification of complex data (such as those generated in the State-owned submerged lands program), and replication of the results by any investigator studying the same data. Flexibility is an additional advantage, allowing the researcher to apply different sorting methods, standardization methods, transformations, and correlation coefficients.

Cluster analysis begins with the computation of a resemblance measure between all pairs of entities being classified. The resemblance measure is a numerical expression of the degree of similarity or, conversely, dissimilarity between the entities on the basis of their attributes (Boesch, 1977). The entities may be grouped either by station, species content being the attribute (normal classification), or by species, abundance at each station being the attribute (inverse classification). Specific steps followed in the cluster analysis procedure include (1) reduction and standardization of data, (2) calculation of the similarity matrix using the Canberra metric dissimilarity coefficient (Boesch, 1977), (3) formation of dendrograms using the flexible-sorting method on dissimilarity coefficients (Clifford and Stephenson, 1975), and (4) construction of two-way tables. Dendrograms (fig. 38) are constructed from the matrix composed of dissimilarity coefficients for each pair of species or stations. Two-way tables based on the arrangement of stations and species in the order they appear on dendrograms can then be assembled. Dendrograms are a convenient way of visualizing the results of cluster analysis, but they do not solve the problem of deciding which branches are significant and distinctive groups of species or stations. Determining which groups are distinctive is essentially a subjective decision that requires comparing the breakdown of the groups with other data such as textural, hydrographic, or bathymetric data.

Large data sets require some reduction for easier handling by the computer and for ease of interpretation. Data reduction was often necessary because the capacity of the cluster program is 150 species and 150 stations. Rare species occurring at only one station in a bay system or on the inner shelf were not included in cluster analyses. Ecologists who favor data-reduction techniques suggest that distinctly rare species can be neglected in ecological classifications (Clifford and Stephenson, 1975). All rare species were included in diversity computations.

Other data manipulations were station and species standardization. Station standardization involves computing proportions of the total number of individuals contributed by each species at a site. This reduces the dominance of those species having a large number of individuals. Species standardization involves calculating the proportion of individuals of a given species at each of the sites.

The next step in the numerical classification procedure was the calculation of the degree of resemblance between all possible pairs of stations or species. A data matrix composed of dissimilarity coefficients was constructed for each pair of stations or species. The Canberra metric dissimilarity coefficient (Boesch, 1977) was used to compute coefficients for all data sets. The Canberra metric measure is insensitive to outstandingly abundant species, and no data transformation was needed. Dendrograms were then constructed using the flexible-sorting method.

When both normal and inverse analyses were run, a two-way table was constructed using the original station-by-species data matrix that has stations and species arranged in the order they appear in the dendrograms (fig. 38). The table permits direct comparison of the relation between the dendrograms and the original data, thus facilitating analysis of the results.

Mapping Procedures

The Distribution of Wetlands and Benthic Macroinvertebrates Map (pl. V) depicts the distribution of benthic macroinvertebrate assemblages (all benthic macroinvertebrates living together in any given type of environment) in the Kingsville map area. Cluster analyses helped delineate three assemblages on the inner shelf and four in the bay-estuary-lagoon system.

Station clusters from each system generally fall into three basic groups according to species content: (1) stations with few or no species, (2) those containing primarily the ubiquitous or sububiquitous species, and (3) those stations with the ubiquitous species and other species limited in their distribution by some environmental condition. Many stations contain both a ubiquitous group and one or more groups that are part of another cluster grouping. Station groupings in the bays are less distinct than those on the inner shelf.

The Distribution of Wetlands and Benthic Macroinvertebrates Map represents the distribution of species at a given time and does not convey information concerning sequential changes in map units. Assemblage boundaries are variable at given sites and areas because of many events, including (1) movements of individuals, (2) addition to or loss of species from an area, (3) patchiness in spatial and temporal distribution of many populations, (4) natural seasonal variations in distributions as a result of hydrographic changes, (5) population changes resulting from cyclic reproduction, and (6) the apparent random distribution of many species (Holland and others, 1975).

The number of control points (stations examined) used to determine the distribution of

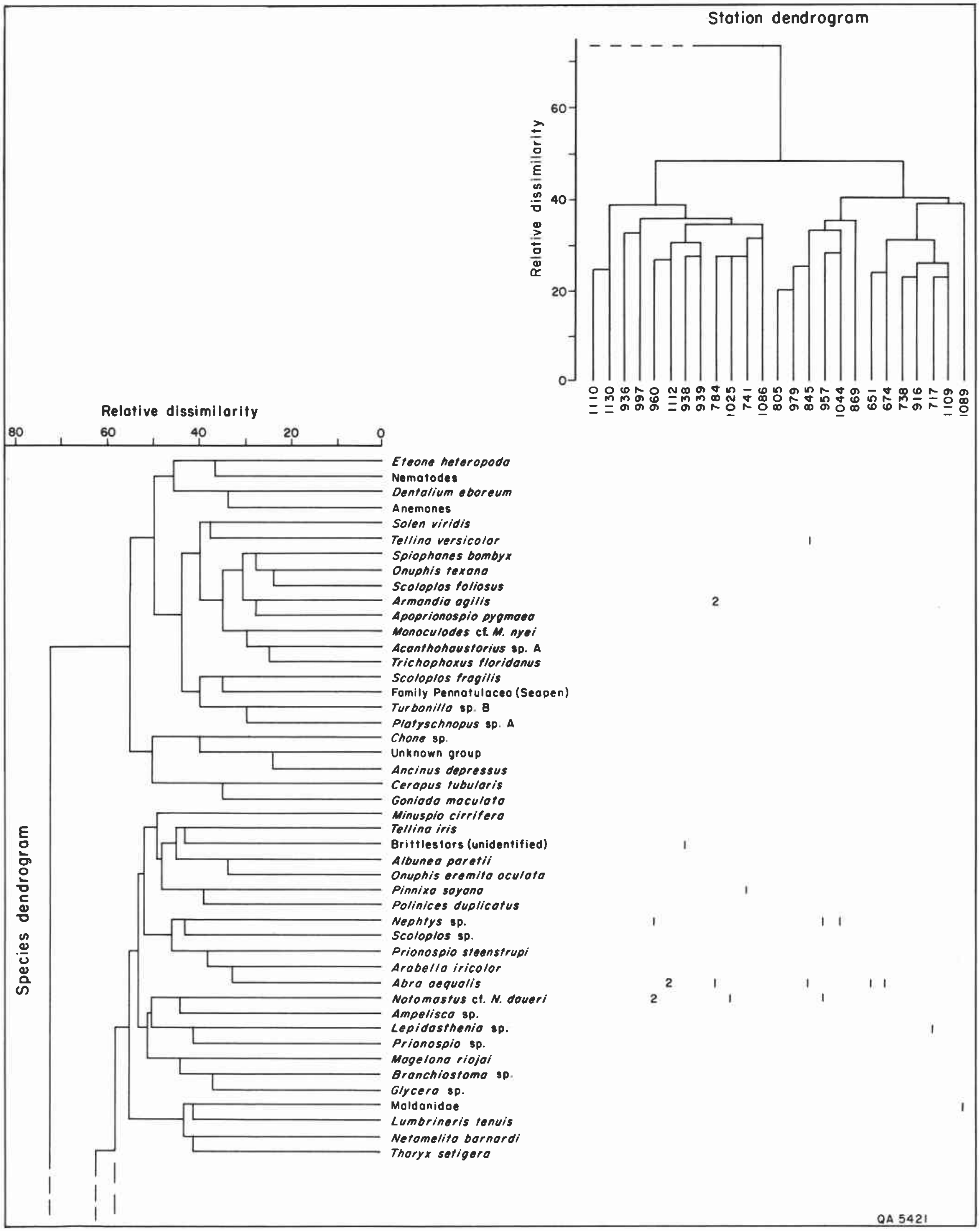


***Figure 38.* Station and species dendrogram for part of the inner shelf. Number of individuals is listed under station numbers.**

Table 15. Characteristics of benthic faunal assemblages, Kingsville area.

Assemblage	Total number of stations	Average number of species per station	Average number of individuals per station	Average percent sand per station	Approximate depth range ft (m)	Range in diversity (H')
BAY-ESTUARY-LAGOON						
Laguna Madre						
Grassflat	27	22.6	199.4	89.0	1–6 (0.3–1.8)	0.84–3.08
Bay center	12	23.0	160.1	48.3	6–16 (1.8–4.9)	0.80–3.08
Bay margin	2	11.5	90.0	94.5	0.5–2.0 (0.2–0.6)	1.21–1.45
Baffin Bay						
Bay center	15	6.3	111.9	18.1	2–9 (0.6–2.7)	0.00–1.63
Grassflat	7	29.3	233.4	83.5	2–3 (0.6–0.9)	1.56–3.19
Bay margin	4	14.3	43.8	85.4	2–5 (0.9–1.5)	2.06–2.52
Serpulid reef	3	11.3	53.0	74.3	3–6 (0.9–1.8)	1.22–2.20
Alazan Bay						
Bay center	5	5.0	17.2	36.1	2–6 (0.9–1.8)	0.86–1.66
Grassflat	1	24.0	231.0	—	2 (0.6)	2.41
Bay margin	4	17.2	119.0	80.7	2–4 (0.9–1.2)	0.00–2.15
INNER SHELF						
Nearshore	15	32.5	167.5	96.6	26–60 (7.9–18.3)	0.38–2.48
Transitional	40	38.0	205.0	53.1	48–90 (14.6–27.4)	1.85–3.22
Outer	26	11.9	93.5	5.4	73–98 (22.3–29.9)	1.84–3.63

—Not analyzed.

map units in each bay-estuary-lagoon system and on the inner shelf is variable (pl. V). Sample stations were carefully selected according to a number of criteria, including sediment type and proximity to other examined stations. The number and spacing of data points provided adequate control for the overall distribution of map units. Table 15 lists the average number of species and individuals, their diversity, and some physical characteristics of stations where each assemblage is found. A list of the characteristic species is given in table 16.

Bay-Estuary-Lagoon System

The four assemblages mapped in the bay-estuary-lagoon system are grassflat, bay center, bay margin, and serpulid reef (pl. V). Cluster analysis of data in the bay-estuary-lagoon systems generally yielded less-defined station groupings and assemblages than did data from stations on the inner shelf. This was expected because of the greater sediment and hydrographic variability in the bays. Many species occur in most of the assemblages, as well as in Laguna Madre and Baffin and Alazan Bays.

Laguna Madre

The three assemblages in Laguna Madre are grassflat, bay center, and bay margin. The grassflat assemblage covers the largest area, whereas the bay-margin assemblage is restricted to an area (only two stations) along the bay side of Padre Island just south of the Land-Cut Area.

Table 16. Characteristic species in macroinvertebrate assemblages, Kingsville area.

BAY-ESTUARY-LAGOON SYSTEM

Laguna Madre

GRASSFLAT
- Mollusca
  - Bivalvia
    - *Amygdalum papyrium*
    - *Laevicardium mortoni*
    - *Crepidula convexa*
  - Gastropoda
    - *Bittium varium*
    - *Caecum pulchellum*
- Polychaeta
  - *Exogone dispar*
  - *Chone duneri*
  - *Prionospio heterobranchia*
  - *Melinna maculata*
  - *Mediomastus californiensis*
  - *Spirorbis corrugatus*
- Crustacea
  - *Oxyurostylis salinoi*
  - *Elasmopus levis*
  - *Grandidierella bonnieroides*
  - *Harrieta faxoni*

BAY CENTER
- Mollusca
  - Bivalvia
    - *Nuculana acuta*
    - *Tellina texana*
    - *Lyonsia hyalina floridana*
    - *Mulinia lateralis*
    - *Aligena texasiana*
    - *Cumingia tellinoides*
    - *Chione cancellata*
  - Gastropoda
    - *Mitrella lunata*
    - *Caecum pulchellum*
    - *Odostomia gibbosa*
    - *Acteocina canaliculata*
    - *Nassarius acutus*

Laguna Madre cont.

- Polychaeta
  - *Magelona pettiboneae*
  - *Clymenella torquata*
  - *Mediomastus californiensis*
- Sipunculida
  - *Phascolion strombi*

BAY MARGIN
- Mollusca
  - Bivalvia
    - *Tellina tampaensis*
- Polychaeta
  - *Heteromastus filiformis*
  - *Axiothella mucosa*
  - *Scoloplos foliosus*

Baffin-Alazan Bays (including Laguna Salada and Cayo del Grullo)

BAY CENTER
- Mollusca
  - Bivalvia
    - *Mulinia lateralis*
  - Gastropoda
    - *Acteocina canaliculata*
    - *Acteon punctostriatus*
- Polychaeta
  - *Paraprionospio pinnata*
- Crustacea
  - *Ampelisca abdita*
  - *Grandidierella bonnieroides*

GRASSFLAT
- Mollusca
  - Bivalvia
    - *Mulinia lateralis*
    - *Amygdalum papyrium*

Baffin-Alazan Bays cont.

- Gastropoda
  - *Crepidula convexa*
  - *Bittium varium*
  - *Acteocina canaliculata*
- Polychaeta
  - *Prionospio heterobranchia*
  - *Typosyllis (Langerhansia)* sp.
  - *Exogone dispar*
  - *Spio pettiboneae*
- Crustacea
  - *Harrieta faxoni*
  - *Ampelisca abdita*
  - *Erichsonella attenuata*
  - *Grandidierella bonnieroides*
  - *Oxyurostylis salinoi*
  - *Cymadusa compta*
  - *Cerapus tubularis*

BAY MARGIN
- Mollusca
  - Bivalvia
    - *Mulinia lateralis*
  - Gastropoda
    - *Acteocina canaliculata*
- Crustacea
  - *Ampelisca abdita*
  - *Grandidierella bonnieroides*

SERPULID REEF
- Mollusca
  - Bivalvia
    - *Mulinia lateralis*
    - *Lyonsia hyalina floridana*
    - *Brachidontes exustus*
- Polychaeta
  - *Nereis succinea*
- Crustacea
  - *Edotea montosa*

INNER SHELF

NEARSHORE
- Mollusca
  - Bivalvia
    - *Parvilucina multilineata*
    - *Tellina versicolor*
    - *Solen viridis*
  - Gastropoda
    - *Natica pusilla*
- Polychaeta
  - *Lumbrineris verrilli*
  - *Mediomastus californiensis*
  - *Magelona pettiboneae*
  - *Onuphis texana*
  - *Owenia fusiformis*
  - *Spiophanes bombyx*
  - *Apoprionospio pygmaea*
  - *Armandia agilis*
  - *Scoloplos fragilis*
  - *Scoloplos foliosus*
- Crustacea
  - *Monoculodes* cf. *M. nyei*
  - *Acanthohaustorius* sp. A
  - *Platyschnopus* sp. A
  - *Trichophoxus floridanus*

TRANSITIONAL
- Mollusca
  - Bivalvia
    - *Abra aequalis*
    - *Parvilucina multilineata*
    - *Linga amiantus*
  - Gastropoda
    - *Natica pusilla*
    - *Terebra protexta*
  - Scaphopoda
    - *Cadulus carolinensis*
- Polychaeta
  - *Diopatra cuprea*
  - *Magelona* cf. *M. phyllisae*
  - *Aricidea taylori*
  - *Tharyx marioni*
  - *Aglaophamus verrilli*
  - *Lumbrineris ernesti*
  - *Lumbrineris verrilli*
  - *Sthenelais boa*
  - *Cossura delta*
  - *Scoloplos rubra*
  - *Tauberia gracilis*
  - *Isolda pulchella*
  - *Spiochaetopterus costarum oculatus*
  - *Nereis micromma*
  - *Magelona* sp. A
  - *Paraprionospio pinnata*
  - *Spiophanes bombyx*
  - *Litocorsa antennata*
  - *Mediomastus californiensis*
- Crustacea
  - *Ampelisca brevisimulata*
- Sipunculida
  - *Phascolion strombi*

OUTER
- Polychaeta
  - *Cossura delta*
  - *Lumbrineris verrilli*
  - *Nereis micromma*
  - *Paraprionospio pinnata*
  - *Nephtys incisa*
  - *Magelona* sp. A
  - *Ninoe* cf. *N. nigripes*
- Crustacea
  - *Ampelisca agassizi*

A bay-center assemblage is found at 12 stations, including 3 stations located in an area from Baffin Bay to near the Land-Cut Area, 4 stations in a part of the Intracoastal Waterway that extends through the Land-Cut Area, and 5 stations south of the Land-Cut Area.

Much of Laguna Madre contains a grassflat assemblage, characterized by a large number of invertebrate species and individuals (tables 15 and 16). The average number of species per station (22.6) is higher than that for grassflat stations in upper (14.8) or lower (22.0) Laguna Madre (White and others, 1983, 1986). The grassflat assemblage generally occurs where sand percentages are greater than 80 percent. Species diversities in the grassflats are generally high to very high (pl. V). Only 9 of the 27 grassflat assemblage stations (33 percent) have indices below 2.000.

Several studies have shown that macrofaunal densities at sites vegetated by seagrasses are higher than densities at nearby unvegetated sites (Santos and Simon, 1974; Stoner, 1980; Virnstein and others, 1983). Numbers of invertebrate species within a seagrass habitat are not significantly related to the numbers of plant species. However, both species number and abundance of invertebrates at sample sites are significantly correlated with plant biomass (Heck and Wetstone, 1977).

Most of the characteristic species in the grassflat assemblage (table 16) are abundant in the grassflats of upper or lower Laguna Madre (White and others, 1983, 1986), and six species, including *Bittium varium, Chone duneri, Prionospio heterobranchia, Melinna maculata, Oxyurostylis salinoi,* and *Harrieta faxoni,* are abundant in all areas with grassflats in Laguna Madre.

The bay-center assemblage is found at deeper and muddier stations than is either the grassflat or bay-margin assemblage. Water depths at stations with a bay-center assemblage range from 6 to 16 ft (1.8 to 4.9 m), and sediments average 48.3 percent sand. The average number of species per station is the highest of the three assemblages in Laguna Madre. Mollusks, especially *Nuculana acuta, Tellina texana, Lyonsia hyalina floridana,* and *Caecum pulchellum,* are dominant.

A bay-margin assemblage occurs at stations 141 and 149, very shallow sandy stations located just south of the Land-Cut Area. Polychaetes are dominant in this assemblage.

Parker (1959) recognized an enclosed, hypersaline-lagoon assemblage in the shallow, central part of northern Laguna Madre. This assemblage extended from near the Land-Cut Area to just south of Corpus Christi Bay. Although Parker found only four live mollusks, including *Mulinia lateralis, Tellina tampaensis, Cerithium lutosum,* and *Anomalocardia auberiana,* the number of individuals per sample of each species was extremely high. Parker (1959) stated that this molluscan population constituted the largest assemblage of living mollusks, except for oyster reefs, along the northern Gulf coast, despite the salinities being always hypersaline, the temperatures being high, and the water being extremely shallow.

Of the four molluscan species in Parker's (1959) enclosed, hypersaline-lagoon assemblage, *Mulinia lateralis, Tellina tampaensis,* and *Cerithium lutosum* are abundant in samples collected from Laguna Madre during this study. Also, fragments and whole shells of *Anomalocardia auberiana* are abundant in nearly all Laguna Madre samples, even though only seven live individuals were found.

Baffin-Alazan Bay System (including Cayo del Grullo and Laguna Salada)

Most of Baffin and Alazan Bays contain a bay-center assemblage composed primarily of *Mulinia lateralis, Ampelisca abdita,* and *Grandidierella bonnieroides.* The mollusks *Acteocina canaliculata* and *Acteon punctostriatus* and the polychaete *Paraprionospio pinnata* also occur at several stations having a bay-center assemblage. The most abundant species in this assemblage is *A. abdita*; however, 82 percent of all *A. abdita* individuals were collected at stations 47 and 69 in Baffin Bay. Diversity values in the bay-center assemblage are low to medium (0.00 to 1.66), and the average number of species per station is the lowest of the four assemblages.

A grassflat assemblage is found at six stations in Baffin Bay near its connection with Laguna Madre, at one station in Laguna Salada, and at one station in Alazan Bay. A large number of invertebrate species, especially crustaceans (table 16), occur in the grassflats. Crustaceans are more abundant in the grassflats of the Baffin-Alazan Bay system than in Laguna Madre. Several of the most abundant invertebrates, including the polychaetes *Prionospio heterobranchia, Spio pettiboneae,* and *Exogone dispar,* the mollusks *Bittium varium* and *Crepidula convexa,* and the crustaceans *Erichsonella attenuata* and *Cerapus tubularis,* occur only at grassflat stations. Many species, such as the polychaetes *Spirorbis spirillum* and *Melinna maculata,* although not abundant, also are found only in the grassflats.

Species diversities in the grassflats of Baffin and Alazan Bays are relatively high; only one station has a diversity index (H′) below 2.000. Species and individual averages per station (table 15) are the highest of any bay assemblage.

A bay-margin assemblage, consisting primarily of mollusks and crustaceans, occurs at four stations in Baffin Bay and at four stations in Alazan Bay. Species diversities vary considerably, with H′ values ranging from 0.00 to 2.52. The crustaceans *Ampelisca abdita* and *Grandidierella bonnieroides* are the most abundant species in the bay-margin assemblage.

Stations 38, 54, and 60 in Baffin Bay contain a serpulid-reef assemblage. The serpulid reefs are composed of calcareous tubes of live and dead serpulid worms. Three unidentified fragments of serpulid worms were found at station 60 in Baffin Bay. The most abundant species in the assemblage are the bivalve *Brachidontes exustus* and the polychaete *Nereis succinea.* Other abundant species in the assemblage include the mollusks *Mulinia lateralis* and *Lyonsia hyalina floridana* and the crustacean *Edotea montosa.*

Andrews (1964) studied serpulid reefs in Baffin Bay and Laguna Madre but found no live serpulid worms. Cole (1981) found *Hydroides dianthus,* a serpulid worm, living at several serpulid reefs in Baffin and Alazan Bays and in Cayo del Grullo and Cayo del Infiernillo. Worms occurred at a depth of several centimeters along the margins of reef fragments, indicating that growth of reefs had occurred (Cole, 1981). In this study, *Hydroides dianthus* was not found at any station in the Baffin-Alazan Bay system, but it was found at stations that did not contain serpulid reefs—two stations in Laguna Madre and two in the Intracoastal Waterway. *Hydroides dianthus* was abundant on oyster reefs in Corpus Christi Bay (White and others, 1983).

Others who have studied the serpulid-reef assemblage in the Baffin-Alazan Bay system include Mackin (1971), Martin (1979), and Cole (1981). Mackin (1971) found that crustaceans and polychaetes dominated the assemblage in Baffin Bay, the mollusks being next in abundance. The crustacean *Corophium acherusicum* was the most abundant species. Cole's study (1981) contained a list of all organisms associated with the four serpulid-reef sites in the Baffin-Alazan Bay system. Organisms that occurred at all four sites included a nemertean; a bivalve, *Brachidontes exustus*; a barnacle, *Balanus balanus*; and the polychaetes *Diopatra cuprea, Polydora* sp., *Mediomastus californiensis, Pectinaria gouldii, Marphysa sanguinea, Hydroides dianthus,* and a species in the family Dorvilleidae.

Inner Shelf

Cluster analysis separated the inner-shelf fauna into nearshore, transitional, and outer assemblages. Polychaetes are dominant (abundant) in all three assemblages. *Lumbrineris verrilli* is the only species abundant in all three assemblages. Species characteristic of each of these assemblages are shown in table 16.

Nearshore Assemblage

The nearshore assemblage generally extends from the shoreline to approximately 2 to 3 mi (3.2 to 4.8 km) offshore (pl. V). It also occurs 6 mi (9.7 km) offshore at station 589, near the southern boundary of the map area.

The nearshore assemblage generally follows the same trend as that of sediment with high sand (80 to 100 percent) content (pl. IC). Sandy sediment (80 to 100 percent sand) extends offshore from 2 to 3 mi (3.2 to 4.8 km) over most of the Kingsville area. Near the southern boundary of the map area, sands extend approximately 8 to 9 mi (12.9 to 14.5 km) offshore beneath water as much as 84 ft (25.6 m) deep. The average percent sand at stations with a nearshore assemblage is 96.6 percent.

Characteristic species in the nearshore assemblage include a large number of polychaetes (table 16). Many crustaceans are restricted almost entirely to this nearshore, sandy environment. Several mollusks and polychaetes, including *Parvilucina multilineata, Natica pusilla, Lumbrineris verrilli,* and *Mediomastus californiensis,* are also characteristic of the transitional assemblage. *Lumbrineris verrilli* is the most ubiquitous species, occurring at all but one station with a nearshore assemblage. Only 6 of the 18 characteristic species are not abundant in the nearshore assemblage in the Brownsville-Harlingen area (White and others, 1986).

Transitional Assemblage

The transitional assemblage covers most of the area from the outer boundary of the nearshore assemblage, or approximately 2 to 3 mi (3.2 to 4.8 km) offshore, to approximately 7 to 10 mi (11.3 to 16.1 km) offshore. Depths for stations with a transitional assemblage vary considerably, ranging from 48 to 90 ft (14.6 to 27.4 m). The dominant sediment type is either muddy sand or sandy mud.

Polychaetes dominate the transitional assemblage. Nineteen of the 27 characteristic species are polychaetes. The polychaete *Magelona* cf. *M. phyllisae* is the most abundant and ubiquitous species, occurring at each of the 40 stations having a transitional assemblage. Only 4 percent (41 individuals) of a total of 2,120 individuals of *Magelona* cf. *M. phyllisae* occur in the nearshore and outer assemblages. Several other polychaete species, including *Lumbrineris verrilli, Aricidea taylori, Tharyx marioni, Aglaophamus verrilli, Lumbrineris ernesti,* and *Cossura delta,* are also very abundant at most transitional assemblage stations.

Species and individual averages per station are the highest of the three assemblages (table 15). Species diversities are also high; only 3 of the 40 stations have diversity values below 2.000.

Outer Assemblage

The outer assemblage extends from the transitional assemblage boundary, approximately 7 to 10 mi (11.3 to 16.1 km) offshore, to the limit of the study area, approximately 11 mi (17.7 km) offshore. Water depths at stations having an outer assemblage range from 73 to 98 ft (22.3 to 29.9 m). Muddy sediment (less than 20 percent sand) is dominant (pl. IC), and the average percent sand is 5.4 percent, reflecting a range of 0.7 to 19.6 percent sand.

The crustacean *Ampelisca agassizi* is the most abundant and widespread species in the outer assemblage, occurring at all 26 stations and ranging from 3 to 232 individuals at each station. Most of the characteristic species are polychaetes.

Other workers have used cluster or ordination analysis to identify macrobenthic assemblages on the inner shelf. Hill and others (1982) delineated four assemblages, one of which (assemblage I) occurred in a zone parallel to shore and was confined generally to that part of the shelf in the Kingsville area between the 66- and 131-ft (20- and 40-m) isobath. This area includes most of the transitional and outer assemblages identified in this study. Hill and others (1982) found that assemblage I had the second highest number of species, individuals, and biomass of the four assemblages. It was also characterized by high percentages of polychaete species and individuals.

Flint and Rabalais (1981) used ordination analysis to identify five station groupings on the South Texas shelf. Two stations occurred within the State-owned submerged lands in the Kingsville area and were included in two different station groupings, shallow and middepth. Water depth at the shallow station was 49 ft (15 m) and was 82 ft (25 m) at the middepth station. High numbers of species and individuals resulted in high diversity at the shallow-water station. The middepth station was defined as being in a transition zone between the middepth community and the deep-water community. Polychaetes were dominant at both shallow and middepth stations.

SUMMARY

The following significant findings resulted from this baseline study:

(1) Species distribution
- (a) Total numbers of species per station on the inner shelf range from 5 to 71. The greatest number of species per station generally occurs at stations 1 to 5 mi (1.6 to 8.1 km) offshore.
- (b) In the bay-estuary-lagoon system, species numbers per station (1 to 52 species) vary considerably. Stations in the marine grassflats of Baffin and Alazan Bays and in Laguna Madre generally have high numbers of species and individuals.
- (c) On the inner shelf, the average number of species per station is generally greatest in a depth range of 42 to 60 ft (12.8 to 18.3 m).

(2) Substrate-species relationships
- (a) In general, on the inner shelf there is a positive correlation between number of species and percent sand. The optimum percent sand range for all species and for mollusks and crustaceans is approximately 50 to 95 percent sand.
- (b) Stations on the inner shelf with very high diversity values (greater than 2.500) have sandier substrates than those stations with diversity values of less than 2.500.

(3) Species diversity
- (a) Of the three bays in the study area, the median diversity value is highest in Laguna Madre and lowest in Alazan Bay. The highest diversity values in Baffin Bay occur at grassflat stations near Laguna Madre. The highest values

in Laguna Madre occur at grassflat stations south of the Land-Cut Area and north of the mouth of Baffin Bay.

(b) Diversity values on the inner shelf are generally high to very high (greater than 2.000). Medium to low diversity values (less than 2.000) occur at only 35 percent of the stations.

(4) Macroinvertebrate assemblages

Cluster analysis permitted delineation of three assemblages on the inner shelf and four in the bay-estuary-lagoon system. Much of Laguna Madre contains a grassflat assemblage, which is characterized by a large number of species and individuals. Most of Baffin and Alazan Bays contain a bay-center assemblage. On the inner shelf, polychaetes are dominant in all three assemblages.

WETLANDS

by
William A. White and Thomas R. Calnan

CLASSIFICATION OF WETLANDS

Preparation of the Environmental Geologic Atlas (Brown, 1972-1980) and participation in the National Wetlands Inventory (NWI) by the Bureau of Economic Geology facilitated the expansion and revision of maps showing the distribution of wetlands along the Texas coast. Although the Bureau publication was termed an environmental "geologic" atlas, the complexity, dynamics, and interrelationship of physical, biological, and chemical processes in the Coastal Zone required the recognition of more than geologic units and facies. Thus, among the numerous map units depicted were "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" (Brown and others, 1977, p. 45-46). One of the special-use maps that evolved in the Environmental Geologic Atlas Project and that is included in each of the atlases is an Environments and Biologic Assemblages Map, which illustrates coastal wetlands and their distribution. Maps from this earlier atlas series were major sources of wetland information for this submerged lands study.

Maps prepared by the U.S. Fish and Wildlife Service and the Minerals Management Service, U.S. Department of the Interior, for the NWI were used as collateral data in delineating wetlands in many areas. These NWI maps depict wetlands photointerpreted by researchers at Texas A&M University in accordance with the classification of wetlands and deep-water habitats devised by Cowardin and others (1979).

The wetland units described and mapped in this report (table 17) are patterned, with some modifications, after those established specifically for the Texas coast in the Environmental Geologic Atlas Project initiated in 1969. General differences between this mapping effort and the earlier Environmental Geologic Atlas are described in the introduction to this report (p. 3).

A major departure in this classification from that of the earlier atlas series is the subdivision of fresh-, brackish-, and salt-water marshes into predominantly wet or dry areas. Thus, each of the marsh types has two major categories based on vegetation types and the amount of moisture or degree of wetness (suggesting relative frequency of inundation) of the soils or substrates, as determined through photographic analyses. Wind-tidal flats were also subdivided in terms of relative frequency of flooding, as denoted by the amount of inundation or degree of wetness of the substrate as seen on the photographs. Shallow subaqueous flats (mapped as water) are differentiated from topographically higher wind-tidal flats that appear to be frequently flooded. These frequently flooded wind-tidal flats having intermediate elevations are also differentiated from higher and drier flats. The resulting map categories that depict degrees of wetness or inundation are comparable to, but are much broader

Table 17. Wetlands and associated environments, Kingsville area.

Map Units Generally Barren of Higher Order Plants:
Beaches
Washover areas
Sand flats, wind-tidal, relatively frequent flooding
Sand flats, high wind-tidal, includes fluvial-channel margins and bars
Shallow subaqueous flats, tidal pools, inland reservoirs and ponds, and natural and dredged channels
Beaches and berms along bay-estuary-lagoon margins
Map Units Characterized by Vegetation Assemblages:
Grassflats
Salt-water marshes
Proximal marsh
Distal marsh
Brackish-water marshes
Low marsh
High marsh
Fresh-water marshes
Low marsh
High marsh
Sand or mud flats/marshes, undifferentiated
Wetland/upland areas, undifferentiated
Transitional areas
Woodlands in fluvial areas and in poorly drained depressions

and more generalized than, the water regimes established in the U.S. Fish and Wildlife Service classification system (Cowardin and others, 1977, 1979).

Another departure from the earlier geologic atlas classification of wetlands is the use of a few new map units, including (1) transitional areas—used to map those areas that, in terms of vegetation types and wetness, lie between marshes and uplands; (2) wetland/upland areas, undifferentiated—used to designate complex, difficult-to-separate mixtures of wetland and upland areas; and (3) sand flats or mud flats/marshes, undifferentiated—used to encompass complex mixtures of barren flats and marshes. Other departures from the earlier atlas are shown in table 18. One change involves depicting wetlands that have developed on dredged spoil, rather than simply designating them as spoil. Also, numerous small circular depressions shown on the Environmental Geologic Atlas as water features were mapped in this study according to the "signature" on the aerial photographs; for example, those depressions supporting marsh vegetation were mapped as marshes.

INTERPRETATION AND DELINEATION OF WETLANDS

Wetlands in most of the map area were interpreted and delineated using stereoscopic, color-infrared, 1:66,000-scale positive transparencies taken in November 1979 by NASA. In this volume, emphasis is placed on vegetative communities and the presence of water or moisture, or low elevations, which suggests flood frequency. As mentioned previously, several units such as salt-water marshes, brackish-water marshes, fresh-water marshes, and wind-tidal flats have been subdivided into areas defined by frequency of flooding. These different flood-prone units were determined primarily through photographic analysis supported by a limited number of field studies in which the kinds of vegetation and the soil moisture or degree of inundation were recorded. More than 100 field-site surveys, including revisited sites, were conducted in the Kingsville area. The additional field data and the use of color-infrared photographs have allowed better resolution of salt-, brackish- and fresh-water assemblages than was possible previously in the Environmental Geologic Atlas series. However, many of the map-unit boundaries in this study are based solely on photographic interpretation, without field verification.

Map boundaries are shown as distinct lines, but the lines are often approximations because the boundaries are gradational. Many species overlap within the various map units. In nature, the boundary between one vegetation type or moisture regime and another is inexact. Commonly a gradation occurs involving a mixture of species or a variable moisture content of soils or substrates. Nevertheless, broad assemblages and general moisture levels can be differentiated on the photographs, and their depiction on the map adds useful information about the coastal wetlands.

Two factors enhanced our ability to interpret moisture levels or inundation frequency: (1) photographs were of high quality and represented the same period (November 7-13, 1979) for almost the entire coast, and (2) records of precipitation indicated that few, if any, areas were affected by local rainfall for several days before the photographs were taken. It should be noted, however, that bay tide levels were above normal on the days the 1979 photographs were taken. In addition, higher than normal precipitation occurred in 1979; September 1979 (2 months before the photographs were taken) was a time of above-normal precipitation (figs. 7 and 8). Both of these phenomena, high tides and above-normal precipitation, tend to produce wetter than normal conditions. Still, in a given region, wetland environments can be compared and classified relative to each other. Marshes and flats can be delineated according to their moisture or water content (high and low marshes), although there is a tendency toward an upland shift in the map units because of wetter than normal conditions. Accordingly, some areas that under normal conditions might more appropriately be included within the drier, high-marsh map unit are included in the wetter, or more frequently inundated, low-marsh map unit; likewise, some flats that could be designated as wind-tidal flats might be classified as shallow subaqueous flats (water).

High and low marshes and flats are relative designations that can vary among geographic areas. For example, a low marsh in the southern coastal area is not necessarily equivalent in permanence of moisture or water to a low marsh mapped in the northern coastal area. In the lower Rio Grande Valley, where evapotranspiration greatly exceeds precipitation, many low marshes are intermittently wet and are best designated as

Table 18. Comparison of wetlands classified in this report with those classified in the Environmental Geologic Atlas of the Texas Coastal Zone, Kingsville area (Brown and others, 1977). The X's indicate those units that are similar in characteristics or that encompass similar map areas.

CLASSIFICATION OF WETLANDS AND ASSOCIATED MAP UNITS DEFINED AND MAPPED IN THIS REPORT	CLASSIFICATION OF WETLANDS FROM ENVIRONMENTAL GEOLOGIC ATLAS ENVIRONMENTS AND BIOLOGIC ASSEMBLAGES MAP (From Brown and others, 1977)													
	Beach	Washover channel, fan, and wind-deflation trough and storm runnel	Sand flats, wind-tidal	Fresh- to saline-water bodies, landlocked ponds and playas	Berms along bay-lagoon margin, storm deposits	Grassflats	Vegetated barrier flats, salt-tolerant grasses, local fresh-water marsh	Inland fresh-water marsh	Intense wind-deflation and wind-tidal activity, erosion of sand sheet, salt-tolerant grasses, algal mats	Poorly drained depressions, mud substrate, seasonal hydrophytes	Loose sand and loess prairies, fresh-water marsh in blowouts and depressions	Poorly drained depressions, sand substrate, seasonal high-moisture plants	Fluvial woodlands	Subaqueous and subaerial spoil
Beaches	X													
Washover areas		X												
Sand and mud flats, wind-tidal			X						X					X
Sand and mud flats, high wind-tidal, includes barren fluvial-channel margins and bars		X	X						X					X
Shallow subaqueous flats, tidal pools, inland reservoirs and ponds, and natural and dredged channels			X	X					X					
Beaches and berms along bay margins					X									
Grassflats						X								X
Salt-water marshes														
Proximal marsh					X									X
Distal marsh					X		X		X					X
Brackish-water marshes														
Low marsh									X	X	X			
High marsh							X		X	X	X			
Fresh-water marshes														
Low marsh							X	X		X	X			
High marsh							X	X		X	X	X		
Sand or mud flats/marshes, undifferentiated			X						X		X			X
Wetland/upland areas, undifferentiated									X		X			
Transitional areas									X	X	X	X		
Woodlands in fluvial areas and in poorly drained depressions													X	

ephemeral or seasonal. In the Galveston–Houston area, where precipitation exceeds evapotranspiration, water or moisture associated with low marshes is more permanent. The high and low designations, then, reflect the relative moisture levels in depressions in a given area at the time the photographs (from which they are interpreted) were taken. Because marshes are typically topographically lower or geomorphically deeper, they retain moisture longer than do higher marshes. In addition, in drier areas or during drier periods when surface water is lacking, the water table is nearer the surface in the low marsh than it is in the high marsh. The dry South Texas climate also presents a dilemma in defining what constitutes a wetland. More about this problem is presented in the section Mapped Wetland Environments (p. 71).

COASTAL WETLANDS AND RELATED ENVIRONMENTS

Depositional Setting

Several Modern–Holocene and Pleistocene depositional systems are identified along the Coastal Zone. The fluvial, deltaic, barrier-strandplain, eolian, bay-estuary-lagoon, and offshore systems are the major natural systems in the Kingsville area (fig. 9). These depositional and erosional systems have been active along the coast during glacial and interglacial stages from the Pleistocene to the present. During the most recent glacial period (Wisconsinan), lower stands of sea level allowed rivers to erode deep valleys that were flooded during the postglacial sea-level rise. Some of the relict valleys have been filled with sediments deposited by Modern–Holocene fluvial-deltaic processes that have formed present-day deltaic headlands along the Gulf of Mexico. Other relict valleys, which were not filled with sediments, are now the sites of bays and estuaries (fig. 9). Partly enclosing the bay-estuary-lagoon systems are the barrier islands and peninsulas that line the Texas coast.

Interconnected facies and geomorphic features that characterize the numerous types of coastal wetlands are the result of Modern–Holocene and Pleistocene deposition and erosion. Physical processes acting on the wetlands include rainfall, runoff, and streams; evapotranspiration; waves and longshore currents; astronomical and wind tides; hurricanes and tropical storms; eolian activity; subsidence; faulting; and sea-level rise. These processes have produced a gradational array of permanently inundated to infrequently inundated environments ranging in elevation from the submerged lands of the Gulf and bay-estuary-lagoon systems through the topographically higher (1) astronomical-tidal zone, characterized by low elevations and a high frequency of flooding, (2) wind-tidal zone, characterized by intermediate elevations and intermediate frequency of flooding, and (3) storm-tidal zone, characterized by higher elevations and a low frequency of flooding.

Beginning in the inland areas and extending gulfward, a set of fluvially related environments, including active and abandoned stream channels, natural levees, point bars, crevasse splays, and floodbasins, are flooded at varying frequencies, depending on topography, climatic conditions, and locations of streams and drainage systems. Discharge of the rivers into the bay-estuary-lagoon system or into the Gulf has produced a suite of deltaic environments, including distributary and tidal channels, levees, marshes, interdistributary basins, and bay-margin environments (Environmental Geologic Atlas Project [Brown, 1972–1980]). In the Kingsville area, a vast eolian system extends from nearshore to the inland margin of the study area (fig. 9). Within many of these depositional and erosional environments flood-prone lands extending inland from the bay margins and flood-prone depressions scattered across the Texas Coastal Plain are integral parts of the suite of wetlands.

Other coastal wetlands include those associated with (1) ancient barrier-strandplain sands, characterized by ridge-and-swale topography that has been modified along the southern coast by eolian activity, and (2) modern barrier islands and peninsulas, characterized by ridge-and-swale topography in the central and northern coastal areas and by deflation flats or depressions in the south. The modern barriers are cut by tidal inlets and washover channels and are composed in part of beaches, tidal flats, and marshes.

Added to these natural systems of wetlands is a complex array of human-modified units. Modifications include intricate channel networks, extensive dredged-spoil deposits, and ponds and reservoirs.

Relation to Climatic Controls

The types of wetlands occurring along the coast are influenced largely by climate. Average annual precipitation ranges from about 54 inches (135 cm) along the upper Texas coast near Beaumont–Port Arthur to 26 inches (65 cm) along the lower coast near South Padre Island (fig. 5). South of the Bay City–Freeport area, average annual evapotranspiration exceeds precipitation, producing a water deficit (fig. 5). These climatic variations not only affect the water budget and corresponding levels of stream flow, runoff, and ground water but also influence the geologic processes that in turn dictate the origin of many wetlands. In the Kingsville area, for instance, low precipitation and high evapotranspiration amplify eolian processes, resulting in an extensive eolian system. Most of the marshes in this area occupy mainland depressions formed by wind deflation. In contrast, where precipitation rates are high and evapotranspiration is relatively low, an ample water supply from rivers and a near-surface water table result in large marshes in areas formed by fluvial-deltaic processes.

The increasing water deficit from northeast to southwest along the coast also is reflected by increasing average and extreme salinities in the bay-estuary-lagoon system, which in turn are reflected in the wetland environments. The extensive salt- and brackish-water marshes that occupy wind-tidal zones along the upper coast (for example, in the Galveston–Houston area) are replaced by barren wind-tidal sand and mud flats capped by algal mats and evaporite deposits along the lower coast (for example, in the Brownsville–Harlingen and Kingsville areas).

WETLANDS IN THE KINGSVILLE AREA

Mapped Wetland Environments

Seventeen wetland environments are delineated within the Kingsville area (table 17; pl. V). These wetland units are defined principally on the basis of (1) vegetation communities, which reflect salinities and substrate moisture, among other conditions, (2) elevation or frequency of flooding, as determined by surface water or soil moisture, and (3) hydrodynamic processes or conditions (for example, fluvial or tidal processes) that have formed and that maintain the wetland environments.

In this dry, semiarid South Texas area, it is difficult to define the boundary between salt- or brackish-water marshes and the drier, vegetated saline flats or transitional areas into which many of the marshes grade. Broad "barren" wind-tidal flats in the Kingsville area, such as those in the Land-Cut Area (pl. V), are sources not only of clay and silt that accumulate in clay dunes along the leeward side of the flats (Price, 1958; Brown and others, 1980) but also of saline dust that is transported miles inland (Johnston, 1955) by prevailing southeasterly winds. In addition, shallow ground water in many areas is slightly to very saline. Thus, saline soils are not limited to intertidal areas along the bay and lagoon margins but extend inland several miles as well as into areas with elevations higher than the low flats. Seasonal precipitation freshens or reduces salinities in ponds, shallow lagoons, and flats, but during dry periods, the ponds shrink and salinities rise as salts become more concentrated. Surrounding flats support a low-diversity mixture of halophytes that can tolerate the salinity stress.

Although data are not available to provide a good record of inundation frequencies of many of the topographically low flats, such as those supporting extensive *Borrichia frutescens,* the presence of scattered *Opuntia* sp. in some areas suggests that inundation is infrequent. Members of the cactus family, such as *Opuntia,* need well-drained soils to allow oxygen to be supplied to their roots; extended periods of inundation cause root rot (Park Nobel, University of California at Los Angeles, personal communication, 1984). Wetlands, according to a definition by Cowardin and others (1979), occur where substrates are periodically wet enough to produce anaerobic, or oxygen-deficient, conditions in the soils. Thus, topographically low flats supporting *Opuntia* would be excluded from the wetland or marsh category. Other site-specific data that provide evidence that a site has a shallow water table or periodic standing water are the presence of mud-shrimp and crab burrows, algal mats, and desiccation cracks. Because field data on all sites are impractical to collect in such an extensive mapping project, interpreting and extrapolating data from aerial photographic signatures that have been verified in the field are necessary to determine which areas constitute wetlands. Interpretation and delineation of upper marsh boundaries using aerial photographs cannot, however, substitute for on-the-ground, site-specific data supported by seasonal field surveys.

Following is a discussion of the wetland and associated units mapped in the Kingsville area. Six of the mapped environments are generally barren of vegetation, and 11 are characterized by vegetation communities (table 17). Examples of areas typically barren or sparsely covered by vegetation (higher order plants) are beaches, washover areas, and wind-tidal flats; areas defined by vegetation include marine grassflats and salt-, brackish-, and fresh-water marshes. Typical plants found in various wetland environments are listed in table 19.

Beaches

Gulf beaches in the Kingsville area lie between the Gulf shoreline and the edge of fore-island dunes. The beach can be subdivided into the more frequently inundated forebeach, flooded by the periodic rise and fall of astronomical tides, and the less frequently inundated backbeach, flooded during abnormal events, such as storms, when wind and low atmospheric pressure elevate Gulf waters. The forebeach is typically barren of vegetation, whereas the backbeach, along its landward edge, may contain scattered coppice dunes and salt-tolerant plants. Common plants on the backbeach are *Sesuvium portulacastrum, Ipomoea pes-caprae, Ipomoea stolonifera,* and *Spartina patens.* Vegetation encroaches farther toward the forebeach in areas where there is little vehicular traffic.

Washover Areas

Washover areas (figs. 39 and 40), which include storm channels and portions of the washover fans that lie bayward of the channels, are barren sand flats subject to rapid inundation and intense wave and current energy during hurricanes and tropical storms (Hayes, 1967; Andrews, 1970; McGowen and others, 1970; Brown and others, 1974). The dynamic nature of these environments prevents them from becoming colonized by vegetation except locally along their margins and on small coppice dunes. In these areas, scattered stands of salt-tolerant plants such as *Salicornia* sp., *Batis* sp., *Distichlis* sp., *Monanthochloe* sp., and *Sesuvium* sp. occur. In higher fringing areas, *Spartina patens, Spartina spartinae, Ipomoea* spp., and *Croton punctatus* occur. Active (barren) washover areas are widely distributed in the southern half of the Kingsville map area. Relict washover channels that have gained some protection through the formation of continuous to discontinuous fore-island dunes or berms are more densely vegetated and, depending on the degree of isolation from Gulf waters, may contain a brackish- to fresh-water assemblage. These areas have been mapped as marshes.

***Figure 39.* Oblique aerial photograph of the Gulf beach and washover channel/fan complex on Padre Island. Washover channel connects to broad wind-tidal flats (in distance) on the lagoonward side of Padre Island.**

Sand and Mud Flats (Low and High Wind-Tidal) and Fluvial-Channel Deposits

Lying slightly higher in elevation than shallow subaqueous flats are low wind-tidal sand and mud flats, which are subject to relatively frequent flooding by wind tides. The frequency of flooding cannot be expressed quantitatively because of limited field data, but generally these flats are characterized by wet surfaces, blue-green algal mats, or both (fig. 41). On the mainland side of Laguna Madre (and on the Intracoastal Waterway), flats commonly have substrates containing more mud than sand and thus are more accurately described as mud flats. These flats are source areas for clay dunes that are formed on the leeward sides of the flats or depressions (Price, 1958).

Lying topographically above the frequently flooded wind-tidal flats are less frequently flooded high wind-tidal sand flats that grade into upland

Table 19. Typical plants found in wetland environments mapped in the Kingsville area.*

Unit	Scientific name	Common name
GRASSFLAT (subaqueous marine grasses)	*Halodule beaudettei*	shoalgrass
	Halophila engelmannii	clovergrass
	Ruppia maritima	widgeongrass
	Cymodocea filiformis	manatee grass
SALT-WATER MARSH	*Batis maritima*	saltwort
	Salicornia virginica	glasswort
	Salicornia bigelovii	glasswort
	Distichlis spicata	seashore saltgrass
	Borrichia frutescens	sea-oxeye
	Monanthochloe littoralis	shoregrass
	Suaeda spp.	seablite or seepweed
	Lycium carolinianum	Carolina wolfberry
	Heliotropium curassavicum	salt heliotrope
	Spartina spartinae	gulf cordgrass, sacahuista
	Spartina patens	marshhay cordgrass
	Iva spp.	sumpweed
	Limonium nashii	sea-lavender
	Sporobolus spp.	dropseed
	Sesuvium portulacastrum	sea purslane
	Avicennia germinans	black mangrove
BRACKISH-WATER MARSH	*Spartina spartinae*	gulf cordgrass, sacahuista
	Borrichia frutescens	sea-oxeye
	Distichlis spicata	seashore saltgrass
	Monanthochloe littoralis	shoregrass
	Scirpus americanus	three-square bulrush
	Scirpus californicus	California bulrush
	Scirpus maritimus	salt-marsh bulrush
	Typha domingensis	narrowleaf cattail, tule
	Eleocharis spp.	spikerush
	Cyperus spp.	flatsedge
	Bacopa monnieri	coastal waterhyssop
	Aster spinosus	spiny aster
	Paspalum spp.	paspalum
	Iva spp.	sumpweed
	Fimbristylis castanea	fimbry
	Salicornia spp.	glasswort
	Suaeda spp.	seablite or seepweed
	Limonium nashii	sea-lavender
	Lycium carolinianum	Carolina wolfberry
	Sporobolus spp.	dropseed
	Spartina patens	marshhay cordgrass
	Hydrocotyle spp.	marsh pennywort
FRESH-WATER MARSH	*Spartina spartinae*	gulf cordgrass, sacahuista
	Typha domingensis	narrowleaf cattail, tule
	Scirpus americanus	three-square bulrush
	Scirpus californicus	California bulrush
	Paspalum spp.	paspalum
	Eleocharis spp.	spikerush
	Cyperus spp.	flatsedge
	Aster spinosus	spiny aster
	Ludwigia spp.	seedbox
	Polygonum spp.	knotweed, smartweed
	Sagittaria sp.	arrowhead
	Bacopa monnieri	waterhyssop
	Juncus spp.	rush
	Echinodorus spp.	burrhead
	Lemna spp.	duckweed
	Hydrocotyle spp.	marsh pennywort
	Sesbania drummondii	rattlebush
	Salix nigra	black willow
	Parkinsonia aculeata	retama
TRANSITIONAL AREAS AND VEGETATED SALINE FLATS	*Spartina spartinae*	gulf cordgrass, sacahuista
	Borrichia frutescens	sea-oxeye
	Cynodon dactylon	bermuda grass
	Monanthochloe littoralis	shoregrass
	Salicornia spp.	glasswort
	Batis maritima	saltwort
	Suaeda spp.	seablite or seepweed
	Lycium carolinianum	Carolina wolfberry
	Paspalum spp.	paspalum
	Panicum spp.	panicum
	Andropogon glomeratus	bushy bluestem
	Andropogon sp.	bluestem
	Iva spp.	sumpweed
	Aristida spp.	threeawn
	Setaria spp.	bristlegrass
	Helianthus spp.	sunflower
	Sorghum halepense	johnsongrass
	Cyperus spp.	flatsedge
	Eleocharis spp.	spikerush
	Croton spp.	doveweed
	Baccharis sp.	groundsel bush
	Cassia fasciculata	partridge pea
	Scirpus spp.	bulrush
	Sesbania drummondii	rattlebush
FLUVIAL AND FLOOD-PRONE WOODLANDS	*Parkinsonia aculeata*	retama
	Acacia farnesiana	huisache
	Tamarix gallica	salt cedar
	Salix nigra	black willow
	Celtis spp.	hackberry/sugarberry
	Sapium sebiferum	chinese tallow
	Fraxinus sp.	ash
	Ulmus crassifolia	cedar elm

*List compiled from field work and with reference to Johnston (1955), Gould and Box (1965), Correll and Correll (1975), Jones (1975), and Baccus and Horton (1979). Plants are listed in approximate order of prominence for the map area.

Figure 40. **Water-filled washover channel on Padre Island. Gulf of Mexico and beach are to the left; fore-island dune ridge can be seen across the channel.**

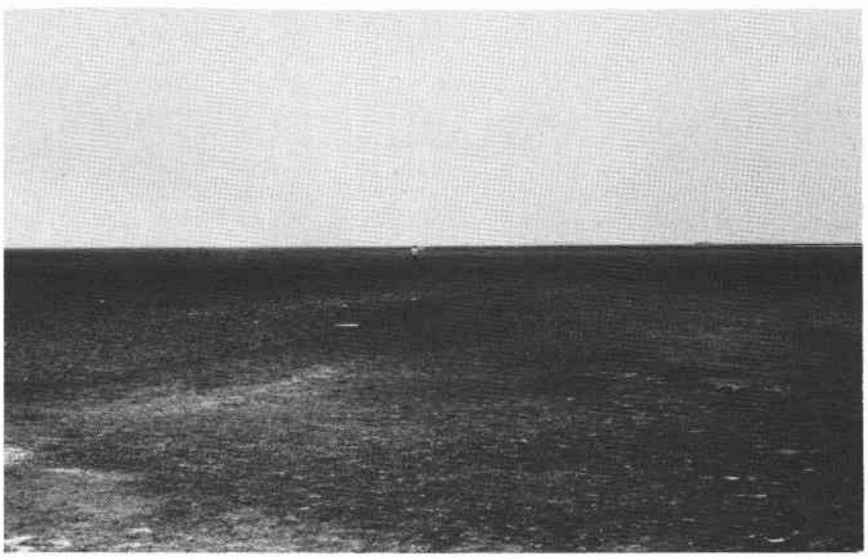


Figure 41. **Wind-tidal flat covered with algal mats on the lagoonward side of Padre Island. Person photographed indicates the vastness of sand and mud flats in this South Texas region.**

areas. These higher wind-tidal flats are better drained and are defined by a drier surface layer of sand, mud, or muddy sand. These flats and the upland areas into which they grade are inundated during storms. Included within the higher sand-flat unit are (1) wind-deflation flats and storm runnels on the barrier islands (Brown and others, 1977), which are flooded by storm tides, and (2) fluvial-channel deposits that include barren channel margins, flats, and bars along the various creeks that drain into the Baffin-Alazan Bay system. On the mainland, barren flats also occur in areas adjacent to inland saline flats and water bodies far from lagoon waters. For cartographic simplicity, these barren flats, although unaffected by wind tides influencing the

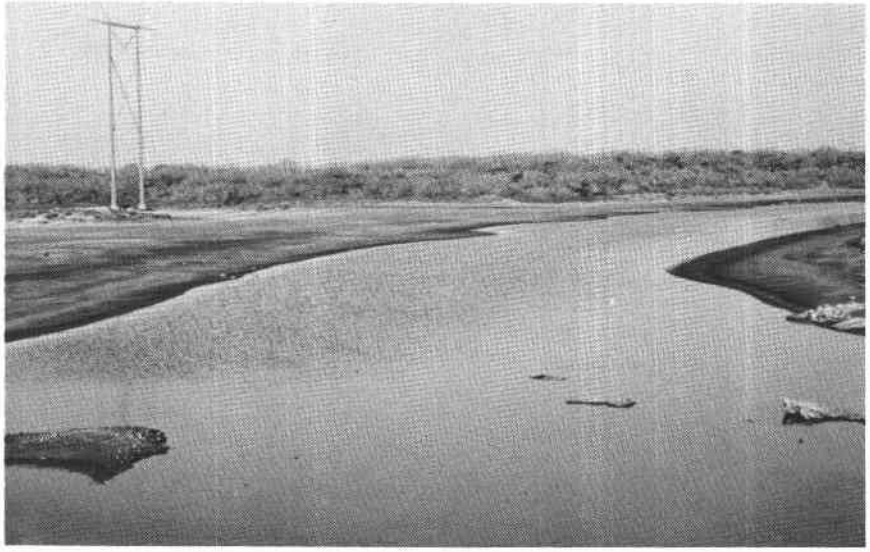


***Figure 42.* Tidally influenced channel along an intermittent stream that discharges at the head of Cayo del Grullo south of Santa Gertrudis Creek.**

bay and lagoon system, are mapped with the high wind-tidal flat units.

Wind-tidal flats and higher flats are generally barren because of intermittent salt-water flooding, ponding, and subsequent evaporation—a process that concentrates salts and inhibits the growth of most plants. Where evaporation rates exceed precipitation rates, such as in the Kingsville area (which has the greatest areal extent of wind-tidal flats), these evaporitic wind-tidal basins fit the classification of sabkhas (Kinsman, 1969; Herber, 1981). Wind-tidal flats may locally have scattered salt-water-marsh vegetation, particularly along tidal channels that fill and drain the flats. Common plant species are *Salicornia virginica, Salicornia bigelovii, Batis maritima, Suaeda* spp., *Monanthochloe littoralis,* and *Heliotropium curassavicum.*

Shallow Subaqueous Flats, Tidal Pools, Inland Reservoirs and Ponds, and Channels

Shallow subaqueous flats were delineated as water (pl. V) where water depths indicated that the flats are more frequently submerged than not. However, some of these areas are shallow enough to occasionally become emergent (subaerial). Large, deeper tidal pools, inland reservoirs and ponds, and natural (fig. 42) and dredged channels are included in this map unit (pl. V). The tidal pools locally support submerged grasses such as *Ruppia maritima.*

Beaches and Berms along Bay-Estuary-Lagoon Margins

Barren sand beaches and shell beaches and berms that locally fringe the bay-estuary-lagoon shoreline were mapped because these areas are subject to inundation by either wind tides or storm tides. For the most part, they are relatively narrow features along bay margins. Although shell berms and sand beaches are mapped as a single unit, the shell berms are topographically higher features constructed by storm waves that pile shell debris at levels out of reach of the daily tides and waves. Only barren areas are included in this map unit. Where beaches and berms are low enough and extensively vegetated with marsh plants, they are mapped as marshland.

Grassflats

The distribution of marine grasses (grassflats) was determined primarily from aerial photographs but also by referring to sample descriptions made in the field and to live benthic macroinvertebrates identified in sediments taken

Figure 43. **Oblique aerial photograph of grassflats in Laguna Madre near the Intracoastal Waterway. Islands have been formed by spoil disposal along a dredged channel that connects to the Intracoastal Waterway shown at the top of the photograph.**

from submerged lands. Although this map unit consists primarily of areas relatively densely vegetated with marine grasses, it also includes areas of moderate to sparse vegetation. Grassflats are widely distributed in the Kingsville area (fig. 43; pl. V). Plant species in grassflats include the following spermatophytes: *Halodule beaudettei, Halophila engelmannii, Ruppia maritima,* and *Cymodocea filiformis.* More information on grassflats appears in the section Macroinvertebrate Assemblages (p. 58).

Salt-Water Marshes

Salt-water marshes were defined principally on the basis of (1) vegetation communities, (2) proximity to tidal channels and open waters of the bay-estuary-lagoon system, and (3) soil and surface moisture as determined by photographic analysis. The small tidal range along the Gulf coast generally prevents the establishment of distinct and extensive high- and low-marsh environments, as defined along the Atlantic coast. Yet attempts were made to differentiate areas that are more frequently flooded because of lower elevations and proximity to open water (proximal salt-water marshes; fig. 44) from those areas less frequently flooded because of higher elevations and distal locations with respect to bay-estuary-lagoon water (distal salt-water marshes; fig. 45). Proximal salt-water marshes commonly contain one or more of the following species: *Batis maritima, Salicornia virginica, Salicornia bigelovii, Distichlis spicata, Borrichia frutescens, Monanthochloe littoralis, Suaeda* spp., *Lycium carolinianum, Sesuvium portulacastrum,* and *Avicennia germinans.* Many species grow in a range of elevations and occur in both distal and proximal assemblages. *Spartina alterniflora* is abundant in the proximal community along the upper Texas coast but is apparently absent in the Kingsville area. Black mangroves (*Avicennia germinans*), evergreen shrubs no taller than 3 to 6 ft (1 to 2 m), occur scattered along bay margins of Padre Island and on spoil islands that border the Intracoastal Waterway (Sherrod and McMillan, 1981).

Plant species present in the distal community include many of those listed for proximal areas, but the order and dominant type vary. *Borrichia frutescens, Monanthochloe littoralis, Distichlis spicata, Suaeda* spp., *Heliotropium curassavicum,* and *Iva* spp. are more common. Species such as *Spartina spartinae* and *Spartina patens,* which are more characteristic of brackish-water marshes (table 19), are scattered overall but

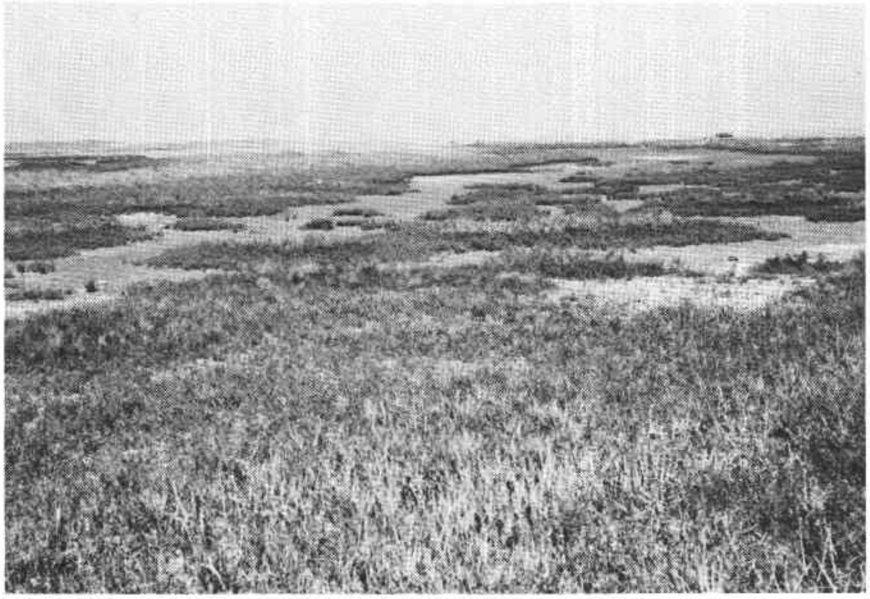


Figure 44. **Proximal salt-water marsh on the western margin of the head of Cayo del Grullo. *Batis maritima* and *Salicornia* spp. are abundant on lower flats and grade into higher marginal areas of *Monanthochloe littoralis, Suaeda* sp., *Distichlis spicata, Lycium carolinianum,* and *Borrichia frutescens. Spartina spartinae* is mixed with other species in surrounding transitional areas.**

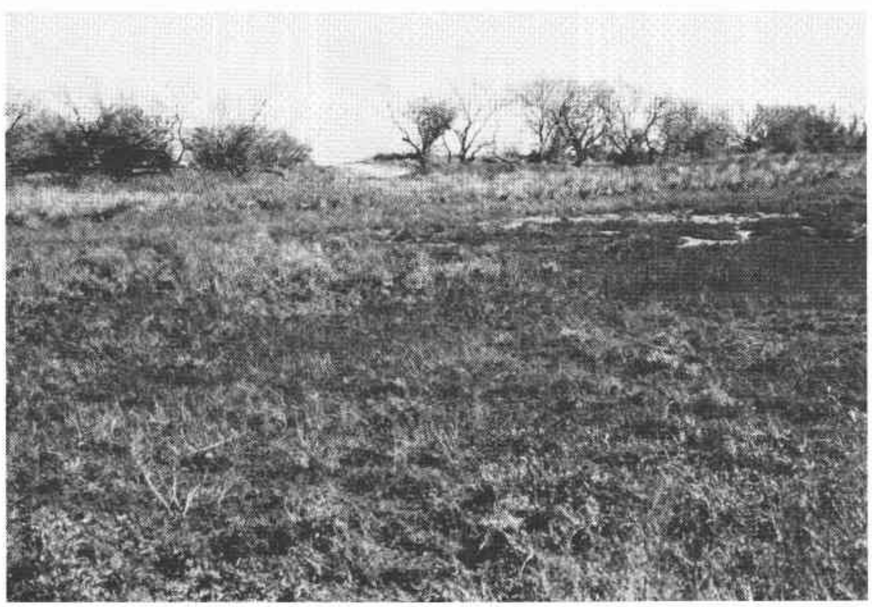


Figure 45. **Distal salt-water marsh behind a protective upland ridge along the western margin of Cayo del Grullo north of Loyola Beach. At lower elevations, *Salicornia* spp. and *Batis maritima* are common, grading at slightly higher elevations into areas of *Monanthochloe littoralis, Borrichia frutescens,* and scattered *Lycium carolinianum* and *Limonium nashii,* and at still higher elevations, into areas of *Spartina spartinae.***

Figure 46.* Low brackish-water marsh around ponds above the margin of Santa Gertrudis Creek near Kingsville Naval Air Station. Vegetation species in this area include *Typha* sp., *Aster spinosus,* and *Scirpus americanus,* and in adjacent areas along the creek, *Borrichia frutescens.

locally abundant. Distal marshes locally grade into vegetated saline flats.

Brackish-Water Marshes

Brackish-water marsh environments usually occur inland from salt marshes and are transitional between the salt-water and fresh-water marshes. These areas, influenced by storm-tidal flooding from bay-estuary-lagoon waters and by fresh-water inundation from rivers, runoff, or ground water, contain a mixed-vegetation assemblage, including some species that are typical of salt-water-marshes and some that are typical of fresh-water marshes. Although the breaks between salt-, brackish-, and fresh-water marshes are shown along distinct lines on the map (pl. V), the boundaries are actually gradational and their widths may vary. Brackish-water marshes are subdivided into two units: (1) areas characterized by relatively frequent inundation, as denoted by vegetation types and soil moisture or by standing surface water ("low" marshes; fig. 46) and (2) areas that appear to be less frequently flooded, having a drier wetland-plant assemblage and less soil and surface moisture ("high" marshes, fig. 47). Among the plants found in the lower marshes are *Scirpus* spp., *Eleocharis* spp., *Paspalum vaginatum,* and *Typha* sp. These lower marshes grade into saline to brackish flats of *Monanthochloe littoralis, Salicornia* spp., *Batis maritima,* and *Distichlis spicata* and into higher assemblages of *Spartina spartinae, Spartina patens, Borrichia frutescens, Iva* spp., *Sporobolus* sp., *Limonium nashii,* and others (table 19).

In many places, the distinction between brackish- and salt-water marshes occurs where *Spartina spartinae* and *Borrichia frutescens* become significant components of the brackish marsh; fresher water species such as *Scirpus americanus, Scirpus californicus,* and *Typha* sp. may occur in wetter areas. As with salt-water marshes, high brackish-water marshes may grade almost imperceptibly into vegetated saline flats.

Fresh-Water Marshes

Fresh-water marshes occur inland along river or fluvial systems and in upland-surrounded basins and depressions (fig. 48). Environments in which fresh marshes occur are generally beyond the limits of salt-water flooding except perhaps during hurricanes. The fresh-water influence from rivers, precipitation, runoff, and ground water is sufficient to maintain a fresher

***Figure 47.* High brackish-water marsh along Santa Gertrudis Creek, located across road from site shown in figure 46. *Borrichia frutescens* is predominant in this area.**

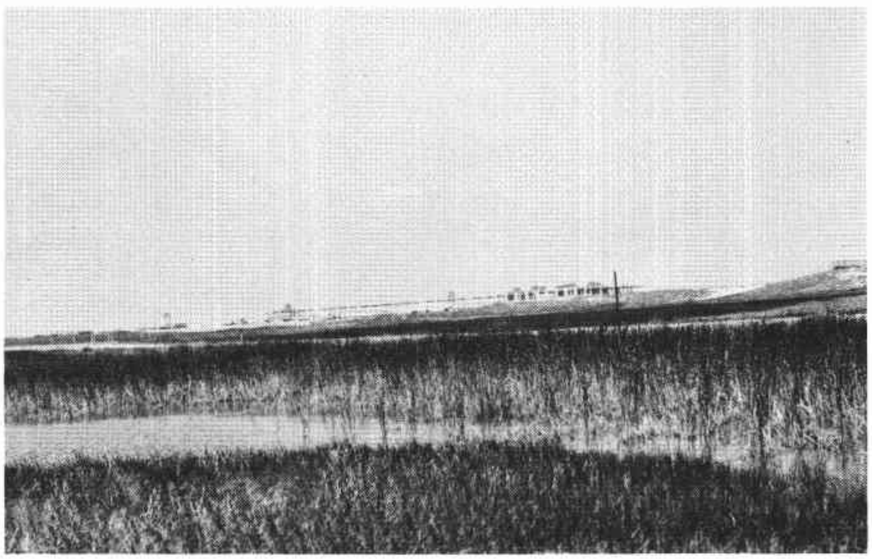


***Figure 48.* Low fresh-water marsh in a deflation trough or flat on Padre Island near Malaquite Beach (in distance). *Typha* sp., *Scirpus americanus,* and *Eleocharis* spp. are common species in areas like this one.**

water vegetation assemblage consisting of species such as *Typha* sp., *Scirpus americanus, Scirpus californicus, Eleocharis* spp., *Cyperus* sp., *Bacopa monnieri, Ludwigia* sp., and *Paspalum lividum* in wetter areas ("low" marshes, fig. 48). The drier areas ("high" marshes, fig. 49) are typified by such species as *Spartina spartinae, Paspalum* sp., *Polygonum* spp., *Aster* sp., scattered *Scirpus* spp., and *Cyperus* spp. Shrubs such as *Sesbania drummondii, Parkinsonia aculeata,* and *Salix nigra* are scattered around the margins of some fresh-water marshes.

***Figure 49*. High fresh-water marsh in a depression on the King Ranch north of Baffin Bay. The dominant species in this area is *Aster spinosus*.**

Many vegetation species characterizing the brackish-marsh assemblage also grow in areas mapped as fresh-water marsh. Some species, such as *Spartina spartinae,* occur in salt-, brackish- and fresh-water marshes along the Gulf as well as inland. Drier fresh-water marshes grade (often subtly) into transitional areas, which also may be vegetated by *Spartina spartinae. Spartina spartinae* apparently exists within a relatively broad range of elevations and moisture levels. Although the frequency of flooding necessary to sustain this assemblage to the exclusion of others is unknown, the assemblage apparently requires periodic inundation (McAtee, 1976). McAtee (1976) noted that *Spartina spartinae* flourishes at an elevation between lowland marshes and higher uplands. Johnston (1955) noted that *Spartina spartinae* occurs above communities of *Borrichia, Batis,* and *Monanthochloe.* Fleetwood (1973) reported that *Spartina spartinae* in Laguna Atascosa National Wildlife Refuge (Brownsville-Harlingen area) covers hundreds of acres of low, salty, poorly drained soils where the water table is within 2 to 4 ft (0.6 to 1.2 m) of the surface; after storms and heavy rainfall, depressions are often filled with fresh water. The homogeneity of these assemblages and their relationship to the water table produce a definite mappable "signature" (color, hue, and texture) on color-infrared photographs. *Spartina spartinae* also occurs in transitional areas and is mixed with upland species at slightly higher elevations.

Sand or Mud Flats/Marshes, Undifferentiated

This unit depicts sand or mud flats that have become colonized by marsh vegetation covering about 30 to 60 percent of their area. The unit is termed "undifferentiated" because no attempt was made to map separately marsh vegetation and barren sand flats. Separating the vegetation from the flats at the mapping scale (1:125,000) would have been too difficult because of the complex configuration of these areas.

The plants occupying these areas are commonly *Salicornia* spp., *Batis maritima, Suaeda* spp., *Monanthochloe littoralis, Borrichia frutescens, Heliotropium curassavicum, Limonium nashii,* and *Lycium carolinianum,* but others are also locally abundant. Where elevations are slightly higher on sand mounds and small dunes, *Spartina spartinae, Spartina patens,* and other species may occur. Inland deflation flats, away from bay and lagoon waters, are characterized by fresh- to brackish-water marsh plants (table 16).

***Figure 50.* Transitional area or vegetated saline flat grading into topographically lower areas of brackish-water marsh along U.S. Highway 77 south of Kingsville. Vegetation includes *Monanthochloe littoralis* and *Spartina spartinae*.**

Wetland/Upland Areas, Undifferentiated

These mapped environments are undifferentiated mixtures of wetland/upland areas typically characterized on the mainland by numerous small depressions (generally less than 130 ft [40 m] in diameter) containing water, fresh-water marshes, or transitional areas, surrounded by upland dunes or lag ridges. Along bay-lagoon margins of the mainland and barrier islands, this environment consists of hummocky upland areas (dunes and mounds) surrounded by either wind-tidal flats or salt- to brackish-water marshes or both. The complex configurations of these areas generally precluded separation of wetlands from uplands at the mapping scale used, yet the overall areal distribution and importance of the wetlands encompassed by this unit are significant.

Vegetation in the depressions on the mainland is widely varied; it is difficult to list the species that characterize a typical depression. Generally, the depressions are the result of deflation; deeper ones are usually filled with water, whereas those that are infrequently wet support a transitional community composed of wetland and wet-meadow to prairie species.

Transitional Areas and Vegetated Saline Flats

Transitional areas and topographically low, vegetated saline flats as defined in this report are those that, in terms of flooding and plant communities, lie between wetland and upland areas (fig. 50). They are occasionally inundated but with less frequency and duration than are marshes. Generally, transitional areas contain a mixture of wetland plants and upland prairie grasses and shrubs, although they may locally contain species that are able to exist in either wet or dry conditions. The "signature" denoted on color-infrared photographs is transitional between upland and wetland signatures. Wetland species present are similar to those occurring in drier areas of fresh-, brackish-, and salt-water marshes. No attempt was made to differentiate fresh-water transitional areas from brackish-water or salt-water transitional areas. The predominant species in many areas is *Spartina spartinae* (refer to discussion on fresh-water marshes, p. 78). Other representative species are listed in table 19. Scattered shrubs include *Parkinsonia aculeata, Acacia farnesiana,* and *Sesbania* spp.

Figure 51.* Woodlands on the margins of a fresh-water pond southwest of Kingsville. The dominant tree in this area is *Acacia farnesiana.

The dilemma of separating vegetated saline flats (fig. 50) from marshes was discussed in the introductory comments in this section on wetlands in the Kingsville area (p. 71). The difficulty is that vegetation species such as *Monanthochloe littoralis, Borrichia frutescens,* and others that are typical of salt marshes also occur on the saline flats. Johnston (1955) recognized varying communities at different elevations. At the strandline or lowest elevation, a community of *Batis, Salicornia,* and *Suaeda* grades almost imperceptibly into slightly higher elevations characterized by *Borrichia, Batis,* and *Monanthochloe,* which in turn grade upward into a community of *Spartina spartinae.* Differentiation of marshes and saline flats is based principally on an interpretation of photographic signatures that is supported by spot field surveys.

Woodlands in Fluvial Areas and in Poorly Drained Depressions

Areas along the floodplains of streams or along the margin of channels that support assemblages of water-tolerant trees and shrubs were delineated as fluvial woodlands (fig. 51). These areas are distinguishable on aerial photographs by slight color variations, which indicate wetter conditions in the fluvial woodlands than in adjacent topographically higher woodlands. Woodlands at the higher elevations may occasionally be flooded but usually not as often as their mapped counterparts.

Fluvial woodlands include such trees and shrubs as *Parkinsonia aculeata, Acacia farnesiana, Tamarix gallica, Salix nigra, Celtis* spp., *Sapium sebiferum, Fraxinus* sp., and *Ulmus crassifolia.*

In many areas, modern and ancient depositional and erosional processes have produced depressions that occasionally pond water and support woodland assemblages of trees and shrubs. Water-tolerant trees associated with the depressions include those found in fluvial areas. Moisture that sustains the woodland assemblages in these poorly drained depressions comes from precipitation runoff and ground water. Origins of the depressions range from abandoned stream channels to deflation troughs or flats that are common on the eolian plain in the Kingsville map area. Woodlands associated with manmade ponds, reservoirs, and stock tanks also are shown on the map.

MAJOR WETLAND AREAS IN RELATION TO DEPOSITIONAL SYSTEMS AND GEOGRAPHIC LOCATION

Wetlands Associated with Modern-Holocene Fluvial Systems

Modern-Holocene fluvial systems are not significant depositional features in the coastal plain in the Kingsville area. Fluvial systems in this area are made up of small, ephemeral, headward-eroding streams (creeks) (Brown and others, 1977). The creeks are located on the northern one-third of the map area and discharge into the Baffin-Alazan Bay system, which developed within valleys that were incised during lower stands of sea level and were subsequently flooded when sea level rose. The incised valleys have been progressively filled by Holocene and Modern fluvial, estuarine, tidal, and open-marine sedimentation (Brown and others, 1977). Marsh-covered bay-head deltas like those that occur at the mouths of larger rivers in other areas along the Texas coast (fig. 1) have not developed in the Kingsville area. Instead, the heads of the bays are characterized by relatively broad sand and mud flats (wind-tidal) with scarce marsh vegetation. Stream discharge is intermittent, and deposition of sediments occurs primarily during periods of high discharge associated with tropical storms and hurricanes. Depositional processes on the sandy flats at the bay heads are similar to those on fan deltas and lacustrine deltas where braided channels deposit high-bed-load sediments in shallow bays (Brown and others, 1977). Between floods, eolian and wind-tidal processes modify the deposits on the flats. As Brown and others (1977, p. 54) observed about Baffin Bay, the bay-head deltas "undergo short periods of rapid deposition or construction followed by long periods of eolian and wind-tidal modification and destruction."

San Fernando and Santa Gertrudis Creeks

Extensive wind-tidal flats occur near the mouth of San Fernando Creek at the head of Cayo del Grullo. The tidal flats are essentially barren of spermatophytes. Salt-water marshes that occur near the head of Cayo del Grullo are restricted to small protected areas, primarily along the western shore northwest of Loyola Beach (pl. V). Marsh vegetation includes *Distichlis spicata, Borrichia frutescens, Monanthochloe littoralis, Spartina spartinae, Lycium carolinianum,* and *Limonium nashii,* grading into topographically lower areas of *Salicornia* spp. and *Batis maritima* (figs. 44 and 45). Johnston (1955) reported that in South Texas the *Batis-Salicornia-Suaeda* community occurs at lowest elevations (at the strandline), the *Borrichia-Batis-Monanthochloe* community at slightly higher elevations, and the *Spartina spartinae* community above it.

Salinity of the bay water adjacent to the marshes at the head of Cayo del Grullo was about 32 parts per thousand (ppt) on February 18, 1986, but salinities can become substantially higher (Breuer, 1957; Behrens, 1966). Behrens (1966) concluded that under normal conditions salinities in Baffin Bay are between 40 and 50 ppt (fig. 10). Russell (1986) reported salinities between 50 and 60 ppt in open-bay water of the Baffin Bay system during 1970, 1978, and 1980. The high salinities inhibit the growth of marsh plants, resulting in the extensive wind-tidal flats that are the dominant features along the creeks from the bay-head waters to approximately 5 mi (8 km) upstream, where marsh vegetation has become established in scattered stands. Farther upstream, near the confluence of San Fernando and Santa Gertrudis Creeks, marsh vegetation becomes more abundant (pl. V), presumably because of decreasing salinities. Along San Fernando Creek north of the Kingsville Naval Air Station, salinities measured in the creek in February 1986 were less than 5 ppt. Vegetation on the floodplain along the creek in this area includes *Aster spinosus, Borrichia frustescens,* and *Spartina spartinae. Acacia farnesiana* is an abundant tree or shrub along the creek. Fluvial woodlands, transitional areas, and barren sand and mud flats are the predominant units mapped in inland areas along San Fernando Creek, although marshes and water bodies occur locally (pl. V). Vegetation in fluvial woodlands includes *Acacia farnesiana, Parkinsonia aculeata,* and *Celtis* sp., among others listed in table 19.

Near the mouth of Santa Gertrudis Creek, barren flats and scattered salt-water marshes occur. Farther upstream in the area south of the Kingsville Naval Air Station, brackish-water marshes characterize the creek. Salinities along the creek in February 1986 were about 8 ppt. Vegetation in this area includes abundant *Borrichia frutescens* (fig. 47), and *Typha* sp. and *Scirpus americanus* occur around a pond adjacent to the creek (fig. 46). The salinity in the pond on

February 17, 1986, was about 3.5 ppt. Scattered *Parkinsonia aculeata* occurs on higher ground near the pond and creek.

Among the other creeks that intermittently discharge at the head of Cayo del Grullo is Jarachinal Creek, located south of Santa Gertrudis Creek (fig. 4). The creek extends inland beyond U.S. Highway 77. Along the lower reaches of the creek, salinities are high— exceeding 40 ppt on February 17, 1986. The creek is characterized primarily by relatively broad barren flats and by vegetation on slightly elevated, localized terraces. Farther upstream, transitional areas or vegetated saline flats and local marshes occur in conjunction with barren sand and mud flats along the creek bed. Vegetation includes *Monanthochloe littoralis, Suaeda* sp., *Salicornia* spp., *Borrichia frutescens, Distichlis spicata,* and at higher elevations, *Spartina spartinae.* Several miles farther inland (across U.S. Highway 77), marshes and sand and mud flats occur along and near the creek. Locally, salinities are relatively high in these more inland areas. For example, about 2 mi (3.2 km) inland from the highway, the salinity of water in a pond/marsh complex was about 20 ppt on February 18, 1986. Marsh vegetation in this area included *Borrichia frutescens, Lycium carolinianum, Aster spinosus,* and scattered *Sesbania* sp. Less than 0.5 mi (0.8 km) inland from this location, the salinity in water associated with a marsh was 3 ppt. Vegetation includes abundant *Eleocharis* sp., some *Typha* sp., and scattered *Borrichia frutescens* and *Sesbania* sp. Both areas were mapped as brackish-water marshes. Salinities at these two sites suggest that other marsh systems along this intermittent stream (Jarachinal Creek) are also brackish.

Variations in salinities along intermittent creeks may be the result of ground-water discharge into these topographic lows or drainage ways. Shallow ground water (water table) in the Kingsville area is moderately to very saline (brine), and seepage inflow into ponds can measurably increase salinities of the ponded water (Baker, 1971); this relationship between ground water and ponded water is discussed in more detail in the section Modern-Holocene Eolian System (p. 89). Higher salinities also may be partly the result of past oil field operations and associated disposal of brine, which increases the salinity of some drainageways (Texas Department of Water Resources, 1983). Discharge of brine along lower reaches of some creeks is still permitted. For example, Russell (1986) reported that 1.3 million gallons per day of salt water produced in association with oil is disposed of along Petronilla Creek, which discharges into Alazan Bay.

Los Olmos Creek

Los Olmos Creek discharges into Laguna de los Olmos at the head of Laguna Salada (fig. 4). This bayhead area, much like the head of Cayo del Grullo, is characterized by barren wind-tidal flats of sand and mud (pl. V). Marshes are rare, although a narrow band of marsh vegetation occurs along a sand and shell spit that projects westward into Laguna de los Olmos (pl. V). Marsh vegetation in this area includes *Monanthochloe littoralis, Suaeda* sp., *Batis maritima, Distichlis spicata,* and scattered *Limonium nashii, Borrichia frutescens,* and *Salicornia* sp. Salinity in Laguna de los Olmos at this location was about 36 ppt on February 18, 1986. Marine grasses occur in much of the submerged portion of the lagoon and extend in a narrow belt along the northern margin of Laguna Salada (pl. V).

Inland along the lower reaches of Los Olmos Creek, sand and mud flats affected by wind-generated tides occur along the creekbed and on terraces adjacent to the creek. Salinity along the creek at U.S. Highway 77 on February 18, 1986, was about 23 ppt. Inland from U.S. Highway 77, the creek is more entrenched and less affected by tides. This area is characterized locally by small water bodies and primarily by a V-shaped valley, which has a narrow stream at the bottom.

Tunas and Petronilla Creeks

Tunas and Petronilla Creeks discharge into Alazan Bay. Only a small portion of Petronilla Creek occurs in the study area; most of the creek is located in the Corpus Christi area to the north. Between the mouth of the creeks and Alazan Bay are extensive wind-tidal sand and mud flats that are the principal features constituting Cayo de Hinosa and Cayo del Mazon (pl. V). As in the other bays, marsh vegetation is rare on the flats at the bay heads. Marshes that do occur are located at higher elevations on localized terraces or depressions that are somewhat protected from the high salinities that characterize the bay water and associated wind-tidal flats. Salinities along Petronilla Creek are high in part because of brine disposal. Jensen and Shipley (1986) reported about 18 oil field brine discharge sites located along Petronilla Creek above the estuarine mixing zone (north of the Kingsville study area). The salinity measured along Tunas

Creek near the northern boundary of the study area was greater than 40 ppt (maximum reading on the instrument used) on February 19, 1986. Salinities in this creek are also affected to some degree by permitted disposal of brine from oil production. Marsh vegetation occurs along more inland stretches of Tunas Creek; initial occurrences are in scattered patches (mapped on pl. V as sand and mud flats/marshes, undifferentiated). Farther upstream the vegetation becomes more abundant and covers broader areas of the creekbed. Vegetation includes many of the species listed under salt-water marshes in table 19. Transitional areas and marshes also occur along several short, intermittent tributaries connected to Tunas Creek. Near the mouths of the tributaries, barren flats are common; toward the heads of these small, locally dendritic drainage systems, transitional areas and marshes are the predominant units mapped (pl. V).

Barrier-Strandplain System

The modern barrier system in the Kingsville area is made up of Padre Island, which extends from the northern to the southern boundary of the study area (fig. 4). The Pleistocene barrier-strandplain system, termed the Ingleside barrier by Price (1933), is well preserved only at the northernmost part of the Kingsville area that is inland from the mainland shore of Laguna Madre (fig. 9). It has been extensively modified by eolian activity, and its original extent south of Baffin Bay can only be estimated (Brown and others, 1977).

Modern Barrier Island

Environments associated with Padre Island have been mapped and described by Brown and others (1977) and Weise and White (1980). In these reports, broad expanses of vegetated flats and intervening fresh- and brackish-water marshes, lying between the fore-island dunes and back-island tidal flats, were mapped as vegetated barrier flats. During the late 1970's, and especially 1979 (the year the wetlands photographs were taken), above-normal precipitation produced higher than normal water tables and soil moistures on the barriers. Accordingly, fresh-water marshes became more numerous and extensive, as shown on northern Padre Island (plate V). Much of the vegetated barrier flat that surrounds the marshes and also occurs in other areas would fit the definition of transitional area used in this report. However, because of the complexity of showing transitional areas in conjunction with the marshes at the mapping scale used, these areas were not mapped on the barrier islands.

For this discussion, Padre Island can be subdivided into three segments in the Kingsville area: (1) a northern segment, between Yarborough Pass and the northern boundary of the study area, (2) a central segment, between Yarborough Pass and the southern tip of The Hole, and (3) a southern segment, between the southern tip of The Hole and the southern boundary of the map area.

Northern Padre Island.—Extensive fresh- to brackish-water marshes (mapped as fresh-water marshes on pl. V) occur on northern Padre Island. Active dunes that have migrated across the island (Hunter and Dickinson, 1970; Weise and White, 1980; fig. 52) have left behind numerous deflation flats and troughs that during the late-1970's wet cycle (figs. 5 through 7) contained abundant water-tolerant plants and hydrophytes. Typical of many areas are local ponds surrounded by wet, emergent zones (figs. 48 and 53) supporting *Typha* sp., *Scirpus americanus, Eleocharis* spp., and *Bacopa* sp. These low fresh-water marshes grade into higher, drier fresh-water marshes, where vegetation assemblages include *Spartina spartinae, Scirpus americanus,* scattered *Fimbristylis* spp., *Hydrocotyle* sp., *Andropogon* spp., *Cyperus* spp., and *Spartina patens.* Some fringing areas may support a more brackish water assemblage but for mapping are included with fresh marshes. The marshes become more brackish during periods of decreasing rainfall and increasing evaporation. Also, during drier periods, areas mapped as high, fresh-water marsh will probably become transitional between uplands and wetlands.

Toward Laguna Madre, brackish- and salt-water marshes are present, but their distribution is limited. On the northern half of this segment of Padre Island, large active dune fields characterize the lagoonward half of the island. Only a narrow, discontinuous wind-tidal flat separates the dune fields from Laguna Madre, where abundant marine grasses (grassflats), composed primarily of *Halodule beaudettei, Ruppia maritima,* and *Halophila engelmannii,* grow in the shallow water. On the southern half of this segment of northern Padre Island, inland from Little Shell Beach (pl. V), broader wind-tidal flats (fig. 41) occur in back-island areas. Active dunes and fresh- to brackish-water marshes are less extensive, with the exception of one marsh/pond

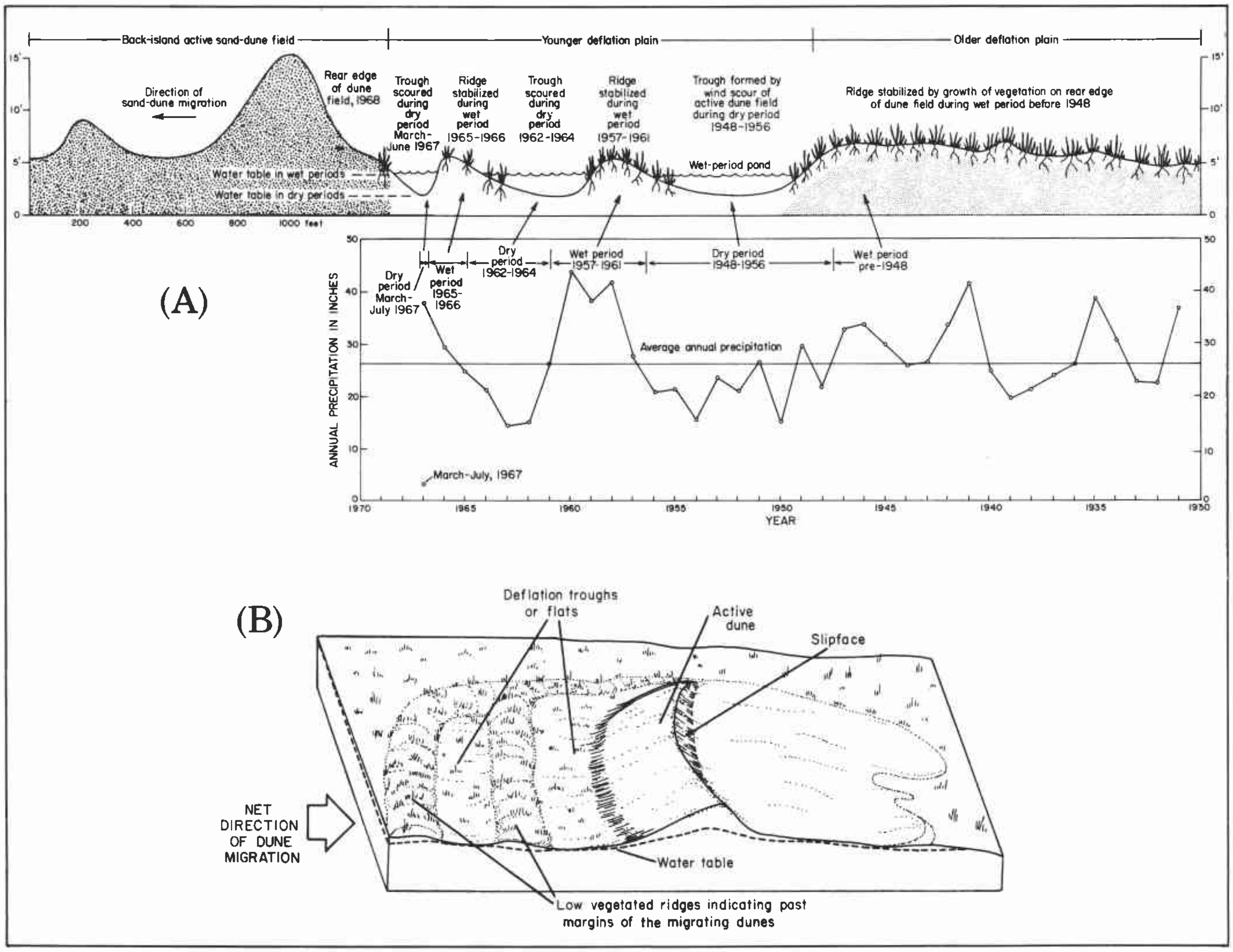


Figure 52. **(A) Diagrammatic cross section of deflation troughs and interlying stabilized ridges compared with a graph of rainfall (from Hunter and Dickinson [1970]); (B) Generalized sketch of an active dune and related deflation troughs (from Weise and White [1980]). Past positions of dune, which is migrating toward the right, are indicated by the deflation troughs and low vegetated ridges (past margins). Hydrophytes, such as *Scirpus americanus,* are common in the depressions.**

complex occurring in midisland about 2.5 mi (4 km) north of Yarborough Pass (pl. V). Water salinities in this area on February 21, 1986, averaged about 2.5 ppt. Common marsh species associated with standing water include *Scirpus americanus, Bacopa* sp., and *Typha* sp. On higher areas around the marsh, *Spartina patens* is abundant. South of this marsh to Yarborough Pass, scattered, more saline- to brackish-water marshes occur along the back margin of the vegetated barrier flat and locally intergrade with wind-tidal flats. *Monanthochloe littoralis* is a common species in these areas.

Central Padre Island.—This segment is characterized by a relatively narrow island that lacks fresh-water marshes. High brackish-water or distal salt-water marshes or both are more common along this part of the island (pl. V). Many of these marshes, shown on plate V, border on being transitional areas or vegetated saline flats instead of marshes. However, because transitional areas were not mapped on the barriers and because these marshes have signatures on the color-infrared photographs that contrast sharply with surrounding upland areas, they were mapped as topographically high marshes.

The areas are locally extensive, and vegetation commonly includes short stands of *Monanthochloe littoralis* and *Distichlis spicata* (fig. 54). As expected, a field survey of a few of these areas in 1986 showed some areas to be wetter than others. Algal mats were common, which indicates that these back-island areas are occasionally flooded, but the frequency of flooding is unknown. Wind-tidal flats along this segment of the island slope gradually toward the waters of Laguna Madre (including The Hole), where marine grasses are common.

Southern Padre Island.—Most of the southern segment of the barrier island in the Kingsville area occurs gulfward of the Land-Cut Area, which is characterized by a wind-tidal flat that extends several miles landward and is cut by the Intracoastal Waterway (fig. 4). This broad sand flat is largely the result of prevailing southeasterly winds that transport sands from Padre Island and fill the lagoon (Fisk, 1959). According to Fisk (1959), before the dredging of the Intracoastal Waterway, wind-driven tides would inundate the flats in the Land-Cut Area repeatedly during a year. He noted that during 1948, total inundation occurred 18 percent of the time, with flooding from the south being most common as a result of the northwest orientation of the lagoon, which is in alignment with the prevailing southeasterly winds. When the flats are moistened, blue-green algae flourish and produce a dense mat over the surface.

In addition to the broad wind-tidal flats, this segment of Padre Island is characterized by numerous hurricane washover channels and extensive back-island dune fields that intergrade with the wind-tidal flats onto which they are moving. Storm washover channels grade almost imperceptibly into other environments that are also washed over during storms, including wind-tidal flats, wind-deflation troughs, and storm runnels (Brown and others, 1977). The division between the washover channels and sand flats (wind-tidal flats) is an arbitrary one. Some washover areas were not mapped because of belts of small fore-island sand dunes (mapped as uplands) that were located along the bayward edge of the Gulf beach. For additional information on the location of washover channels and fans, see Brown and others (1977) and Weise and White (1980).

The large back-island active dune complexes are generally made up of long, narrow, east-west-oriented oblique dunes (Hunter and others, 1972) and interdune flats. Because of the cartographic complexity of showing the interlying flats and

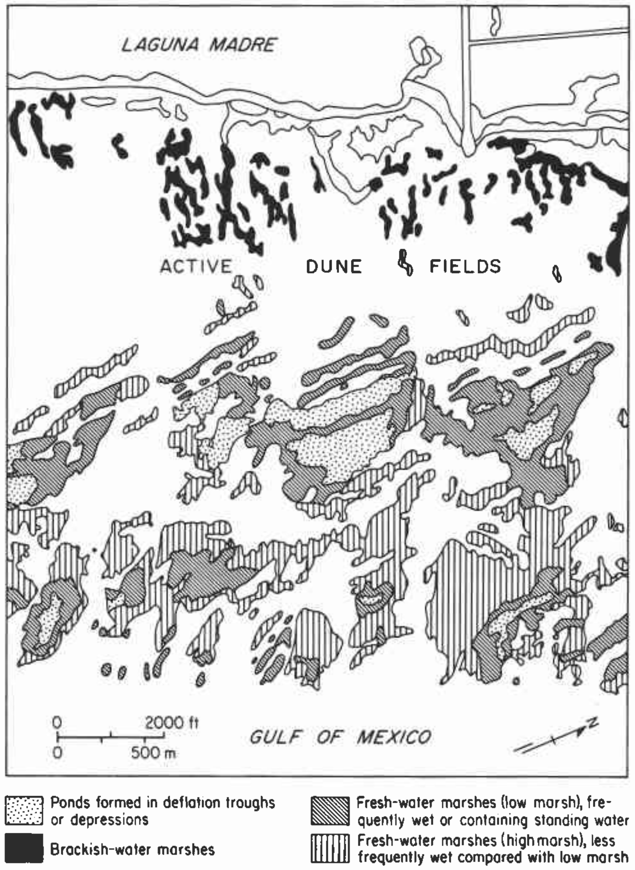


Figure 53. **Fresh-water marsh system on Padre Island north of Malaquite Beach (Corpus Christi map area, fig. 1). From White and others (1983).**

upland dunes separately, they were generally mapped together as uplands. Gulfward of these large dune complexes are extensive deflation flats that lie between the washover channels and generally parallel to the Gulf shoreline. Many of these broad flats are extensively vegetated with *Monanthochloe littoralis, Distichlis spicata,* and, locally, *Borrichia frutescens* (fig. 54). Toward the fore-island dunes, in deflation troughs farther from the saline wind-tidal flats, *Scirpus americanus* and *Spartina patens* are more common. At the southern end of the island in the study area, broad wind-tidal flats slope gently toward lower Laguna Madre, where marine grasses occur along a belt that borders this sandy flat.

Pleistocene Barrier Strandplain

North of the Kingsville area, the Pleistocene barrier strandplain, or Ingleside sand (Price,

Figure 54. **High brackish-water marsh on central Padre Island. Fore-island dunes are in background. Vegetation is predominantly *Monanthochloe littoralis* and *Distichlis spicata*.**

1933), has a trend similar to that of the modern barriers and lies landward of much of the modern bay-lagoon system, such as Laguna Madre. This relatively large sand system is traceable into the northern part of the Kingsville area between Laguna Madre and Alazan Bay, but its extent south of Baffin Bay is indistinct (fig. 9). Although accretionary beach ridges and interlying swales may have characterized this linear sand body early in its history, eolian activity has eradicated most distinctive traces of relict beach ridge-and-swale topography that is common along this ancient barrier farther north (for example, in the Port Lavaca area). The following discussion of wetlands that have developed on the barrier strandplain in the Kingsville area is limited to that area north of Baffin Bay where the sand body is more intact, although still greatly modified by eolian activity (fig. 9).

Within the Pleistocene barrier strandplain between the head of Alazan Bay and Laguna Madre, numerous small, closely spaced, elongate depressions are the sites of ponds, high and low fresh-water marshes, and transitional areas (pl. V). Some of the depressions, which are deflation troughs formed in the wake of sand dunes that migrated across this area, are strikingly aligned en echelon, indicating the systematic progression of dunes toward the northwest (fig. 55). The ridge-and-swale topography is similar to that shown in figure 52, which developed on parts of Padre Island. The

Figure 55. **Vertical aerial photograph of numerous water- and marsh-filled deflation troughs on the mainland (top half of photograph) west of Laguna Madre north of Baffin Bay. Active dune fields that have migrated into Laguna Madre are apparent on Padre Island (bottom of photograph).**

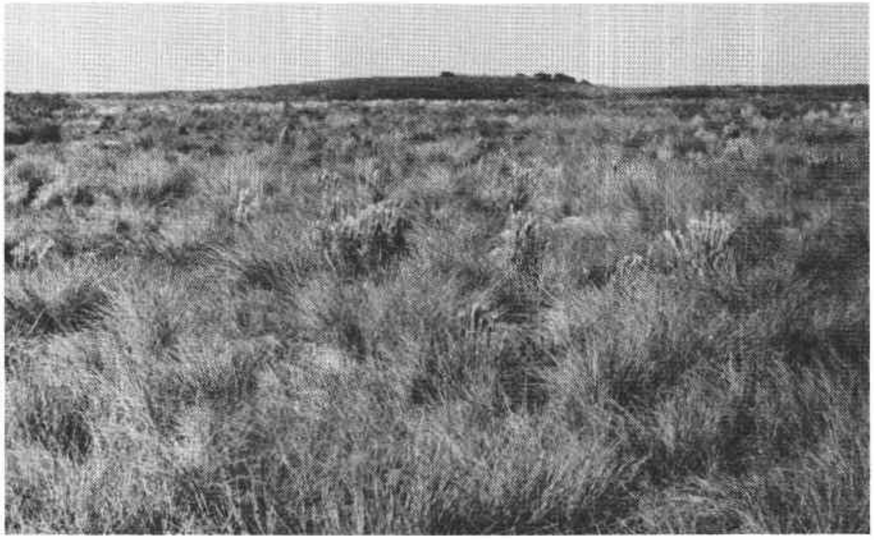


Figure 56. Deflation trough north of Baffin Bay. Vegetation is predominantly _Spartina spartinae._ A sand dune stabilized with live oak shrubs is in background.

orientation of the depressions is the result of the combined effect of annual winds; although the prevailing southeasterlies are most important, winds from the northeast quadrant also have a significant role (Weise and White, 1980).

Wet conditions in 1979 produced abundant water bodies and marshes (pl. V) in the depressions that stand out on the aerial photographs taken during that year. Wetlands include both low and high fresh-water marshes, the low marshes occurring in the deeper deflation troughs. Vegetation in the depressions during wet cycles, such as those occurring in 1979, probably includes many species listed in table 19, such as abundant *Eleocharis* spp., *Paspalum* spp., *Typha* sp., *Scirpus* spp., and *Cyperus* spp. However, during a field survey in February 1986, the marshes in this area were much drier than shown on the 1979 aerial photographs. In many depressions, high-marsh species, such as *Spartina spartinae* and scattered *Andropogon* sp. (fig. 56), were common.

Modern-Holocene Eolian System

Extensive wetlands occur in deflation areas associated with the vast eolian system that stretches miles inland from the edge of Laguna Madre. This complex South Texas eolian system is discussed in detail by Price (1958) and Brown and others (1977). Among its principal elements are (1) eolian sand lobes and dune trains composed of active and relict dune fields and associated blowouts, (2) loess sheets composed of airborne silt derived from upwind areas of wind deflation, (3) sand and loess plains subjected to varying degrees of wind deflation and deposition, and (4) large areas of wind deflation associated with fluctuating levels of the ground-water table (Brown and others, 1977). In addition, clay-sand dunes have formed on the leeward margins of many playas and barren flats (Price, 1958; Fisk, 1959; Brown and others, 1977). For this discussion, the South Texas eolian system is geographically subdivided by county.

Kenedy County

Inland from the Intracoastal Waterway to U.S. Highway 77 is an area that encompasses most of the active dune fields in the Kingsville area. The active dune systems are characterized by banner dune complexes (fig. 57) composed of spot blowouts and deflation troughs, longitudinal stabilized lag deposits, and active transverse and, locally, barchan sand dunes (fig. 57). Principal sources of the sand are relict Pleistocene barrier-strandplain, meanderbelt, and distributary channel deposits (Brown and others, 1977). Some areas have had a complex history of eolian activity, which has included repeated deflation or

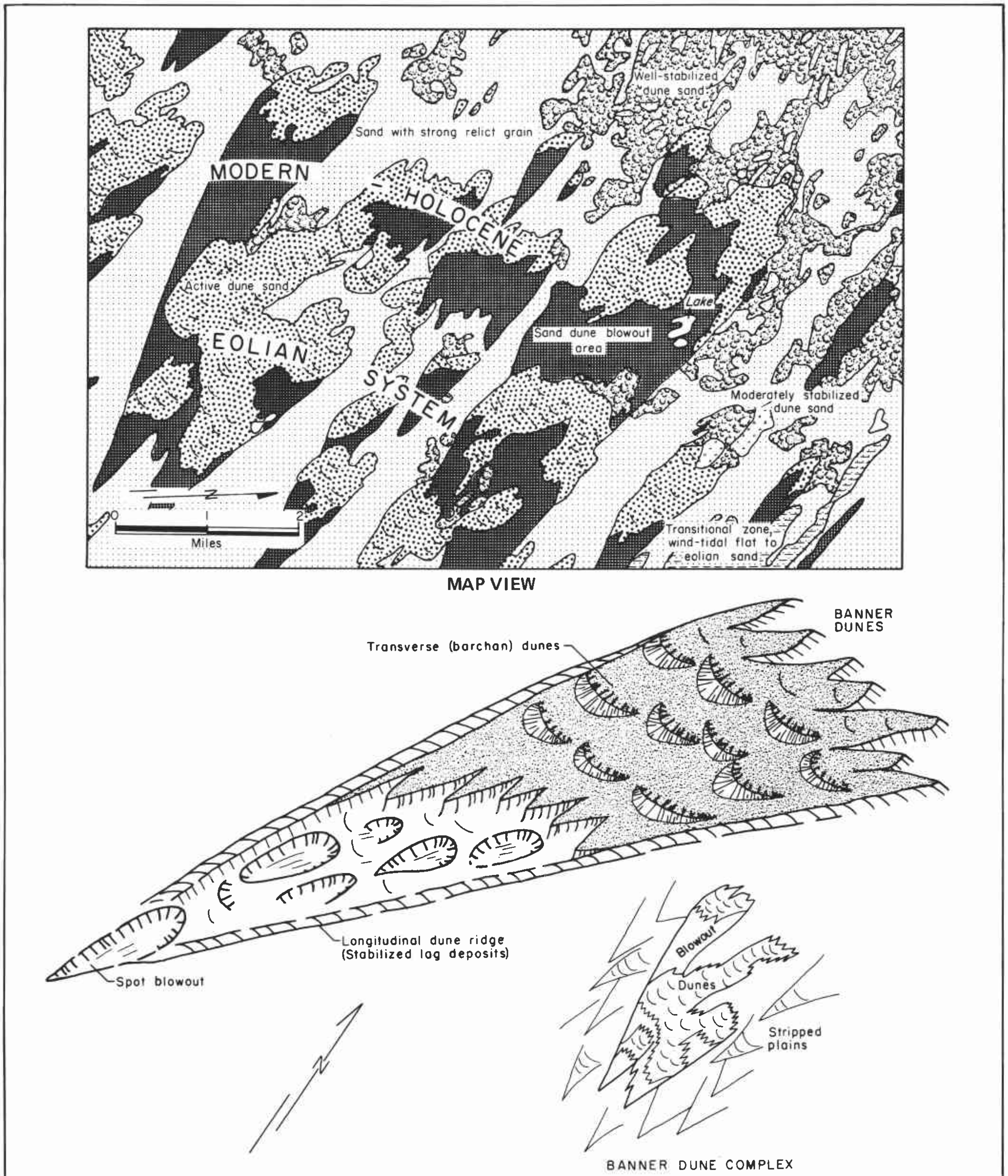


Figure 57. **Active banner dune field, eolian system, Kingsville area. Banner dunes are composed of a unique kind of large parabolic dune complex that has smaller transverse and barchan dunes within the sand field. Strong relict grain of earlier base-leveled dunes indicates long history of dune activity. Schematic view illustrates the various features that compose an individual banner dune. From Brown and others (1977), after Price (1958) and Scott and others (1964).**

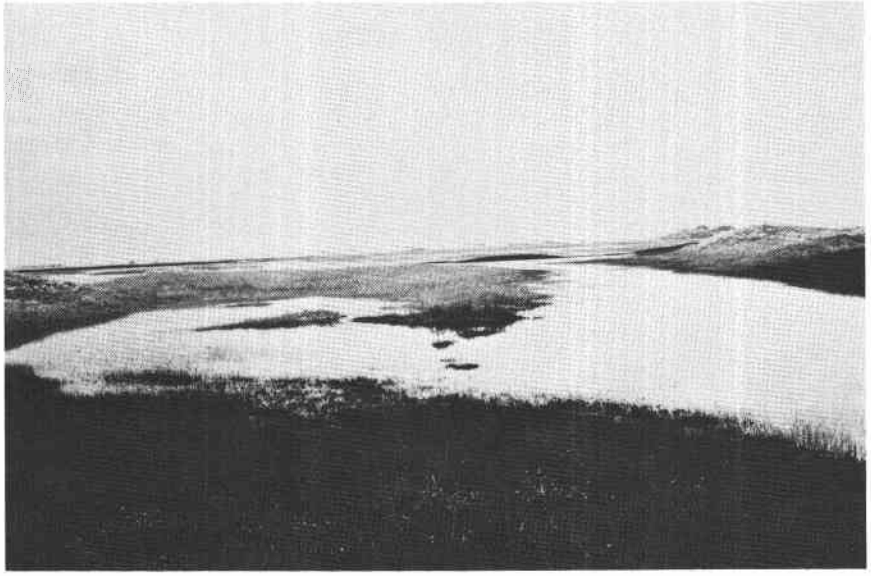


Figure 58. **Water ponded in a deflation trough in a banner dune complex north of Baffin Bay. A vegetation-stabilized lag ridge is shown along the right side of the photograph.**

erosion and transportation of sediment toward the northwest.

Active dunes are located principally south of Baffin Bay, gulfward of U.S. Highway 77, and north of Cayo Soledad (fig. 4). The banner dunes that make up the active dune system are complex units bordered by stabilized lag ridges that diverge, from a spot blowout, downwind at an angle of about 25 degrees and form a triangular pattern (fig. 57). Between the lag ridges is a deflation area (called a stripped plain by Price, 1958) characterized overall by depressed, yet hummocky, relief (fig. 58) composed of ridges and swales that mark the past positions of the migrating dunes, which are located along the downwind margins of the banner complex (fig. 59). Active and relict banner dune complexes overlap in many areas and produce a complex network of wetlands and interlying and adjacent uplands. The triangular-shaped features at Rincon Mesquite (fig. 4; pl. V) show the pattern of overlapping relict banner complexes (Fisk, 1959).

From near the Intracoastal Waterway, extensive wind-tidal flats (fig. 60), which are the result of deflation and wind-tidal processes, stretch inland from The Hole and Land-Cut Area. Deflation troughs and flats extend northwestward from the edge of the flats, indicating the effects of the onshore southeasterly winds. Saline dust is transported miles inland by the onshore winds (Johnston, 1955), producing saline soils in areas inland from the intertidal zone. Vegetation in these brackish to saline depressions includes *Monanthochloe littoralis, Batis maritima, Distichlis spicata, Borrichia frutescens,* and *Spartina spartinae.* Map units include distal salt-water marshes and low and high brackish-water marshes, barren flats, water, and transitional areas or vegetated saline flats. Farther inland the salinities decrease, and vegetation reflects these changes. Species include *Eleocharis* spp., *Scirpus* spp., *Cyperus* spp., *Paspalum* spp., *Andropogon* spp., *Dichromena colorata,* as well as *Spartina spartinae* (fig. 61). Moisture levels vary from depression to depression. Map units range from ponded water to transitional areas.

Most of the wetlands occurring in blowouts or deflation areas of active dune systems are located between Cayo Soledad and Baffin Bay (pl. V). A significant part of the topography in this area consists of vegetation-stabilized dune fields. Many of the sand dunes are covered with dense live oak mottes. In some areas the active dunes are migrating over the mottes. South of Cayo Soledad there are fewer active dune systems with associated blowouts or deflation areas in which wetlands can form. Instead, there are extensive dune fields that have been stabilized by live oaks and brushlands (Brown and others, 1977). These stabilized sand dunes provide a

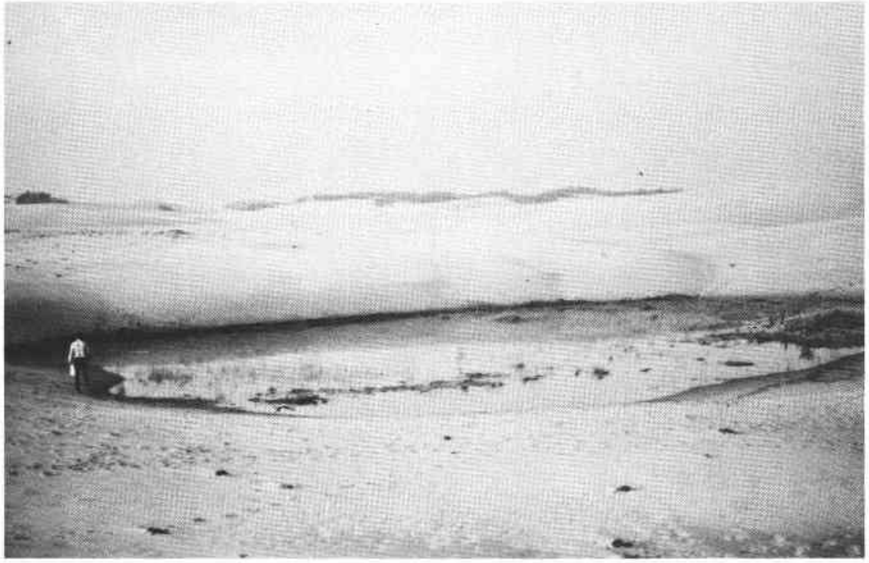


***Figure 59.* Active dune field and associated pond in deflation trough.**

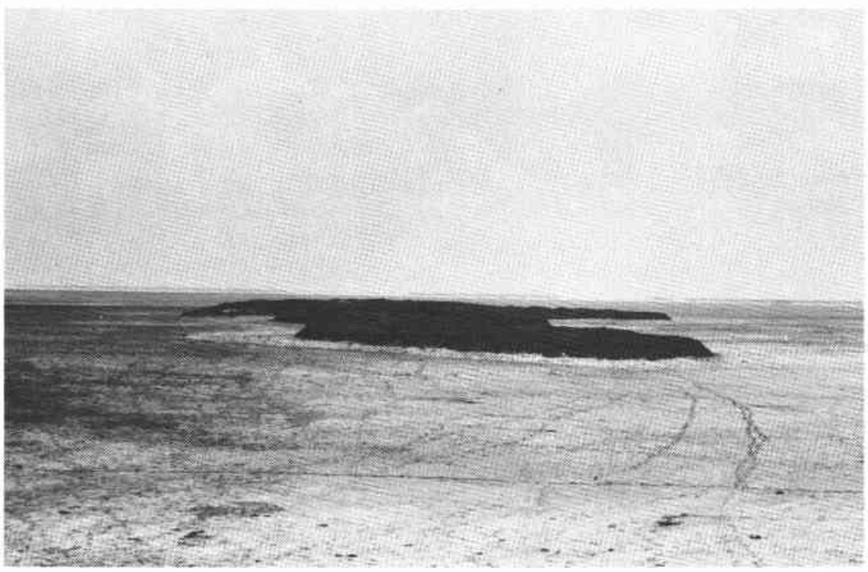


***Figure 60.* Wind-tidal flat and grass-covered upland outlier along the mainland margin of the Land-Cut Area.**

rolling topography of uplands whose highly permeable substrates are virtually barren of wetlands.

Near U.S. Highway 77 and inland to the edge of the map area, numerous ponds, marshes, and transitional areas occur in depressions that are scattered across the land. Most of the wetlands occur within a large deflation complex that is occasionally flooded and is characterized by poorly drained depressions and a shallow water table (Brown and others, 1977). The ponds vary from fresh to saline. Brackish to saline conditions in these inland areas are reflected by the vegetation, which includes *Monanthochloe lit-*

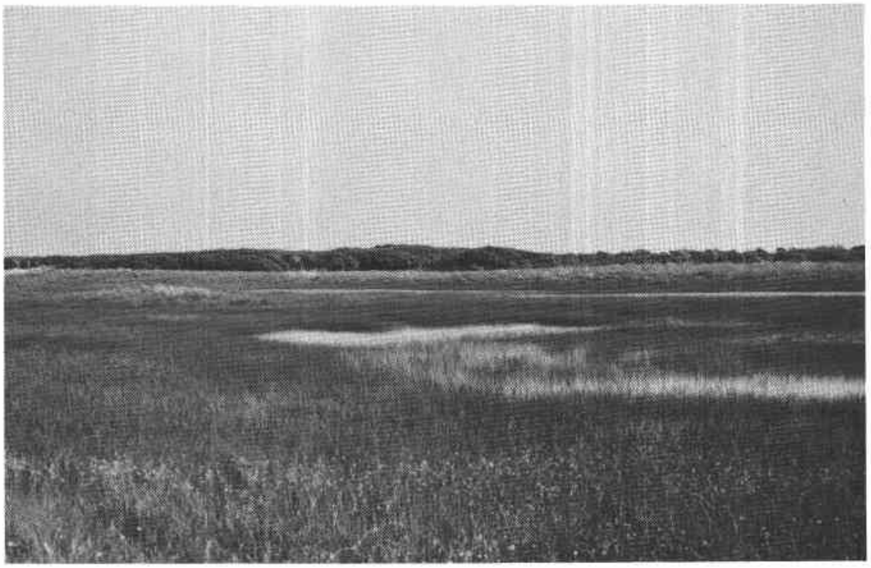


***Figure 61.* Fresh-water marsh in deflation trough in the vicinity of the active-dune eolian system north of Baffin Bay. *Eleocharis* spp. and *Scirpus americanus* are common in these areas.**

toralis, Distichlis spicata, Suaeda spp., *Lycium carolinianum, Borrichia frutescens,* and *Spartina spartinae.* In other depressions salinities are lower, and marsh species may include *Eleocharis* spp. (including *E. quadrangulata*), *Typha* sp., *Paspalum* spp., *Scirpus* spp., *Cyperus* spp., and *Spartina spartinae.*

Variations in salinities from pond to pond are controlled in part by the relationship between the ponded water and the water table, as well as by precipitation levels. Salinities of shallow ground water at sites in Kleberg and Kenedy Counties ranged from moderately saline to brine in 1968–1969 (Baker, 1971). In a pond located along U.S. Highway 77 about 3 mi (4.8 km) south of Armstrong, Baker (1971) noted that salinities in 1968 and 1969 reached about 10 ppt. The pond was filled with water from extremely heavy rains accompanying Hurricane Beulah in 1967. Between April 1968 and September 1969, salinities at this site near Armstrong increased by a factor of at least 6. Contiguous ground water, which had salinities ranging between 40 and 57 ppt, discharged into the pond during the latter part of the observation period (April 1968 through September 1969) (Baker, 1971). During this same period, Baker (1971) measured salinities of ponded water and adjacent ground water in a depression located 1 mi (1.6 km) west of Riviera. Water in the depression was fresh, with salinities reaching a maximum of about 0.2 ppt in 1969. According to Baker (1971), the pond was above the water table and received no ground-water discharge (water from the pond, however, did recharge the ground water). Ground-water salinities in this area ranged from 8.5 to almost 22 ppt during the period of observation.

Baker (1971) concluded that differences in salinities from pond to pond are controlled by the relationship of the ground water to the ponds. Because of the high salinities of the ground water, ponds that are affected by ground-water discharge (seepage inflow) are more saline than those that are not. Salinities also increase as water in the ponds evaporates. In February 1986, salinity at the pond near Armstrong was 22 ppt, which is considerably higher than that measured by Baker (1971). However, water levels in the pond were much lower in 1986 than in 1968–1969, when they were still high following the torrential rainfall that accompanied Hurricane Beulah in 1967. A past method of salt-water disposal also may have contributed to local salinity variations and to high salinities in shallow aquifers. Until 1969, a common method for disposal of salt water produced with oil in Kenedy and adjacent South Texas counties was placing the water in unlined surface pits. In 1967, this method was used to dispose of 36,500 barrels of salt water produced in an oil field in Kenedy County (Shafer and

Figure 62.* Fresh-water marsh on the King Ranch north of Baffin Bay. Vegetation includes *Typha* sp., *Eleocharis* spp., *Cyperus* spp., and *Spartina spartinae.

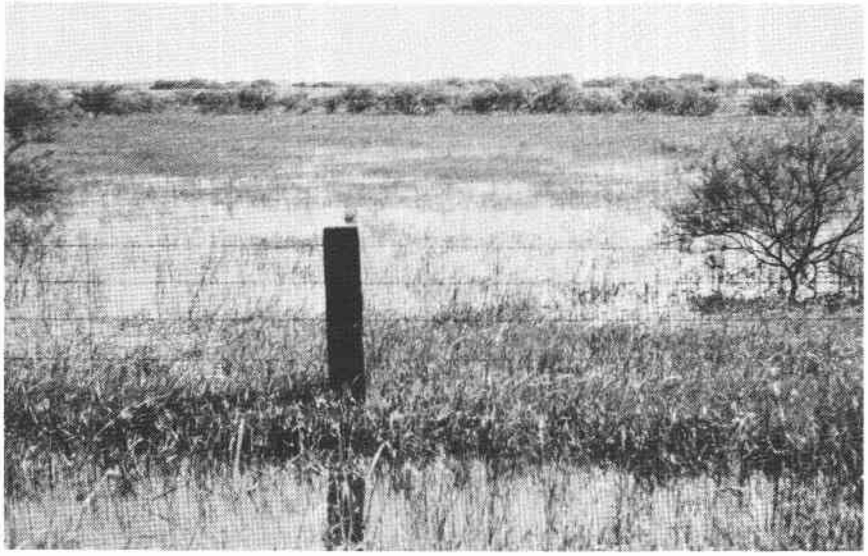
Baker, 1973). The method was discontinued on January 1, 1969, when a no-pit order applicable statewide was issued by the Railroad Commission of Texas. During their investigation of ground-water resources in Kenedy County, Shafer and Baker (1973) found no conclusive evidence of contamination of the water in wells sampled, although they noted that contamination may be occurring.

In addition to variations in salinities in the inland depressions, there are variations in water and soil-moisture levels. These variations are reflected in the different map units that range from ponded water through low and high marshes to transitional areas (or vegetated saline flats). Many of the transitional areas and local high marshes contain dense, essentially homogeneous stands of *Spartina spartinae.* Some depressions that contain *Spartina spartinae* and associated species were classified as uplands because moisture levels on aerial photographs (taken during 1979, a wet year) appear too low to allow classification of the areas as marshes or even as transitional areas. Yet following heavy rains or during extremely wet periods, the sites temporarily will contain higher amounts of moisture than will adjacent uplands, suggesting that a wetlands classification is appropriate. The average annual potential evapotranspiration of this region of South Texas markedly exceeds its average annual precipitation (fig. 5). Moisture levels can vary dramatically during the year, between years, and from one climatic cycle to another. These variations in moisture levels are reflected by the surface environments. During drier periods, areas mapped as marshes on plate V may seem more like transitional areas, and transitional areas may seem more like uplands.

Kleberg County

From Madero Lake to the area around Parra Lake north of the mouth of Baffin Bay are some of the largest marshes in the Kingsville area. Fresh-water marshes and transitional areas occur in an area mapped by Brown and others (1977) as a Pleistocene fluvial-deltaic system. Modern marshes have developed on interdistributary basin muds and delta front sands and muds; the orientation of some marshes, such as at Madero Lake and between Jabancillos Ranch and Cayo del Infiernillo, is parallel to the trend of the relict distributary channels, which are topographically higher features flanking the marshes. Marsh vegetation in these areas includes *Eleocharis* spp., *Typha* sp., *Cyperus* spp., *Paspalum* spp., *Aster spinosus,* and in higher areas, *Spartina spartinae* (figs. 49 and 62). *Lemna* sp. is a floating leaf plant that occurs in many of

(A)



(B)

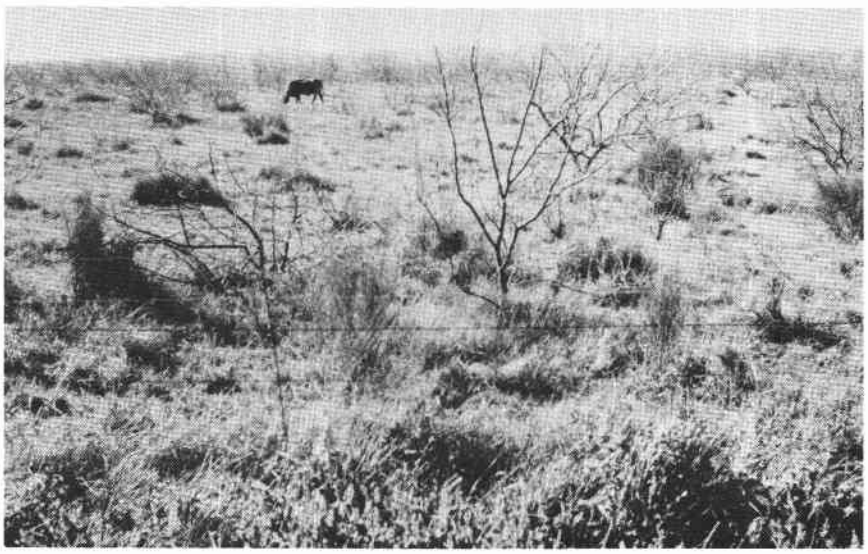


Figure 63. **Vegetated depression (A) with standing water in October 1979 and (B) without water in February 1986. The depression is one of many located east of Riviera, Texas.**

these areas. In some areas, such as the lake approximately 2.5 mi (4 km) northeast of Parra Lake and inland from Laguna Madre, *Sesbania* sp. is abundant.

Some areas north of Baffin Bay and Laguna Salada (Kleberg County) have been extensively modified by eolian activity. Numerous isolated wetlands occur in deflation depressions that are part of the rolling terrain, where topographic highs include inactive clay-sand dune complexes. One such area is between Cayo del Grullo and Laguna de los Olmos (pl. V). Wetlands and associated environments include high and low fresh-water marshes, transitional areas, and water. Marsh vegetation includes many of the species listed in table 19, notably *Typha* sp., *Ludwigia* sp., *Scirpus* spp., *Eleocharis* spp., *Spartina spartinae,* and *Aster spinosus.* Trees and shrubs associated with some of the depressions include *Acacia farnesiana, Parkinsonia*

***Figure 64.* Fresh-water pond and fringing marsh in a depression partly fed by fresh-water inflows from a water-well-supplied stock tank on the King Ranch between Alazan and Baffin Bays. Vegetation includes *Eleocharis* spp., *Typha* sp., and *Scirpus americanus*.**

aculeata, and *Sesbania* sp. The seasonal variation in the moisture levels of some of the depressions is shown in figure 63.

The area between Alazan and Baffin Bays, northeast of Starvation Point, also has been modified by eolian processes and contains numerous depressions and deflation flats, some of which are bordered on their leeward margin by active clay-sand dunes (Brown and others, 1977). Water in the larger depressions, typically bordered by clay-sand dunes, is very saline, partly as a result of hydrologic interconnections with water from (1) Baffin or Alazan Bays through normal or storm tidal exchange and/or (2) shallow (water table) saline aquifers through ground water discharge. In February 1986, water salinity in one of the depressions in this area exceeded 40 ppt. These high salinities are apparently normal (Bill Kiel, King Ranch biologist, personal communication, 1986). Barren flats occur around the margin of the depressions. On flats at slightly higher elevations, extensive *Monanthochloe littoralis* occurs. Several smaller depressions in the area contain fresh to slightly brackish water. These depressions are apparently above the water table and are protected from nearby bay waters. Also, some depressions receive fresh-water inflows from water wells that supply water for livestock. Vegetation in and near the water is characterized by a fresh-water-marsh assemblage of *Typha* sp., *Scirpus americanus, Eleocharis* spp., *Bacopa* sp., and others listed in table 19. Yet in higher fringing areas away from the fresh water, brackish-water species, such as *Monanthochloe littoralis,* occur. The salinities of one of the ponds (fig. 64) partly fed by well water was about 1.5 ppt in February 1986. A relatively large water body that was protected from Baffin Bay by a clay dune had a salinity of approximately 2.5 ppt. Vegetation around the margin of the water-filled depression included *Borrichia frutescens* and *Monanthochloe littoralis*. A smaller depression in an area surrounded by hummocky, vegetation-stabilized dunes had a higher salinity of about 12 ppt and was ringed by *Distichlis spicata, Monanthochloe littoralis,* and scattered *Spartina spartinae.*

Near the margin of Baffin Bay, the vegetation assemblage in a narrow distal salt-water marsh (pl. V) includes *Borrichia frutescens, Batis maritima, Monanthochloe littoralis, Spartina spartinae,* and scattered *Salicornia* spp. The salinity in Baffin Bay near this site on February 19, 1986, was about 38 ppt.

CHANGES IN WETLAND DISTRIBUTION, 1934-1960 TO 1979

General changes in the distribution of wetlands can be determined by comparing plate V with the Environments and Biologic Assemblages Map of the Environmental Geologic Atlas—Kingsville Area (Brown and others, 1977). Aerial photographs used in the earlier coastal atlas project were taken during (1) 1960 for areas south of the Baffin Bay system (Kenedy County), (2) 1934 for about 75 percent of the area north of Baffin Bay (Kleberg County), and (3) 1938, 1951, 1956, and 1959 for the remaining 25 percent of this area. The 1950's topographic maps were used with the photographs to define some units, such as water features, shown on the Environmental Geologic Atlas. Together they provided an updated depiction of areas where the 1930's photographs were used. Photographs used in the Submerged Lands Project (pl. V) were taken in 1979. Accordingly, changes in natural environments reported here occurred primarily during a 25- to 45-year period. Caution must be used in making comparisons, however, for the following reasons: (1) wetland map units defined and mapped in this report, although similar to those defined and mapped in the coastal atlas, are not identical to them (table 18); (2) moisture and tidal conditions vary between photographs—precipitation levels were above normal during 1979, and although 1960 also had above-normal precipitation, it followed a severe drought that occurred in the mid-1950's; precipitation levels for 1934 were apparently below normal (by state averages), although standing water in many mainland depressions shown on the photographs indicates relatively wet conditions along the coast; (3) photographic interpreters were able to make more refined judgments concerning wetland distribution using high-quality, color-infrared photographs taken in 1979; and (4) wetland mapping criteria varied slightly between the two mapping projects. Thus, direct, specific comparisons of changes in the distribution of all map units cannot be made; however, general comparisons of selected areas are possible and are presented in the following discussion.

Modern Barrier-Island System

A comparison of wetlands mapped on the Environmental Geologic Atlas (Brown and others, 1977) with those mapped on plate V shows that among the changes on Padre Island is a decrease locally in the areal distribution of wind-tidal (sand) flats because of marine grasses encroaching onto the flats. This trend is particularly apparent near Middle Ground lagoonward of central Padre Island. The more extensive flats shown on the Environmental Geologic Atlas were mapped from 1952 topographic maps and 1960 photographs. The extent of the flats may be partly due to the prolonged effects of a severe drought in the 1950's, which produced (1) increased evaporation and concentration of salts, thereby inhibiting plant colonization of the flats, and (2) lower sea level (Morton, 1977), resulting in more extensive flats as the shoreline moved bayward. The reduction in the areal extent of the flats by 1979 and corresponding increase in shallow subaqueous flats and grassflats can be attributed in part to (1) the recent rise in sea level (Hicks and Crosby, 1975), (2) natural compactional subsidence (Swanson and Thurlow, 1973), and (3) above-normal precipitation during 1976, 1978, and 1979 (fig. 6).

These conditions would tend to raise water levels (tidal and ground water) in 1979, thereby decreasing the width of the flats. With a rise in sea level, some wind-tidal flats would become shallow subaqueous flats, which could be colonized by marine grasses. For example, most of the area around Middle Ground mapped as wind-tidal or sand flats on 1960 photographs was covered with marine grasses in 1979 (pl. V). The gradual submergence of wind-tidal flats from compactional subsidence and relative sea-level rise is a scenario similar to that reported by White and others (1978) at Mustang Island in the Corpus Christi area. In contrast to the expansion of marine grasses in areas near Middle Ground and lagoonward of central Padre Island was the reduction of marine grassflats along lagoon margins of northern Padre Island caused by lagoonward-migrating active dunes (fig. 55).

The apparent increase in fresh- and brackish-water marshes in the central parts of the island (particularly northern Padre Island) and salt-water marshes in back-island areas, is largely due to the difference in mapping criteria and unit definitions. On the earlier atlas these marshes were listed as vegetated barrier flats. A comparison of the 1930's photographs on which northern Padre Island was mapped with the 1979 photographs, however, indicates that the distribution of fresh-water marshes has increased. This increase is a result of active dune fields continuing their lagoonward migration, leaving behind a series of deflation flats and troughs in which the marshes occur (fig. 52). Accompanying dune migration was accretion of the lagoon shoreline of northern Padre Island (fig. 55). The infilling of the lagoon and the burial of some grassflats were reported by Hunter and Dickinson (1970).

Modern-Holocene Eolian System and Other Mainland Environments

In the large South Texas eolian system that covers much of the mainland in the Kingsville area, the wetlands mapped on plate V are much more extensive than those mapped on the earlier atlas. This increase is due primarily to (1) differences in mapping criteria and map units and (2) wet climatic conditions that characterized the year 1979. The apparent increase in wetlands is particularly obvious south of the Baffin Bay system, where active dunes are migrating toward the northwest. Most of the wetlands occur in deflation areas, which were mapped as active dune blowout areas on the earlier atlas; the map unit explanation notes that these areas contain fresh-water marshes in wet seasons or cycles (Brown and others, 1977). The abundant marshes, standing water, transitional areas, and other units shown on plate V indicate the extent of the wetlands in these areas during a wet year. Differences in map units and wetland distribution in an active dune area south of Baffin Bay are shown in figure 65. The extent of the deflation troughs and flats forming windward of the active dune systems increased between 1960 and 1979 as the dunes migrated toward the northwest. Dune migration rates vary, but they average about 85 ft (26 m) per year. (The rate was determined primarily by comparing the location of the windward edge of several dunes on the 1960 photographs with their location on the 1979 photographs.) This rate is similar to rates of dune migration reported by Hunter and Dickinson (1970) and Price (1971) for northern Padre Island. While new deflation depressions, in which wetlands may develop, are forming behind the migrating dunes, older depressions and associated wetlands in the path of the dunes are being buried by the migrating sand.

The more inland areas, such as those between the Baffin Bay system and U.S. Highway 77 and those south and west of this area, contain numerous depressions in which water, marsh vegetation, and transitional assemblages were mapped (plate V). On the Environmental Geologic Atlas many of the depressions were mapped as water features (fresh to saline water bodies and landlocked ponds and playas), as shown on the U.S. Geological Survey topographic maps from which the map base was derived. Wetlands shown on plate V also occur within areas mapped on the Environmental Geologic Atlas as sheet deflation areas characterized by poorly drained depressions, high water table, occasional floods, and seasonal hydrophytes and other high-moisture plants (Brown and others, 1977). As in the active dune areas, the apparent increase in wetlands in more inland areas shown on plate V, compared with those shown in the earlier atlas, primarily results from variations in (1) map units in which geologic-related definitions took precedence over biologic categories on maps in the Environmental Geologic Atlas and (2) precipitation levels in which above-normal rainfall in 1979 provided wet conditions for marshes to thrive.

In several areas north of the Baffin Bay system, the distribution of wetlands shown on the earlier atlas is similar to, although less extensive than, that shown on plate V. One reason for the similarity of distribution in the northern areas, compared with that in the area south of Baffin Bay where wetlands were not mapped (although they were described in conjunction with units that were mapped), is that the wetlands are larger and less ephemeral in some of these areas (for example, between Madero Lake and Alazan Bay). But east of Alazan Bay and Cayo de Hinoso, wetlands have developed in smaller depressions or deflation troughs, and their abundance and similarity to wetlands mapped on plate V may be related to moisture conditions reflected on the 1934 photographs used in this area. Depressions shown on the 1934 photographs appear to contain water levels that are higher than those levels shown on the 1960 photographs and that approach levels shown on the 1979 photographs.

In a few areas, such as that between Alazan Bay and Laguna Salada, changes in wetlands are locally related to human activities. This area is one of the few that has been cleared for cropland. Some depressions that are the sites of ephemeral wetlands during wet cycles are drained and plowed to produce additional cropland when soil moisture conditions allow.

Bay-Estuary-Lagoon Margins

Among general changes along the bay-estuary-lagoon margins (excluding Padre Island)

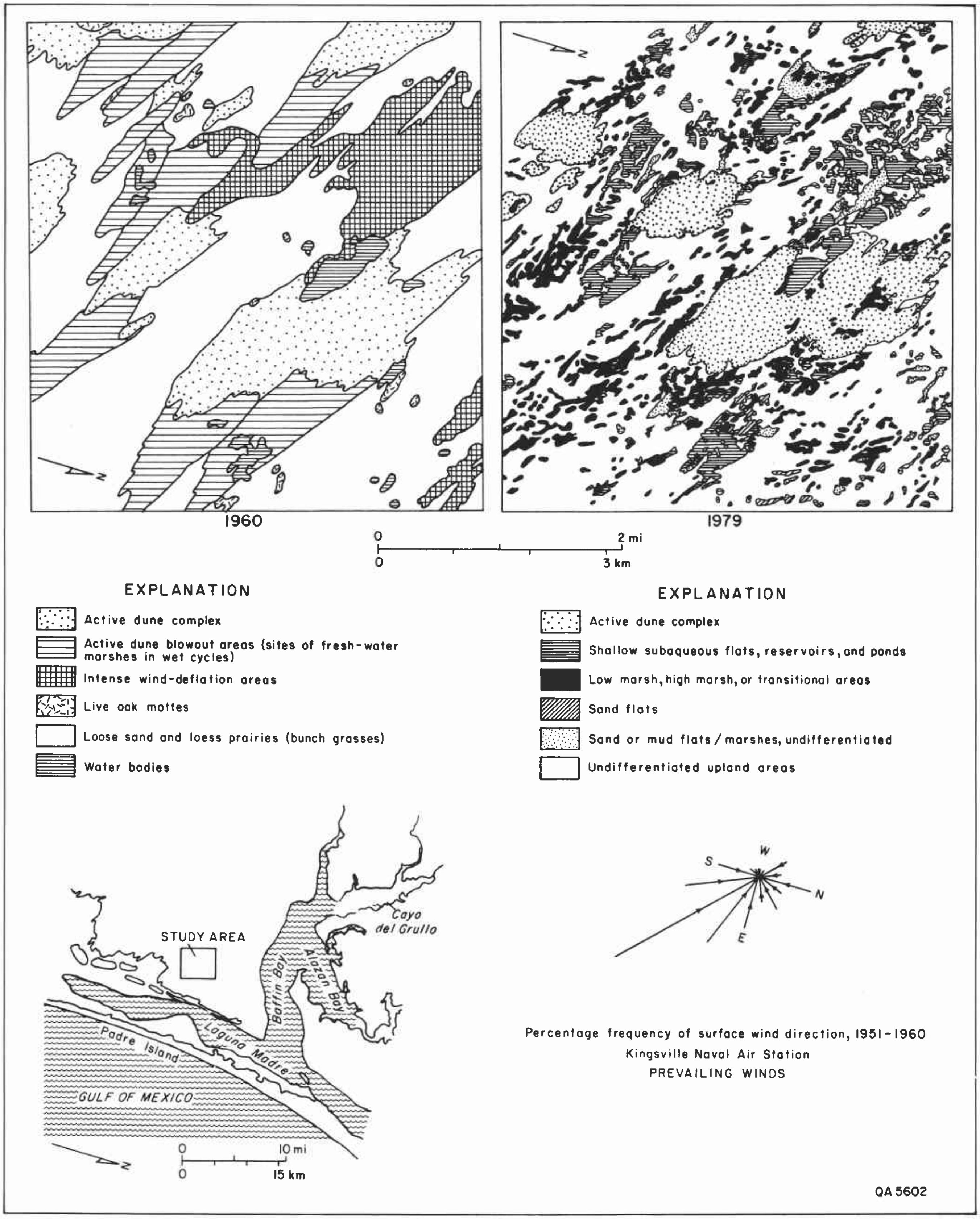


Figure 65. **Historical changes in the distribution of wetlands between 1960 and 1979 in an area south of Baffin Bay where active sand dunes are migrating toward the northwest. Map for 1960 and wind directions from Brown and others (1977).**

is a slight increase in the distribution of salt-water marshes, as depicted on plate V, in some areas mapped (in the earlier atlas) as berms. Again, a geologic-related map unit (berms or storm deposits) is shown on the earlier atlas as taking precedence over a biological unit. The map unit explanation indicates that brackish-water marshes and salt-tolerant plants occur in swales between berms and that a narrow, unmappable band of salt-water marsh occurs along the shore (Brown and others, 1977). On plate V, berms and associated swales that support marsh vegetation, such as along the spit that projects westward into the mouth of Laguna de los Olmos, were mapped as marshes.

The appearance of marine grasses was a significant change that occurred in shallow subaqueous areas along margins of the Baffin Bay system. Examples of these areas are at the mouth of Laguna de los Olmos, the head of Cayo del Grullo, and along parts of the northern margins of Laguna Salada and Baffin Bay. Marine grasses also occur in patches and narrow belts in other areas. No marine grasses were mapped in the Baffin Bay system by Brown and others (1977); Breuer (1957) reported that marine grasses were absent in Baffin and Alazan Bays. He attributed their absence primarily to turbidity rather than salinity by noting that Laguna Madre, which is less turbid than Baffin Bay and has experienced high salinities similar to those in Baffin Bay during the 1940's, still has marine grasses. Attempts to establish marine grasses in Baffin Bay by planting various species were unsuccessful (Breuer, 1957). Marine grasses have apparently become established in the Baffin Bay system in recent years. Martin (1979) reported large areas of *Ruppia maritima, Halophila engelmannii,* and *Halodule wrightii* (*beaudettei*) in Alazan Bay. Exactly why the grassflats have become established in the Baffin Bay system since the 1950's is not completely understood, but one reason may be a moderation of salinities caused by the Intracoastal Waterway, which was completed in 1946.

Marine grasses also increased in some areas of Laguna Madre. Areas previously mapped as wind-tidal flats along the mainland margin of Laguna Madre at Rocky Slough were mapped as marine grasses on plate V (fig. 66). This encroachment of marine grasses in an area previously mapped as a wind-tidal flat is similar to that in some areas along the lagoon margins of Padre Island; the encroachment is possibly related to relative sea-level rise due to compactional subsidence (Swanson and Thurlow, 1973) and to above-normal precipitation levels (Breuer, 1957; Morton, 1977) in the mid-to-late 1970's. The distribution of marine grasses also increased in The Hole—an area shown on the earlier atlas as a barren to sparsely vegetated subaqueous sand flat.

Among the changes related to human activities in bay-estuary-lagoon margins was the dredging of additional channels for petroleum exploration and production. The channels were dredged primarily from the Intracoastal Waterway across wind-tidal flats (sand and mud flats) in the Land-Cut Area. Spoil dumped along the channels commonly forms circular upland mounds on the flats. Marshes increased locally after the encroachment of marsh vegetation in Laguna Madre along margins of reworked spoil deposits beside the Intracoastal Waterway near Middle Ground.

Modern Fluvial Systems

A comparison of wetlands and associated environments on plate V with those mapped on the Environmental Geologic Atlas (Brown and others, 1977) indicates minor changes occurred along the modern fluvial systems. These areas are characterized by wind-tidal flats that extend for several miles from the mouths of the intermittent creeks upstream. However, marshes do occur along some stretches, as shown on plate V near the confluence of San Fernando Creek and Santa Gertrudis Creek. This area was previously mapped as a barren wind-tidal flat. Along more inland reaches of the creeks, more extensive fluvial woodlands were mapped on the earlier atlas than on plate V.

Summary of Changes

Visual comparison of wetlands and associated environments shown on maps from the Environmental Geologic Atlas (Brown and others, 1977) with those depicted on plate V of this report reveals that changes occurring, at least locally, in the Kingsville area include:

(1) the conversion of wind-tidal flats and shallow subaqueous flats to grassflats,
(2) the apparent extensive increase in fresh- and brackish-water marshes in mainland areas,
(3) the development and conversion of barren deflation flats or troughs (associated with active dune fields on Padre Island) to fresh-water marshes,

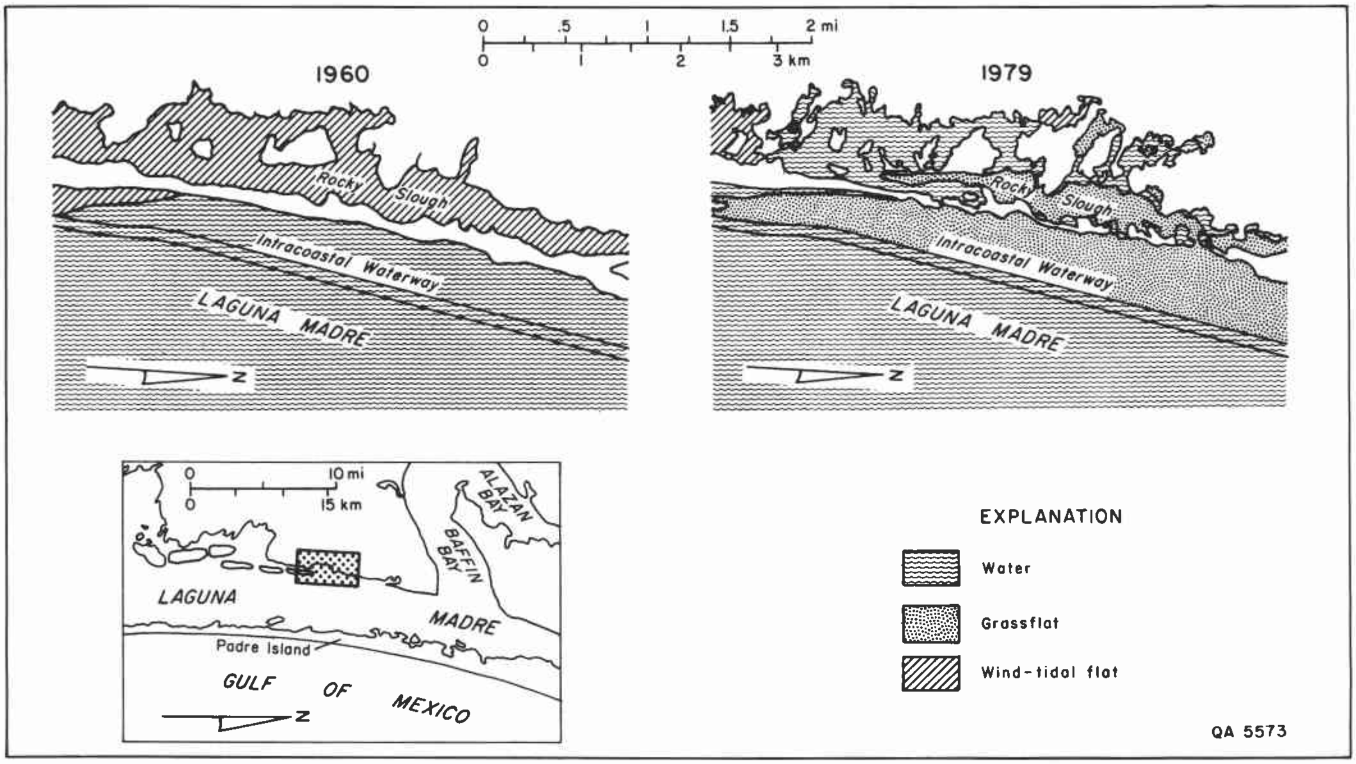


Figure 66. **Historical changes in the distribution of grassflats and shallow subaqueous flats between 1960 and 1979 along the mainland margin of Laguna Madre at Rocky Slough. Map for 1960 from Brown and others (1977).**

(4) the conversion of grassflats to sand flats and uplands along the lagoonward margin of Padre Island (as a result of lagoonward-migrating dunes on Padre Island), and

(5) the erosion of subaerial spoil and encroachment of marsh vegetation along spoil-island margins.

For the most part, changes in wetlands are difficult to determine when comparing plate V with the earlier Environmental Geologic Atlas because of differences in map units and mapping criteria, which in part reflect the differences in quality between the 1979 color-infrared stereoscopic photographs used in this project and the 1934-1960 black-and-white monoscopic photomosaics used in the earlier project. Still, some changes, such as the spread of marine grasses in some areas previously mapped as wind-tidal flats, can be verified by comparing the different photographs. Among the possible processes contributing to the expansion of marine grasses in these areas is a rise in relative sea level due to (1) natural compactional subsidence (Swanson and Thurlow, 1973), (2) eustatic sea-level rise (Hicks and Crosby, 1975), and (3) secular sea-level rise (Morton, 1977). With a rise in sea level, the invasion of shallow subaqueous flats and low wind-tidal flats by marine grasses (grassflats) would be expected in areas adjacent to existing marine grassbeds, such as those areas along the mainland margin of Laguna Madre.

The most dramatic apparent difference in wetlands shown on plate V and those shown on the Environmental Geologic Atlas occurs in the Modern-Holocene eolian system (Brown and others, 1977), which covers most of the map area in the Kingsville atlas. The primary reasons for the more extensive wetlands depicted on plate V are (1) differences in map unit definitions and mapping criteria and (2) wet climatic conditions that were prevalent in 1979—the year aerial photographs were taken for wetlands mapping. Map units used in the Environmental Geologic Atlas were defined more in terms of geologic processes than of biologic processes. Therefore, many topographically low areas that are intermittently or seasonally wet and supporting marshes were mapped as blowouts and poorly drained depressions instead of wetland areas. Still, the map description clearly states that these areas support fresh-water marshes and high-moisture plants during wet cycles (Brown and others, 1977). The wet climatic cycle that occurred during the years 1976, 1977, and 1979 raised water tables and produced the numerous wetlands depicted on plate V.

The more extensive marshes shown on Padre Island are also related to the two conditions noted. But another condition produced an increase in the abundant wetlands on northern Padre Island shown on plate V: numerous active sand dunes on Padre Island migrated lagoonward between the 1930's (years of the photographs on which the earlier atlas for this area was based) and 1979 (pl. V). During this period, more extensive deflation flats and troughs developed behind (upwind from) the migrating dunes, and these areas supported extensive wetlands during 1979. The migration of the dunes into Laguna Madre has buried grassflats along the margin of the lagoon and has slightly reduced the distribution of marine grasses in this area.

When considering changes in wetlands, the normally semiarid conditions, the numerous intermittent wetlands, and the effects of shorter-term climatic variations should be kept in mind. The wetlands are important habitats during cycles that are drier, as well as wetter, than normal. During wet periods, marshes thrive in the numerous depressions. During drier periods, when grasses in topographically higher areas dry out and are overgrazed by wildlife and domestic herds, many lower areas contain higher moisture levels and serve as important food and water reserves.

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Initiated in 1975 by J. H. McGowen and R. A. Morton, the Submerged Lands of Texas Project involved many participants, spanned several years and research phases, and encompassed the entire Texas Coastal Zone.

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A field and laboratory investigation of this magnitude requires much support. The following list of major tasks and primary participants applies to the seven-atlas study as a whole, not necessarily to the Kingsville atlas alone.

Sediment-sample collection in bay areas (McGowen and Morton, 1979) was performed by J. H. McGowen, J. L. Chin, Thomas R. Calnan, Jon P. Herber, C. R. Lewis, L. C. Safe, William A. White, Dale Solomon, Charles Greene, Carl Christiansen, Dwight Williamson, and John Kieschnick of the Bureau of Economic Geology.

Sediment-sample collection on the shelf (also McGowen and Morton, 1979) was performed by R. A. Morton, J. H. McGowen, J. L. Chin, Thomas R. Calnan, Jon P. Herber, C. R. Lewis, L. C. Safe, M. K. McGowen, William A. White, Dale Solomon, Charles Greene, Carl Christiansen, Dwight Williamson, Mike Stewart, Carl Warning, Greg Miller, Pam Luttrell, Steven J. Seni, John Kieschnick, Guy Tidmore, George Granata, Dawn McKalips, Christopher D. Henry, L. E. Garner, and Douglas C. Ratcliff of the Bureau of Economic Geology. George Harrison and Neal Lillard of the U.S. Geological Survey (USGS) assisted with shelf sampling.

Textural analyses of sediment were done at the Sedimentology Laboratory of the Bureau of Economic Geology by H. Seay Nance, Research Associate-in-Charge, Rick Dauzat, Tom C. Freund, and Daniel Ortuño. Geochemical analyses of sediment were performed by the USGS; samples were submitted by Charles W. Holmes of the USGS to F. J. Flanagan, Liaison Officer, USGS Analytical Laboratories, Reston, Virginia.

Determination of major, minor, and trace elements by ICP-AES was made by personnel of the Mineral Studies Laboratory of the Bureau of Economic Geology. Steven W. Tweedy, Cynthia A. Mahan, and Dorothy Gower performed the analyses under the direction of Clara Ho, Chemist-in-Charge. Supplementary analyses were conducted under the direction of David W. Koppenaal. Total organic carbon content analyses were by D. A. Schofield, Nam Bui, Larry McGonagle, Yet-Ming, Kelly Street, and David Woodrum.

Several types of mapping were involved in the project. Sediment textural and geochemical mapping was done by William A. Ambrose, Janice L. Smith, Jon P. Herber, Patricia A. Yates, Jeffrey Paine, and J. K. Miller, under the supervision of William A. White, R. A. Morton, and J. H. McGowen. Benthic macroinvertebrate identification and mapping were by Thomas R. Calnan, Russell S. Kimble, Thomas G. Littleton, James A. DiGiulio, Gary J. Steck, John H. Wilkins; Joseph E. Sullivan, Lisa R. Wilk, and Stephen M. Robertson. Wetlands interpretation and mapping were by William A. White and Thomas R. Calnan.

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Many individuals within the Bureau of Economic Geology assisted in production of the Kingsville area report. The manuscript was reviewed by Mary L. W. Jackson, M. Saleem Akhter, and William A. Ambrose. Technical editing was by Tucker F. Hentz. Manuscript word processing was by Melissa Snell, typesetting was by Susan Lloyd, and proofreading was by Rebecca Tovar and Maris Strautmanis, under the supervision of Susann V. Doenges, Editor-in-Charge. Bobby Duncan edited the publication. Cartography of plates was by Barbara M. Hartmann and the late Tony M. Walston. Drafting of text figures was by Joel Lardon, Nan Minchow, and Ted Samsel, under the direction of Richard L. Dillon, Chief Cartographer. Text illustration camerawork was by Yves Oberlin. Design and layout were by Jamie S. Haynes. Computer data processing was by Elizabeth D. Orr, Audie L. Dobbs, Jack W. Lund, and Mark E. McClelland, under the supervision of Michael P. Roberts. Field vehicles and equipment support were provided by Tommy Glimp, George Donaldson, Dow Davidson, and James Doss.

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APPENDIX A: TEXTURAL ANALYSIS OF BENTHIC SEDIMENTS

Textural analysis involved the handling of approximately 3,700 benthic samples (from the entire coast) by staff at the Sedimentology Laboratory of the Bureau of Economic Geology. Most aspects of the basic sample preparation and particle-size analysis techniques used by that laboratory have been treated by Krumbein and Pettijohn (1938), Ingram (1971), and Folk (1974), among others. In addition to determination of gravel-sand-mud ratios, particle-size distribution within the sand fraction (-1.0ϕ to 4ϕ) was determined using a Rapid Sediment Analyzer and included sand-sized shell material. Most of the shell material was broken and apparently transported. Size distribution within the mud fraction (4.0ϕ to 10.62ϕ) was determined with a Coulter TA II electronic suspended particle counter.

Grain-size analysis of mud by Coulter Counter offers several advantages—including speed of analysis—over traditional methods (pipette and hydrometer). Results may be slightly different, however, depending on the method used. Within the clay size range of particles, traditional methods extrapolate data beyond the range of actual measurement (approximately 0.5 μm) to 0.06 μm, whereas with Coulter Counter analysis (as currently performed), the extrapolation is not made beyond 0.5 μm. Accordingly, with sediments high in clay, the Coulter analysis generally produces a coarser distribution than does the pipette analysis. Thus, the tendency for bay-center and shelf muds (as shown on sand - silt - clay maps) to be more silty than clayey may be, in part, a reflection of the method of analysis (Coulter Counter). Had the pipette method been used, many of the mud samples might have been more clayey than silty. Because the gravel fraction (larger than -1.0ϕ) consisted largely of unbroken shell material (much of which was probably not transported), no size distribution within this fraction was determined. General textural analyses procedures are outlined in the following flow diagram; for a more detailed discussion, see Nance (1982).

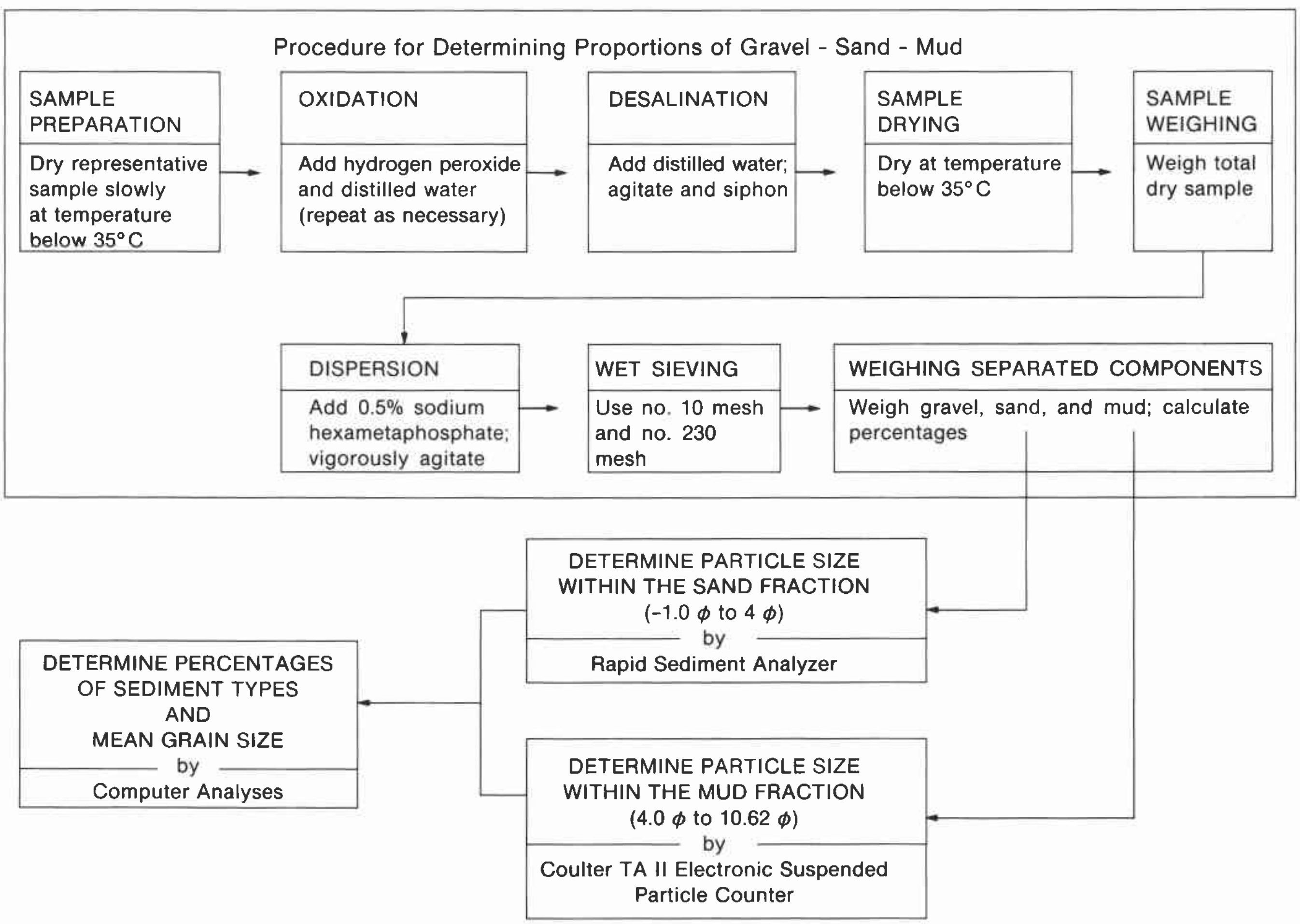

Figure A1. **Flow diagram of general textural-analysis procedures.**

APPENDIX B: TEXTURAL AND GEOCHEMICAL DATA, KINGSVILLE AREA

Sample No.*	Textural Analysis: Gravel %	Sand %	Silt %	Clay %	Mud %	Mean φ	TOC %	Geochemistry: B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
ALAZAN BAY																		
1	1.39	65.39	19.93	13.30	33.22	4.32	0.4	60	420	2.5	13	7.1	1.3	290	7.0	<6.8	270	14
2							1.0											
3							0.8											
4	1.38	82.08	14.42	2.12	16.54	3.38	0.3											
5	0.00	0.51	48.44	51.05	99.49	7.96	1.2											
6	2.78	67.69	17.25	12.28	29.53	4.01	0.6											
7							1.2											
8	3.66	82.52	6.28	7.53	13.81	2.79	0.3	21	510	6.3	48	2.2	0.55	130	3.4	<6.8	680	<10
9							0.3											
10	0.37	88.46	8.99	2.18	11.17	3.61	0.1	26	640	1.6	7.0	2.8	0.43	120	1.8	<6.8	210	<10
11	1.58	6.35	48.43	43.64	92.07	7.42	1.2											
12	1.45	82.76	7.78	8.01	15.79	3.15	0.3											
13							0.6											
14	1.61	6.69	45.78	45.91	91.70	7.40	0.9											
15							1.1											
16							1.1											
17							1.5											
18	2.02	29.78	34.58	33.62	68.20	6.22	1.2	79	340	2.8	22	12	1.8	440	13	13	280	34
19							0.7											
20	7.86	73.05	8.94	10.16	19.09	3.53	0.5											
21	2.39	87.96	5.64	4.00	9.65	2.72	0.2											
22	0.84	5.16	53.70	40.30	94.00	7.14	1.7	85	430	0.70	22	14	1.9	370	12	13	140	32
23	1.94	95.17	1.84	1.05	2.88	3.06	0.2											
24							1.6											
25	8.26	85.24	2.86	3.64	6.51	1.44	0.5	22	72	23	8.0	1.7	0.47	190	1.8	<6.8	6500	<10
BAFFIN BAY																		
1	1.27	82.79	11.83	4.11	15.94	3.17	0.5	58	360	2.1	19	6.7	0.91	370	6.3	<6.8	590	<10
2	3.23	74.33	15.23	7.21	22.44	3.50	1.1											
3	0.98	92.07			6.96		0.6											
4	6.76	80.51	7.25	5.48	12.73	2.85	0.6											
5	6.04	78.14	7.89	7.93	15.82	2.47	0.6	30	340	2.7	8.9	2.4	0.58	91	2.5	<6.8	480	18
6	0.47	42.80	40.40	16.33	56.73	5.25	1.2											
7[a]	1.78	86.11	6.82	5.29	12.11	2.81	0.5		224	3.42	<4	14.6	0.49	64.8	<10	<40	325	82
8							0.6											
9							2.0											
10							1.8											
11							0.7											
12	3.37	91.85	2.34	2.44	4.78	2.74	0.7											
13	1.04	44.86	37.23	16.87	54.10	5.20	2.2	24	180	7.0	6.5	1.9	0.13	130	1.6	<6.8	1600	46
14	0.30	9.94	51.54	38.21	89.76	6.96	2.4											
15	0.37	50.25	24.08	25.29	49.37	5.30	1.0											
16	1.34	87.05	5.44	6.17	11.61	2.95	0.4	61	370	2.5	19	6.4	0.99	350	6.3	<6.8	620	40
17							2.7											
18							0.7											

* Location of sample number, which is also the station number, is shown on plate VI.

[a] Geochemical data for these samples were provided by the Bureau of Economic Geology's Mineral Studies Laboratory. (Other geochemical data, except for total organic carbon, which was analyzed by the Bureau of Economic Geology, were provided by the U.S. Geological Survey.)

Sample No.*	Textural Analysis Gravel %	Sand %	Silt %	Clay %	Mud %	Mean ϕ	TOC %	Geochemistry B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
BAFFIN BAY, cont.																		
19							0.8											
20	1.96	95.32	1.52	1.20	2.72	2.02	0.8	27	110	11	<1	<1.5	0.15	96	<1.5	<6.8	3400	<10
21	2.00	46.77	38.89	12.34	51.23	4.74	0.9											
22	0.00	0.66	45.44	53.90	99.34	7.87	2.2											
23	0.51	12.08	50.71	36.70	87.42	6.77	1.9											
24	0.22	6.73	38.10	54.96	93.06	7.85	2.7	91	330	0.94	17	14	1.7	820	11	11	150	25
24.5	0.44	20.61	48.88	30.07	78.95	6.11	1.6											
25							2.1											
26							0.5											
27	4.93	86.75	5.43	2.89	8.33	3.02	0.3											
28	0.36	14.28	49.99	35.37	85.37	6.72	0.7											
29	0.00	0.34	42.37	57.29	99.66	8.08	2.0											
30							0.3											
31							1.8											
32							2.0											
33	0.00	0.34	41.47	58.19	99.66	8.11	1.9	81	430	0.36	13	12	1.7	420	10	7.7	110	24
34							0.2											
35	4.70	88.15	3.62	3.53	7.15	2.11	0.3											
36	0.00	0.75	47.76	51.49	99.25	7.78	2.2											
37	0.00	1.38	49.37	49.26	98.62	7.83	2.2											
38	12.88	58.98	15.05	13.09	28.14	3.97	0.7	46	230	2.8	15	6.7	0.82	420	5.2	<6.8	580	42
39							2.2											
40							2.1											
41							1.8											
42							0.3											
42.5							0.3											
43	1.41	8.38	53.14	37.07	90.21	6.89	1.6											
44	2.51	13.25	52.39	31.85	84.24	6.66	1.7	90	650	1.7	32	14	2.0	470	13	13	250	38
45	0.00	1.29	52.02	46.69	98.71	7.57	1.9											
46	0.63	95.47	2.08	1.82	3.90	2.84	0.3	23	210	3.2	2.9	<1.5	0.25	310	<1.5	<6.8	720	11
47							1.7											
48							1.8											
49							0.4											
50	1.36	94.92	2.52	1.20	3.72	3.12	0.2											
51	0.21	3.27	56.34	40.17	96.52	7.14	1.7											
52	0.00	3.72	53.46	42.82	96.28	7.35	2.1	93	570	1.4	24	18	2.4	510	14	12	200	36
53	0.43	92.39	3.12	4.07	7.18	2.80	0.3											
54	15.16	76.96	2.93	4.95	7.88	1.95	0.4	11	200	17	4.8	<1.5	0.33	150	1.7	<6.8	3500	<10
55							1.7											
56							1.4											
57							0.5											
58	8.56	74.22	9.95	7.27	17.22	2.65	0.5											
58.5							1.3											
59	0.00	1.87	61.41	36.71	98.13	7.06	1.6	94	560	2.4	34	15	2.5	490	14	16	300	48
60	11.88	87.00	0.52	0.61	1.13	2.66	0.3											
61							1.5											
62							0.5											
63							0.5											
64	0.92	85.63	6.73	6.72	13.45	3.12	0.3	18	300	3.3	3.5	19	0.33	90	<1.5	<6.8	560	15
65	0.12	2.99	67.92	28.97	96.89	6.68	1.7											

Sample No.*	Textural Analysis Gravel %	Sand %	Silt %	Clay %	Mud %	Mean φ	TOC %	Geochemistry B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
BAFFIN BAY, cont.																		
66	1.67	37.29	44.92	16.12	61.04	5.22	0.9	42	310	4.3	20	4.2	0.76	170	4.3	<6.8	3100	42
67							0.2											
68							1.1											
69							1.3											
70	6.69	69.19	13.99	10.14	24.13	3.86	0.4											
71	0.80	18.79	56.75	23.67	80.41	5.96	1.3											
72	5.88	36.34	39.58	18.21	57.79	5.34	0.8											
73	4.02	31.33	35.27	29.39	64.66	5.77	1.7	80	640	2.4	37	13	1.8	380	13	15	260	39
74	7.84	64.24	21.89	6.03	27.92	2.99	0.3											
75							1.2											
76							0.4											
77	1.22	52.84	41.53	4.41	45.94	4.13	0.5											
78	1.88	36.15	48.32	13.65	61.98	4.68	0.4	45	350	5.9	10	4.0	0.74	220	4.4	<6.8	980	44
79	1.94	35.54	44.89	17.62	62.51	5.21	1.2	51	820	2.6	12	5.6	1.1	230	7.0	<6.8	370	35
80	0.00	84.75	10.03	5.22	15.25	3.04	0.4											
80.5							1.9											
81	1.60	82.70	13.03	2.67	15.70	3.38	0.4											
82	0.12	13.97	59.72	26.19	85.91	6.21	1.5	70	670	1.1	20	12	1.8	350	11	11	220	24
83	0.20	33.01	54.07	12.72	66.79	5.33	1.4											
84							2.0											
84.5	5.25	58.71	26.98	9.06	36.04	4.07	0.9	33	510	4.9	11	4.2	0.70	190	3.5	<6.8	1300	40
LAGUNA MADRE																		
66	0.80	96.84	0.89	1.48	2.37	2.78	0.3											
67	1.42	95.81	2.10	0.66	2.76	2.73	0.3	24	240	2.3	1.2	<1.5	0.21	120	<1.5	<6.8	800	14
68	0.00	99.31	0.34	0.34	0.69	2.84	0.1											
69	2.35	88.49	5.25	3.91	9.16	2.92	0.8											
70	1.47	97.08	0.52	0.93	1.45	2.68	0.2											
71	7.89	90.22	0.88	1.01	1.89	2.42	0.2											
72							0.1											
73							0.7											
74	9.25	85.90	3.30	1.56	4.86	2.78	0.7	47	280	2.8	<1	1.6	0.21	120	<1.5	<6.8	380	<10
75	2.90	80.89	6.90	9.31	16.21	2.94	1.1											
76							0.9	65	250	4.3	13	2.1	0.56	140	3.2	<6.8	740	34
77	0.00	99.43	0.21	0.36	0.57	2.94	0.1											
77A	3.95	90.76	3.23	2.07	5.30	2.92	0.3											
78							0.7											
79	10.89	79.29	4.16	5.66	9.82	1.75												
81							0.4											
81A	0.00	95.45	2.35	2.20	4.55	2.80	0.9	12	170	0.19	<1	<1.5	0.14	18	<1.5	<6.8	24	<10
82							1.4											
83							0.5											
84[a]	5.42	79.85	8.88	5.85	14.73	2.87	0.8		230	5.58	<5	<5	0.41	86	<20	<50	480	30
85[a]							0.7		210	8.67	<5	<5	0.24	61	<20	<50	940	25
86	3.48	78.52	8.53	9.46	17.99	3.70	1.0	68	270	1.9	11	4.7	0.76	150	3.7	<6.8	250	16
86A	0.01	98.54	0.86	0.60	1.46	2.70	0.1											
87	1.56	92.21	3.66	2.59	6.24	2.72												
88[a]	2.18	74.79	13.84	9.20	23.04	3.58	0.7		270	2.43	<5	<5	0.62	87	<20	<50	180	43

Sample No.*	Textural Analysis Gravel %	Sand %	Silt %	Clay %	Mud %	Mean φ	TOC %	Geochemistry B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
LAGUNA MADRE, cont.																		
89[a]	1.07	91.99	3.95	3.06	6.93	2.99			220	1.50	<5	<5	0.22	38	<20	<50	240	23
90[a]							0.7		250	4.21	<5	<5	0.43	65	<20	<50	250	32
91[a]	0.00	97.57	1.30	1.12	2.43	2.72	2.1		200	0.42	<5	<5	0.11	18	<20	<50	77	21
92	5.86	78.38	8.72	7.04	15.76	2.91	0.7											
93	2.37	36.09	31.26	30.27	61.53	6.10	1.4											
94[a]							0.2		260	2.00	<5	<5	0.28	52	<20	<50	260	23
95[a]	0.21	93.24	4.24	2.31	6.55	3.18			240	1.20	<5	<5	0.22	40	<20	<50	150	25
96[a]	1.99	91.29	4.39	2.32	6.72	2.84	0.8		260	2.30	<5	<5	0.33	57	<20	<50	170	25
97[a]							0.6		170	19.6	<5	<5	0.32	120	<20	<50	1500	24
98[a]							0.6		240	4.77	<5	<5	0.26	53	<20	<50	340	27
99[a]							0.9		240	3.00	<5	<5	0.23	57	<20	<50	230	21
100[a]							0.3		230	3.68	<5	<5	0.23	52	<20	<50	270	25
101[a]	17.32	55.41	13.21	14.06	27.27	3.97	1.2		180	13.9	<5	<5	0.53	150	<20	<50	1300	30
102[a]	19.92	58.41	9.33	12.34	21.67	4.17	0.4		180	20.2	<5	<5	0.56	220	<20	<50	1400	49
103[a]							0.3		140	27.7	14	<5	0.50	240	<20	<50	1900	36
104[a]							0.7		260	7.30	<5	<5	0.83	280	<20	<50	590	37
105[a]	0.14	95.19	2.66	2.00	4.66	2.87	0.9		240	1.21	<5	<5	0.24	45	<20	<50	130	<10
106[a]							1.7		280	7.39	32	<5	1.01	340	<20	<50	610	42
107[a]	2.88	36.33	40.10	20.69	60.79	5.50	1.1		430	8.28	20	<5	1.08	320	<20	<50	670	39
108[a]							0.6		140	22.9	<5	<5	0.25	160	<20	<50	1800	<10
109[a]	13.20	80.06	3.77	2.98	6.74	2.71	1.3		520	9.55	<7	<5	0.31	110	<20	<50	770	<10
110[a]							1.8		370	6.03	<5	<5	1.60	400	<20	<50	560	52
111[a]	3.93	45.99	31.62	18.45	50.08	5.18	1.3		500	4.86	29	<5	1.25	360	<20	<50	420	46
112[a]	1.55	86.13	8.46	3.86	12.32	2.67	0.8		250	2.84	27	<5	0.41	75	<20	<50	300	18
113[a]							1.2		330	2.50	<5	<5	0.65	150	<20	<50	220	25
114[a]							0.5		260	5.68	11	<5	0.41	140	<20	<50	610	20
115[a]							0.7		120	2.10	<5	<5	0.12	130	<20	<50	1800	12
116[a]	0.26	78.18	14.55	7.02	21.57	3.50	0.4		290	1.89	12	<5	0.51	88	<20	<50	250	21
117[a]							0.6		240	6.33	13	<5	0.42	91	<20	<50	910	23
118[a]							0.7		290	2.23	56	<5	0.58	87	<20	<50	400	29
119[a]	1.60	57.71	23.92	16.77	40.70	4.54	1.3		300	3.00	26	<5	1.12	170	<20	<50	520	41
120[a]							0.9		270	2.51	18	8	0.97	120	<20	<50	430	35
121[a]	1.00	32.13	31.18	35.70	66.88	6.18	1.3		280	5.57	13	7	1.01	160	<20	<50	930	30
122[a]	1.01	49.42	20.82	28.75	49.57	5.28	0.8		260	5.67	12	<5	1.15	230	<20	<50	1100	43
123[a]	0.17	74.16	11.22	14.46	25.67	4.25	1.5		270	1.98	<5	<5	0.44	96	<20	<50	320	27
124[a]	1.31	58.63	19.70	20.89	40.06	4.68	1.0		280	2.94	<5	<5	1.00	190	<20	<50	320	40
125[a]							0.9		290	3.65	<5	<5	1.14	200	<20	<50	570	40
126[a]							0.8		310	1.48	<5	<5	1.18	170	<20	<50	230	38
127[a]							0.7		270	3.22	<5	<5	0.55	120	<20	<50	340	22
128[a]	2.58	81.63	7.08	9.13	15.79	3.03	0.7		280	2.59	<5	<5	0.59	93	<20	<50	280	23
129[a]	0.00	80.22	9.86	9.93	19.78	3.42	0.2		290	0.46	<5	<5	0.35	71	<20	<50	90	14
130[a]	0.39	88.73	5.45	5.13	10.58	2.70	0.4		290	1.13	<5	<5	0.36	63	<20	<50	140	<10
131[a]	0.20	65.96	14.92	18.92	33.84	4.47	0.9		280	0.75	<5	<5	0.47	76	<20	<50	140	20
132[a]	0.36	90.94	5.80	2.90	8.70	2.59	0.7		400	0.96	<5	<5	0.38	66	<20	<50	130	16
133[a]	0.20	91.56	4.08	4.17	8.25	2.66	0.5		330	0.94	<5	<5	0.40	67	<20	<50	160	15
134[a]	0.03	88.72	8.02	3.23	11.27	2.74	0.7		300	0.87	<5	<5	0.41	64	<20	<50	160	17
135[a]	0.07	86.23	8.53	5.17	13.69	2.66	1.1		330	1.24	11	<5	0.92	170	<20	<50	220	28
136[a]	0.00	54.02	24.92	21.06	45.98	4.57	1.2		340	1.42	15	<5	0.84	140	<20	<50	280	28
137	1.11	32.98			65.92													
140	36.80	52.75	5.58	4.88	10.46	2.34	1.0											

	Textural Analysis							Geochemistry										
Sample No.*	Gravel %	Sand %	Silt %	Clay %	Mud %	Mean ϕ	TOC %	B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
LAGUNA MADRE, cont.																		
140A[a]	6.44	88.06	3.17	2.34	5.51	2.13	0.6		232	16.2	<4	12.7	0.28	144	<10	<40	2200	51
141	0.65	95.80	2.20	1.35	3.55	2.59												
142[a]	1.21	65.85	15.18	17.77	32.95	4.44			251	7.77	15.1	10.5	0.80	128	20[b]	<40	1060	8.1[b]
143[a]	2.60	81.39	8.81	7.20	16.01	2.97	0.5		378	8.41	7.9	7.9	0.55	174	6.6	<40	1190	15
144							0.8											
145	4.62	72.35	11.25	11.78	23.03	4.02	0.6											
146	10.58	65.93	10.16	13.33	23.49	3.95	0.9											
149	0.64	93.17	3.43	2.76	6.19	2.57												
150[a]	9.70	64.41	9.84	16.04	25.88	3.86	0.9		251	14.9	22.4	9.2	1.12	333	8.5	<40	818	29
151[a]	4.36	87.14	6.33	2.17	8.50	2.79	0.5		284	2.89	17.7	3.8[b]	0.38	78.3	5.4	<40	207	8.6
152							0.6											
153							0.4											
153A	7.59	16.89	38.93	36.59	75.52	6.57	1.7											
155[a]	2.71	94.19	2.03	1.07	3.10	2.78			375	7.44	5.93[b]	12.0	0.36	74.4	<10	<40	1150	62
156[a]	8.55	58.48	16.78	16.20	32.98	4.02	1.2		294	12.9	17.7	7.5	0.94	287	6.6	<40	819	27
157	8.88	71.27	8.73	11.12	19.85	3.40	0.6											
158[a]	3.00	91.66	3.84	1.50	5.34	2.65	0.2		260	1.70	10.6	<4	0.28	84.2	14[b]	<40	145	<4
159							0.3											
159A							0.3											
160	8.76	53.82	18.41	19.01	37.42	4.44	1.0											
161	0.67	98.34	0.41	0.57	0.99	2.47												
INTRACOASTAL WATERWAY																		
1							3.2	140	770	1.4	34	21	2.6	670	20	20	230	43
2							3.5											
3							4.6											
4							3.6	170	840	1.9	24	15	2.0	670	15	13	420	47
5							4.2											
6							5.7											
47[a]							2.5		345	7.41	31.8	43.5	2.88	924	20	<40	612	79
48							2.3											
49[a]							2.3		299	8.76	<4.00	7.96[b]	0.76	218	<10	<40	1510	95.0
50							3.8											
51[a]							3.4		334	4.90	33.5	31.9	2.96	813	20	<40	460	85
52							3.8											
53[a]							3.5		311	5.72	17.9	25.3	2.93	802	12[b]	<40	520	197
55							2.4											
57[a]							1.0		320	2.01	12	<5	0.81	190	<20	<50	230	23
59[a]							0.9		310	2.44	<5	<5	0.49	120	<20	<50	230	26
61[a]							0.6		300	1.86	<5	<5	0.44	100	<20	<50	180	28
63[a]							0.7		260	0.65	<5	<5	0.22	72	<20	<50	96	23
65[a]							0.5		260	1.30	<5	<5	0.39	88	<20	<50	130	21
67[a]							1.2		260	1.46	<5	<5	0.79	190	36	<50	160	36
69[a]							1.0		250	1.71	<5	<5	0.65	130	34	<50	190	34
71[a]							1.0		230	1.33	<5	<5	0.37	100	33	<50	140	25
73[a]							0.7		290	2.25	<5	<5	0.45	120	<20	<50	260	25

[b] Indicates that the result is near the detection limit and must be interpreted accordingly.

Sample No.*	Textural Analysis Gravel %	Sand %	Silt %	Clay %	Mud %	Mean φ	TOC %	Geochemistry B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
INTRACOASTAL WATERWAY, cont.																		
75[a]							1.5		280	2.25	74	<5	1.11	220	32	<50	230	49
76[a]							0.8		280	3.37	15	<5	0.80	180	<20	<50	300	36
79[a]							2.0		380	3.53	<5	<5	2.14	580	37	<50	400	82
81[a]							0.8		160	25.6	<5	<5	0.70	230	<20	<50	2300	37
82[a]							2.0		350	3.83	<5	13	2.48	790	35	<50	400	90
85[a]									405	2.99	39.3	14.2	2.67	584	17[b]	<40	326	212
89[a]									575	1.91	41.7	19.9	2.62	460	22	<40	263	91
92[a]									533	0.926	34.4	26.5	2.90	422	14[b]	<40	151	141
LAND-CUT AREA CHANNELS																		
7[a]							2.2		450	3.93	<5	<5	1.50	290	<20	<50	520	71
11							0.5		480	0.88	<5	<5	0.38	94	<20	<50	170	27
SHELF																		
562							0.5	46	420	1.6	28	11	2.1	350	13	14	230	19
563							0.4											
577	3.09	96.36	0.20	0.34	0.55	2.28	0.1											
578							0.1											
579	6.85	80.68	8.17	4.30	12.47	2.72	0.2											
580							0.3											
581	10.60	60.34	17.16	11.90	29.06	4.14	0.4											
582							0.5											
583	5.90	45.49	26.21	22.41	48.62	5.24	0.7											
584							0.6	76	530	3.1	42	16	2.4	480	16	19	280	35
585							0.5											
586	0.32	26.86			72.82		0.9	75	420	2.2	48	17	2.6	580	17	15	220	42
587							0.4											
588	4.38	89.99			5.63		0.2	18	460	4.3	3.8	3.8	1.0	230	2.7	11	330	<15
589							0.1											
590							0.3	23	330	1.7	4.6	4.2	1.4	500	3.4	7.2	250	<15
591							0.3											
592							0.3	37	390	2.3	15	6.4	1.5	370	5.3	11	260	<15
593							0.3											
594	7.76	90.24			2.00		0.1	27	380	1.1	21	4.1	2.2	400	3.8	8.6	180	18
595	0.66	97.28	1.44	0.62	2.06	3.21	0.1											
596							0.1											
597	3.29	75.12	13.63	7.96	21.59	3.36	0.3											
598							0.2											
599	2.88	77.73	14.46	4.93	19.39	3.05	0.2											
600							0.5											
601	13.40	73.62	9.52	3.46	12.98	2.59	0.3											
602							0.3											
603	10.94	53.57	27.70	8.23	35.94	4.05	0.4											
604							0.4											
605	0.00	5.09	65.02	29.89	94.91	6.81	0.9											

Sample No.*	Gravel %	Sand %	Silt %	Clay %	Mud %	Mean ϕ	TOC %	B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
	Textural Analysis							Geochemistry										
								SHELF, cont.										
606	0.00	1.20			98.80		1.3	99	380	2.1	48	29	3.2	570	22	24	210	62
607							0.6											
608							0.7	63	530	2.8	35	14	2.3	370	14	16	240	26
609							0.4											
610	9.09	68.41			22.50		0.3	25	340	3.3	<1	5.7	1.5	230	4.5	7.0	380	<15
611							0.2											
612							0.3	39	350	1.6	11	5.2	1.6	310	5.8	9.9	240	<15
613							0.3											
614	1.72	94.60			3.68		0.2	26	350	2.0	16	6.9	1.3	350	4.5	10	250	<15
615							0.1											
616							0.1	49	270	0.66	95	5.0	2.9	520	4.1	12	140	22
617	2.83	93.22	3.34	0.61	3.95	3.25	0.1											
618							0.1											
619	0.00	97.10	2.68	0.22	2.90	2.53	0.1											
620							0.4											
621	1.98	65.82	23.95	8.25	33.84	3.80	0.8											
622							0.2											
623	12.44	61.19	20.06	6.30	26.37	3.55	0.3											
624							0.3											
625							0.7											
626							0.9											
627	0.00	0.24	67.89	31.87	99.76	7.07	1.0											
628							1.1	96	420	2.2	58	18	3.3	550	24	28	210	58
629							0.8											
630							0.6	42	420	2.0	24	9.7	1.6	280	10	14	230	15
631							0.5											
632							0.3	53	420	4.4	24	11	1.9	360	12	17	400	42
633							0.5											
634							0.6	58	360	1.9	25	11	2.0	360	11	17	210	24
635							0.5											
636							0.2	15	350	2.0	16	10	1.1	370	2.3	11	260	<15
637							0.2											
638							0.2	27	320	0.76	35	6.4	0.85	330	2.9	10	160	<15
639	0.00	95.14	4.24	0.63	4.86	3.33	0.2											
640							0.1											
641	13.59	59.07	19.29	8.05	27.34	3.88	0.2											
642							0.4											
643	0.00	59.48	33.10	7.42	40.52	4.32	0.3											
644							0.3											
645	2.99	65.57	24.49	6.95	31.44	3.56	0.3											
646							0.6											
647	0.00	79.89	15.95	4.16	20.11	3.02	0.3											
648							1.2											
649	0.00	0.88	76.05	23.07	99.12	6.47	1.2											
650							1.0	110	410	2.1	50	26	3.3	590	25	25	210	70
651							1.0											
652							0.8	81	420	2.2	44	19	2.9	500	20	25	230	41
653							0.5											
654	1.46	64.10			34.44		0.4	48	350	1.4	13	10	1.4	250	7.8	16	190	<15

Sample No.*	Gravel %	Textural Analysis Sand %	Silt %	Clay %	Mud %	Mean ϕ	TOC %	B ppm	Ba ppm	Ca %	Cr ppm	Geochemistry Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm

SHELF, cont.

Sample No.*	Gravel %	Sand %	Silt %	Clay %	Mud %	Mean ϕ	TOC %	B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
655							0.5											
656	0.65	74.28			25.07		0.4	62	340	1.1	41	9.4	1.6	320	5.8	17	180	<15
657							0.5											
658	1.11	78.49			20.40		0.3	54	620	3.2	23	7.0	2.3	630	8.8	15	320	16
659							0.1	55	480	2.0	17	4.8	1.5	500	5.4	15	250	<15
660	.03	97.03			2.94		0.1	25	270	0.48	29	4.8	1.0	290	2.7	13	45	<15
661	0.00	94.94	4.40	0.66	5.06	3.47	0.2											
662							0.2											
663							0.5											
664							0.4											
665	0.00	76.04	16.18	7.78	23.96	4.41	0.4											
666							0.4											
667	0.00	62.78	28.51	8.71	37.22	4.04	0.6											
668							0.3											
669	0.00	4.24	73.14	22.61	95.76	6.23	0.8											
670							1.4											
671	0.00	2.51	74.17	23.32	97.49	6.38	0.9											
672							0.9	90	420	2.2	48	18	3.1	530	23	24	250	46
673							0.6											
674	0.00	6.45			93.55		0.9	76	420	2.0	46	16	2.5	440	19	22	220	33
675							0.9											
676							0.4	54	380	1.4	39	12	1.6	280	8.3	16	200	15
677							0.5											
678	0.05	58.41			41.54		0.5	66	290	1.1	25	11	1.8	300	8.4	17	170	22
679							0.6											
680							0.4	57	300	1.3	23	12	1.5	320	7.1	14	180	<15
681							0.4											
682	0.04	96.47			3.49		0.2	28	240	0.55	23	9.6	0.82	240	2.3	9.4	120	<15
683	0.00	98.18	1.19	0.64	1.82	3.18	0.1											
684							0.2											
685	0.00	76.70	17.41	5.88	23.30	3.76	0.4											
686							0.4											
687	0.00	73.38	18.56	8.06	26.62	4.41	0.4											
688							0.4											
689	0.00	59.56	29.38	11.06	40.44	4.50	0.5											
690							0.7											
691	0.00	1.44	84.39	14.17	98.56	5.82	0.8											
692							1.1											
693	0.00	1.90	81.57	16.53	98.10	6.01	1.0											
694							0.9	77	350	1.8	36	15	2.6	410	18	21	190	35
695							0.8											
696							1.0	95	490	2.5	67	28	3.8	580	26	27	300	69
697							1.1											
698							0.6	62	420	2.3	50	17	2.5	390	16	21	240	32
699							0.4											
700							0.4	46	400	1.5	48	13	1.9	340	11	19	200	20
701							0.5											
702							0.4	65	410	1.7	27	16	2.0	430	14	20	210	23
703							0.3											

Sample No.*	Textural Analysis Gravel %	Sand %	Silt %	Clay %	Mud %	Mean ϕ	TOC %	Geochemistry B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
								SHELF, cont.										
704							0.1	26	340	1.0	39	8.7	1.1	340	2.3	9.8	200	<15
705	0.00	97.55	1.62	0.83	2.45	3.43	0.1											
706							0.2											
707	0.00	69.82	20.36	9.83	30.18	4.59	0.3											
708							0.4											
709	0.00	69.79	20.17	10.05	30.21	4.64	0.3											
710							0.4											
711	0.00	47.00	38.63	14.37	53.00	3.17	0.5											
712							0.7											
713	0.00	4.83	75.22	19.95	95.17	6.20	0.7											
714							0.8											
715	0.00	2.35	80.51	17.14	97.65	5.98	0.9											
716							0.9	94	500	2.6	81	30	3.5	600	28	31	250	69
717							0.8											
718							0.8	88	480	2.6	54	25	3.3	500	26	27	250	60
719							0.6											
720							0.8	58	430	1.9	41	18	2.3	350	14	19	220	27
721							0.5											
722	0.03	71.75			28.22		0.4	51	400	1.3	24	15	1.8	430	9.6	18	200	36
723							0.3											
724							0.4	56	420	2.3	20	16	2.1	510	11	19	260	25
725							0.4											
726	0.57	97.42			2.01		0.1	41	340	0.53	3.4	8.5	0.64	280	1.9	11	130	<15
727	0.00	97.78	1.57	0.65	2.22	3.50	0.2											
728							0.8											
729	0.00	78.25	13.51	8.24	21.75	4.46	0.7											
730							0.3											
731	0.00	78.14	15.35	6.50	21.86	4.18	0.5											
732							0.4											
733	0.00	52.47	33.63	13.89	47.53	4.98	0.7											
734							1.0											
735	0.00	4.25	75.24	20.51	95.75	6.26	1.0											
736							1.0											
737	0.00	9.39	64.54	26.06	90.61	6.42	1.0											
738	0.28	10.00			89.72		1.0	83	530	2.4	65	28	3.3	530	27	28	270	69
739							0.9											
740	0.05	8.57			91.38		0.9	87	490	2.9	61	29	3.4	510	26	30	280	61
741							0.9											
742							0.5	69	410	1.8	48	15	2.3	410	14	19	250	27
743							0.4											
744							0.5	52	340	1.0	15	13	1.7	350	8.6	15	200	20
745							0.2											
746	0.10	79.40			20.50		0.4	69	380	1.5	29	8.9	1.8	590	7.7	18	210	20
747							0.3											
748							0.1	32	290	0.39	3.4	5.2	1.3	400	2.2	12	45	<15
749	0.00	97.14	1.77	1.08	2.86	3.45	0.2											
750							0.3											
751	0.00	85.20	9.29	5.51	14.80	3.73	0.4											
752							0.8											

Sample No.*	Textural Analysis Gravel %	Sand %	Silt %	Clay %	Mud %	Mean ϕ	TOC %	Geochemistry B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
SHELF, cont.																		
753	0.00	72.30	18.82	8.88	27.70	4.53	0.3											
754							0.3											
755	0.00	37.85	43.69	18.46	62.15	5.62	0.8											
756							0.8											
757	0.00	4.75	73.87	21.38	95.25	6.33	1.0											
758							1.0											
759	0.00	8.63	69.02	22.35	91.37	6.27	1.0											
760							1.0	81	420	2.3	60	24	3.2	570	23	23	230	48
761							1.0											
762							0.9	81	510	2.6	68	22	3.0	540	23	23	250	64
763							0.7											
764							1.0	84	390	2.1	56	25	3.2	500	24	22	230	78
765							0.5											
766							0.5	56	490	2.0	51	8.7	2.0	390	9.8	15	260	28
767							0.5											
768							0.7	71	450	2.2	41	9.2	1.9	460	9.9	15	260	26
769							0.1											
770							0.2	69	400	0.79	44	4.1	1.5	470	4.2	9.7	180	<15
771	0.00	98.17	1.30	0.53	1.83	3.44	0.1											
772							0.1											
773	0.00	77.40	16.29	6.31	22.60	4.17	0.7											
774							0.3											
775	0.00	55.90	32.92	11.19	44.10	4.85	0.5											
776							0.1											
777	0.00	22.55	58.18	19.27	77.45	5.87	0.8											
778	0.00	35.63	49.90	14.47	64.37	5.36	0.6											
779							1.0											
780							0.9											
781	0.00	3.74	72.31	23.95	96.26	6.45	1.1											
782							0.8	110	480	2.0	48	26	3.6	540	24	23	250	58
783							1.0											
784	0.00	6.07			93.93		1.0	110	520	3.0	87	32	3.9	640	27	29	270	70
785							0.7											
786	0.00						0.5	87	600	2.6	56	14	2.8	440	18	20	260	36
787							0.5											
788	0.67	80.93			18.37		0.3	67	540	4.7	89	8.5	2.0	500	9.5	20	320	34
789							0.5											
790							0.5	59	470	1.4	44	5.8	1.7	560	7.4	16	230	17
791							0.3											
792	1.31	95.98			2.71		0.2	40	390	1.4	25	3.9	1.0	350	3.3	11	180	<15
793	0.00	97.24	1.98	0.78	2.76	3.54	0.2											
794							0.2											
795	0.00	68.74	19.71	11.55	31.26	4.78	0.3											
796							0.3											
797	0.00	89.68	7.69	2.63	10.32	3.72	0.3											
798							0.4											
799	0.00	44.89	41.40	13.71	55.11	5.19	0.7											
800							0.8											

Sample No.*	Gravel %	Textural Analysis Sand %	Silt %	Clay %	Mud %	Mean ϕ	TOC %	B ppm	Ba ppm	Ca %	Cr ppm	Geochemistry Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
									SHELF, cont.									
801	0.00	1.98	76.66	21.36	98.02	6.29	1.0											
802							1.1											
803	0.00	4.25	77.44	18.31	95.75	6.05	0.9											
804							1.0	120	440	2.0	67	31	4.0	580	27	28	270	82
805							0.9											
806							0.9	120	590	3.2	89	18	4.1	590	30	33	330	72
807							1.0											
808	1.09	39.47			59.44		0.6	86	600	3.6	55	16	2.8	420	20	25	320	48
809							0.8											
810							0.5	75	480	3.5	60	9.4	2.2	320	12	17	350	27
811							0.4											
812							0.2	78	430	1.2	74	5.1	1.7	520	7.0	14	210	20
813							0.2											
814							0.1	32	380	0.82	3.9	3.8	0.74	300	2.0	9.5	170	<15
815	0.00	97.91	1.73	0.36	2.09	3.51	0.1											
816							0.1											
817							0.2											
818							0.3											
819	1.31	69.87	19.46	9.37	28.83	4.53	0.5											
820							0.4											
821	0.00	38.99	47.02	13.99	61.01	5.23	0.5											
822							0.9											
823	0.00	5.52	77.63	16.85	94.48	5.89	0.9											
824							0.9											
825	0.00	2.54	78.40	19.06	97.46	6.10	0.9											
826							1.0	94	600	2.8	46	16	2.9	450	20	23	290	45
827							0.9											
828							0.9	95	460	2.4	53	27	3.4	490	24	22	230	51
829							0.7											
830							0.7	84	560	3.4	65	22	3.2	510	19	23	310	62
831							0.6											
832							0.5	61	430	2.2	45	12	2.4	460	13	17	240	34
833							0.4	75	410	1.8	63	10	2.4	600	14	20	240	29
834							0.2											
835							0.3											
836	0.98	96.23			2.79		0.2	54	350	1.4	58	4.1	0.87	300	4.0	9.9	150	<15
837	0.00	97.93	1.57	0.49	2.07	3.56	0.2											
838							0.2											
839		78.11	6.15	15.74	21.89	5.08	0.3											
840							0.4											
841	7.11	53.49	25.72	13.68	39.40	4.93	0.4											
842							0.6											
843	0.00	19.60	65.82	14.59	80.40	5.52	0.6											
844							0.9											
845	0.00	1.69	83.47	14.84	98.31	5.84	0.8											
846							0.7											
847	0.00	1.70	74.55	23.75	98.30	6.46	0.9											
848							1.0	61	440	2.2	46	8.9	2.2	450	9.3	16	240	23
849							0.9											

Sample No.*	Textural Analysis Gravel %	Sand %	Silt %	Clay %	Mud %	Mean φ	TOC %	Geochemistry B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
SHELF, cont.																		
850							0.9	97	450	2.3	30	8.3	2.1	440	8.9	17	250	19
851							0.9											
852							0.7	41	340	1.0	22	5.4	1.8	600	4.0	12	160	<15
853							0.6											
854							0.3	130	450	2.6	54	30	3.7	640	24	26	260	68
855							0.3											
856	0.19	77.42			22.39		0.3	120	410	2.7	58	31	3.8	540	26	25	250	70
857							0.4											
858							0.2	73	520	2.2	30	12	2.4	380	15	20	270	32
859	0.00	98.62	1.06	0.32	1.38	3.56	0.1											
860							0.2											
861	0.00	78.29	13.91	7.80	21.71	4.41	0.4											
862							0.4											
863	1.37	65.22	20.74	12.67	33.41	4.87	0.4											
864							0.4											
865	0.00	28.77	52.69	18.54	71.23	5.67	0.6											
866							0.9											
867	0.00	3.13	81.57	15.30	96.87	5.96	0.9											
868							0.7											
869	0.00	2.88	72.76	24.36	97.12	6.45	1.0											
870							1.0	64	370	2.5	52	5.9	1.6	340	7.0	14	270	19
871							1.0											
872							0.8	58	380	1.3	78	5.0	1.5	540	5.6	16	210	28
873							1.0											
874							0.6	30	310	1.6	43	4.4	0.83	260	2.1	13	180	<15
875							0.6											
876							0.5	120	440	2.4	51	26	3.4	520	22	24	240	68
877							0.3											
878							0.3	96	460	2.5	52	25	3.3	480	23	26	240	53
879							0.5											
880							0.2	80	460	3.1	46	13	2.6	450	16	17	290	46
881	0.00	97.57	1.63	0.80	2.43	3.50	0.2											
882							0.2											
883	0.00	72.92	16.38	10.70	27.08	4.60	0.4											
884							0.3											
885	0.00	60.08	25.87	14.05	39.92	4.97	0.4											
886							0.8											
887	0.00	50.46	35.51	14.04	49.54	5.08	0.9											
888							0.9											
889	0.00	7.73	71.40	20.87	92.27	6.09	0.9											
890							0.5											
891	0.00	0.88	71.82	27.30	99.12	6.67	0.8											
892							1.0	84	460	4.4	24	9.6	2.1	470	9.5	17	340	26
893							0.7											
894							0.9	51	380	1.2	41	4.5	1.4	400	4.9	13	190	<15
895							0.8											
896	0.07	28.04			71.88		0.5	33	340	1.6	120	3.8	0.76	250	2.4	12	150	<15
897							0.6											
898							0.4	88	590	2.8	49	16	2.7	420	19	23	290	44

Sample No.*	Gravel %	Textural Analysis Sand %	Silt %	Clay %	Mud %	Mean ϕ	TOC %	B ppm	Ba ppm	Ca %	Cr ppm	Geochemistry Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
								SHELF, cont.										
899							0.4											
900							0.4	30	280	0.67	22	3.5	0.64	280	2.7	11	130	<15
901							0.3											
902							0.2	54	370	2.3	25	10	1.8	340	9.8	16	190	19
903	0.00	96.85	2.15	1.00	3.15	3.58	0.2											
904							0.2											
905	0.00	76.90	16.85	6.25	23.10	4.13	0.4											
906							0.4											
907	0.00	67.37	21.94	10.69	32.63	4.72	0.4											
908							0.5											
909	0.00	26.28	59.09	14.63	73.72	5.48	0.5											
910							0.8											
911	0.00	3.68	78.11	18.21	96.32	6.15	1.0											
912							0.7											
913	0.00	1.46	80.99	17.55	98.54	6.10	1.0											
914							0.8	86	530	2.9	41	16	3.0	520	17	24	280	42
915							1.1											
916	0.00	5.72			94.28		1.0	100	440	3.1	61	26	3.5	570	23	22	230	63
917							1.0											
918							0.9	81	440	2.3	40	15	2.6	400	16	20	240	53
919							0.7											
920							0.5	62	330	2.0	17	9.5	1.7	330	8.4	12	200	27
921							0.5											
922							0.4	61	450	2.1	83	9.7	2.0	430	8.1	16	210	16
923							0.3											
924							0.2	34	300	0.82	3.1	4.3	0.70	320	2.5	10	130	<15
925	0.00	96.75	2.38	0.87	3.25	3.58	0.2											
926							0.2											
927	0.00	72.52	19.17	8.31	27.48	4.52	0.4											
928							0.3											
929	0.00	65.44	25.34	9.21	34.56	4.66	1.0											
930							0.7											
931	0.00	19.50	66.25	14.26	80.50	5.57	0.7											
932							0.6											
933	0.00	5.90	81.01	13.09	94.10	5.65	0.7											
934							0.9											
935	0.00	2.66	79.00	18.34	97.34	6.13	1.0											
936	0.00	6.29			93.71		1.0	100	520	2.5	56	29	2.9	520	21	26	210	59
937							1.0											
938	0.00	4.61			95.39		0.9	99	560	3.1	66	28	3.4	520	23	23	270	67
939							0.9											
940	0.15	28.36			71.48		0.8	90	500	2.7	40	20	2.9	430	19	24	250	55
941							0.4											
942	11.06	59.23			29.71		0.4	72	390	4.5	27	11	1.9	380	9.8	16	350	30
943							0.7											
944	0.38	73.99			25.63		0.4	50	400	1.4	92	7.5	1.7	440	6.8	15	180	<15
945							0.2											
946	0.05	97.16			2.79		0.2	39	280	0.42	25	3.8	0.53	240	2.1	<6.8	87	18

Sample	Textural Analysis							Geochemistry										
No.*	Gravel %	Sand %	Silt %	Clay %	Mud %	Mean ϕ	TOC %	B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm

SHELF, cont.

Sample No.*	Gravel %	Sand %	Silt %	Clay %	Mud %	Mean ϕ	TOC %	B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
947	0.00	97.49	1.91	0.61	2.51	3.53	0.2											
948							0.3											
949	0.00	67.17	25.15	7.69	32.83	4.52	0.4											
950							0.7											
951	0.00	56.98	32.32	10.70	43.02	4.81	0.6											
952							0.4											
952A							0.7											
953	0.00	7.29	75.82	16.89	92.71	5.90	0.9											
954							0.9											
955							1.0											
956							1.0											
957	0.00	3.11			96.89		1.1	120	420	2.7	63	24	4.0	550	25	30	210	79
958							0.9											
959							0.7	97	530	3.0	68	26	3.2	460	20	26	240	49
960							0.7											
961							0.7	89	550	3.2	40	19	3.0	420	18	23	250	59
962							0.6											
963							0.5	77	440	2.6	30	15	2.5	390	16	20	210	38
964							0.3											
965							0.2	47	380	1.0	17	5.3	1.3	400	6.5	10	160	<15
966							0.2											
967							0.2	42	290	0.73	16	5.1	0.73	240	2.4	11	110	<15
968	0.00	96.91	2.53	0.56	3.09	3.54	0.1											
969							0.2											
970	0.00	86.22	9.82	3.96	13.78	3.70	0.3											
971							0.4											
972	2.87	62.86	25.92	8.34	34.27	4.56	0.3											
973							0.6											
974	0.00	12.75	69.12	18.14	87.25	5.81	0.8											
975							0.7											
976	0.00	8.04	72.15	19.81	91.96	6.03	0.7											
977							0.7											
978	0.00	2.41	79.81	17.78	97.59	6.01	0.9											
979	0.03	8.41			91.56		0.8	95	450	2.7	53	23	3.0	480	20	25	220	44
980							0.3											
981							0.9	90	370	1.7	36	19	2.9	460	20	20	220	51
982							0.9											
983							0.6											
984	0.00	47.86	40.82	11.32	52.14	5.02	0.5	75	570	2.4	53	14	3.1	490	18	19	290	40
985							0.4											
986							0.4	71	490	2.4	39	11	2.5	550	14	21	280	34
987							0.3	64	390	1.7	29	7.9	1.6	360	8.3	11	160	<15
988							0.1											
989							0.2	25	340	0.77	4.2	4.9	0.72	260	2.4	7.8	120	<15
990	0.00	96.82	2.55	0.63	3.18	3.50	0.2											
991							0.6											
992	0.00	83.34	9.65	7.01	16.66	3.97	1.1											
993							0.4											

SHELF, cont.

Sample No.*	Gravel %	Sand %	Silt %	Clay %	Mud %	Mean ϕ	TOC %	B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
	Textural Analysis							Geochemistry										
994	0.00	70.60	21.60	7.80	29.40	4.49	0.4											
995	0.00	0.90	74.68	24.42	99.10	6.49	0.5											
996	0.00	20.52	62.23	17.25	79.48	5.70	0.8											
997							0.8											
998	0.00	5.20	73.19	21.61	94.80	6.29	1.0											
999							0.9											
1000	0.00	3.83	77.08	19.09	96.17	6.20	0.8											
1001							0.7	130	570	3.3	89	29	4.4	610	28	32	300	83
1002							1.0											
1003							0.8	110	590	3.1	67	<32	3.7	590	28	32	270	83
1004							0.7											
1005							0.8	100	440	2.5	53	25	3.2	580	21	25	250	81
1006							0.7											
1007	0.02	52.26			47.72		0.5	100	530	3.4	53	30	3.5	610	24	29	250	70
1008							0.3											
1009							0.3	68	400	0.86	36	7.9	1.6	570	8.1	15	210	18
1010							0.2											
1011							0.2	39	410	0.98	85	6.5	1.1	380	5.0	10	150	<15
1012	0.00	96.70	2.60	0.70	3.30	3.59	0.1											
1013							0.1											
1014	0.00	39.52	43.16	17.33	60.48	5.55	0.6											
1015							0.2											
1016							0.7											
1017							0.7											
1018							0.7											
1019							0.8											
1020	0.00	3.38	70.09	26.53	96.62	6.59	0.8											
1021							0.9											
1022	0.00	0.69	74.47	24.84	99.31	6.59	0.9											
1023							0.9	110	520	2.5	67	<32	3.6	500	29	29	260	70
1024							0.9											
1025	0.00	5.81			94.19		0.9	120	520	3.8	59	<32	3.2	570	23	26	250	73
1026							0.8											
1027							0.7	100	490	2.4	52	23	3.0	590	20	25	230	45
1028							0.6											
1029							0.5	85	520	2.5	73	13	2.6	550	14	21	260	38
1030							0.3											
1031	0.07	85.25			14.68		0.2	77	450	1.7	120	7.8	1.7	600	7.5	16	230	15
1032							0.3											
1033							0.1	61	330	0.77	40	4.4	0.78	320	3.4	9.3	120	<15
1034	0.00	95.70	3.51	0.78	4.30	3.55	0.1											
1035							0.1											
1036	0.00	85.70	9.23	5.07	14.30	3.76	0.2											
1037							0.4											
1038	0.00	71.18	19.03	9.79	28.82	4.71	0.4											
1039							0.6											
1040	0.00	12.14	68.69	19.17	87.86	5.94	0.9											
1041							0.9											
1042	0.00	8.62	75.43	15.94	91.38	5.77	0.8											

Sample No.*	Gravel %	Sand %	Silt %	Clay %	Mud %	Mean ϕ	TOC %	B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
	Textural Analysis							Geochemistry										
SHELF, cont.																		
1043							1.0											
1044	0.00	0.90	75.66	23.44	99.10	6.45	1.0											
1045	0.00	.92			99.08		1.2	150	590	3.5	86	21	4.5	560	28	36	250	80
1046							0.9											
1047							1.1	97	500	2.8	55	30	2.9	490	24	21	230	53
1048							0.9											
1049							0.7	110	570	2.4	52	23	3.4	520	22	20	270	49
1050							0.7											
1051							0.6	73	490	2.0	32	12	2.3	460	14	15	280	26
1052							0.3											
1053							0.2	63	470	1.7	44	7.6	1.8	480	9.3	15	250	18
1054							0.1											
1055							0.1	74	390	1.2	43	5.3	0.86	310	3.7	14	170	<15
1056	0.00	96.99	2.33	0.68	3.01	3.57	0.1											
1057							0.2											
1058	0.00	90.77	6.59	2.65	9.23	3.77	0.2											
1059							0.5											
1060	0.00	62.14	30.68	7.18	37.86	4.46	0.3											
1061							0.6											
1062	0.00	15.87	64.38	19.75	84.13	5.99	0.8											
1063							0.8											
1064	0.00	1.40	75.33	23.27	98.60	6.41	1.0											
1065							0.2											
1066	0.00	0.63	29.34	70.03	99.37		1.2											
1067	0.00	2.57			97.43		0.9	130	450	2.3	68	21	3.8	540	27	30	240	96
1068							1.0											
1069							0.8	96	550	3.0	67	26	3.7	500	25	24	230	53
1070							0.3											
1071	0.02	24.26			75.72		0.5	90	530	2.8	49	28	3.0	470	19	20	250	55
1072							0.2											
1073							0.5	76	440	2.7	45	21	2.6	500	17	20	250	45
1074							0.2											
1075	0.03	79.17			20.80		0.2	48	420	1.3	22	9.4	1.6	400	7.0	15	190	19
1076							0.1											
1077							0.1	38	260	0.47	42	5.4	0.66	280	2.7	10	94	<15
1078	0.00	95.56	3.32	1.13	4.44	3.54	0.1											
1079							0.1											
1080	0.00	90.15	6.07	3.78	9.85	3.73	0.2											
1081							0.3											
1082	0.00	58.28	31.86	9.86	41.72	4.75	0.3											
1083							0.5											
1084	0.00	21.04	67.32	11.64	78.96	5.28	0.7											
1085							0.9											
1086	0.00	3.84	75.89	20.27	96.16	6.20	0.8											
1087							0.8											
1088	0.00	0.93	69.94	29.13	99.07	6.93	0.9											
1089							1.1											
1090							0.8	110	390	2.5	64	<32	3.7	540	24	26	210	74
1091							1.0											

Sample No.*	Textural Analysis Gravel %	Sand %	Silt %	Clay %	Mud %	Mean ϕ	TOC %	Geochemistry B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
								SHELF, cont.										
1092							0.7	84	520	2.4	45	16	2.8	440	19	19	260	46
1093							0.6											
1094							0.7	70	430	2.5	37	16	2.4	420	13	18	230	31
1095							0.6											
1096							0.2	49	350	0.87	9.8	6.6	1.2	390	4.8	13	160	<15
1097							0.1											
1098							0.2	35	370	0.93	3.3	4.3	0.67	270	3.7	11	150	21
1099	0.00	95.67	3.13	1.20	4.33	3.60	0.2											
1100							0.1											
1101	0.00	94.29	3.38	2.33	5.71	3.74	0.2											
1102							0.2											
1103	0.00	52.92	35.96	11.12	47.08	4.84	0.5											
1104							0.7											
1105	0.00	16.95	58.89	24.16	83.05	6.15	0.8											
1106							0.8											
1107	0.01	5.82	66.73	27.44	94.17	6.42	0.9											
1108							1.1											
1109							1.1											
1110	0.00	3.93			96.07		1.1	100	470	3.6	66	31	3.6	620	24	29	240	70
1111							0.9											
1112	0.04	19.19			80.77		0.7	82	530	3.4	58	17	2.8	490	17	20	260	59
1113							0.7											
1114	0.00	28			72		0.8	100	380	2.3	49	26	3.1	520	19	20	220	62
1115							0.3											
1116	0.00	75			25		0.4	81	440	1.8	38	11	1.9	450	8.5	17	180	19
1117							0.2											
1118	1.00	96			4		0.1	18	300	0.54	16	3.7	0.57	240	3.2	9.1	110	<15
1119	0.00	96.98	2.33	0.69	3.02	3.60	0.3											
1120							0.8											
1121	0.00	93.97	4.24	1.79	6.03	3.69	0.2											
1122							0.6											
1123	0.00	25.42	50.78	23.80	74.58	6.25	0.6											
1124							0.6											
1125	0.00	26.27	52.30	21.43	73.73	5.89	0.7											
1126							0.7											
1127	0.00	1.56	68.78	29.67	98.44	6.84	1.1											
1128							0.9											
1129							0.4											
1130	0.00	1			99		1.0	96	530	2.9	58	31	3.1	630	21	26	240	72
1131							0.8											
1132	0.00	10			90		0.7	98	450	2.5	55	26	3.2	550	21	22	250	63
1133							0.7											
1134	0.00	34			66		0.6	94	400	2.1	41	18	2.6	460	16	16	230	41
1135							0.3											
1136	0.00	80			20		0.2	55	360	1.4	35	6.9	1.4	350	5.5	13	140	<15
1145	0.00	19.68	62.51	17.81	80.32	5.36	0.6											
1146							0.7											
1147	0.00	1.68	73.54	24.79	98.32	6.36	0.8											
1148							1.0											
1149							1.1											

APPENDIX C: DISTRIBUTION OF BENTHIC MACROINVERTEBRATES IN THE KINGSVILLE AREA

Distribution of Molluscan Species

Species	S	L	B	A	Total
Phylum Mollusca					
Class Polyplacophora Blainville, 1816					
Family Ischnochitonidae Dall, 1889					
Ischnochiton papillosus (C. B. Adams, 1845)		76			76
Class Gastropoda Cuvier, 1797					
Family Fissurellidae Fleming, 1822					
Diodora cayenensis (Lamarck, 1822)	D				
Diodora listeri (Orbigny, 1842)	D				
Lucapinella limatula (Reeve, 1850)	D				
Family Trochidae Rafinesque, 1815					
Calliostoma cf. *C. jujubinum* (Gmelin, 1791)	D				
Tegula fasciata (Born, 1778)	D				
Family Phasianellidae Swainson, 1840					
Tricolia affinis cruenta Robertson, 1958	D	D			
Family Neritidae Rafinesque, 1815					
Neritina virginea (Linné, 1758)	D	D			
Family Littorinidae Gray, 1840					
Littorina lineolata Orbigny, 1840		D			
Family Rissoidae Gray, 1847					
Alvania auberiana (Orbigny, 1842)	D				
Family Rissoinidae Stimpson, 1865					
Rissoina catesbyana Orbigny, 1842		D	D		
Zebina browniana (Orbigny, 1842)		D			
Family Littoridinidae Thiele, 1929					
Texadina barretti (Morrison, 1965)	D				
Texadina sphinctostoma (Abbott and Ladd, 1951)	D	D			
Family Stenothyridae Fischer, 1885					
Probythinella louisianae (Morrison, 1965)	D	D			
Family Truncatellidae Gray, 1840					
Truncatella caribaeensis Reeve, 1842		1	D	D	1
Family Vitrinellidae Bush, 1897					
Vitrinella floridana Pilsbry and McGinty, 1946	33	3	1		37
Vitrinella helicoidea C. B. Adams, 1850	1				1
Vitrinella sp.	D				
Cyclostremiscus pentagonus (Gabb, 1873)	4				4
Cyclostremiscus suppressus (Dall, 1889)	D	D			
Cyclostremiscus sp.	D				
Episcynia inornata (Orbigny, 1842)	D				
Parviturboides interruptus (C. B. Adams, 1850)	D				
Solariorbis blakei Rehder, 1944	D				
Solariorbis infracarinata Gabb, 1881	2				2
Teinostoma biscaynense Pilsbry and McGinty, 1945	D				
Teinostoma parvicallum Pilsbry and McGinty, 1945	1				1
Aorotrema cf. *A. pontogenes* (Schwengel and McGinty, 1942)	D				
Family Tornidae Sacco, 1896					
Macromphalina palmalitoris Pilsbry and McGinty, 1950	D				
Cochliolepis parasitica Stimpson, 1858	D				
Family Caecidae Gray, 1850					
Caecum bipartitum Folin, 1870	D				
Caecum cf. *C. condylum* D. R. Moore, 1969	D				
Caecum cooperi S. Smith, 1860	1				1
Caecum johnsoni Winkley, 1908	3	1			4
Caecum nitidum Stimpson, 1851	D	D	D		
Caecum pulchellum Stimpson, 1851	D	1,870	53	D	1,923
Family Turritellidae Clarke, 1851					
Vermicularia fargoi Olsson, 1951	D	D			
Family Architectonicidae Gray, 1850					
Architectonica nobilis Röding, 1798	D				
Heliacus bisulcatus (Orbigny, 1842)	1				1
Family Modulidae Fischer, 1884					
Modulus modulus (Linné, 1758)	D	D			
Family Potamididae H. and A. Adams, 1854					
Cerithidea pliculosa (Menke, 1829)		D			

S = Inner Shelf; L = Laguna Madre (including Intracoastal Waterway); B = Baffin Bay; A = Alazan Bay; D = Dead Only

Species	S	L	B	A	Total
Family Cerithiidae Fleming, 1822					
Cerithium lutosum Menke, 1828	D	89	4		93
Bittium varium (Pfeiffer, 1840)	D	75	10	1	86
Alabina cerithidioides (Dall, 1889)	D				
Cerithiopsis emersoni (C. B. Adams, 1838)	D				
Cerithiopsis greeni (C. B. Adams, 1839)	D				
Seila adamsi (H. C. Lea, 1845)	D	D			
Alaba incerta (Orbigny, 1842)	D		D		
Litiopa melanostoma Rang, 1829	D		D		
Family Triphoridae Gray, 1847					
Triphora nigrocincta (C. B. Adams, 1839)	D	D			
Family Epitoniidae S. S. Berry, 1910					
Amaea mitchelli (Dall, 1896)	D				
Epitonium angulatum (Say, 1830)	D				
Epitonium apiculatum (Dall, 1889)	2	D			2
Epitonium multistriatum (Say, 1826)	1	D	1		2
Epitonium novangliae (Couthouy, 1838)	D				
Epitonium rupicola (Kurtz, 1860)	D	D	D	D	
Family Eulimidae Risso, 1826					
Niso aeglees Bush, 1885	D				
Eulima bilineatus (Alder, 1848)	2				2
Eulima hemphilli (Dall, 1884)	2				2
Balcis arcuata (C. B. Adams, 1850)	D				
Balcis jamaicensis (C. B. Adams, 1845)	2	1			3
Family Aclididae G. O. Sars, 1878					
Aclis sp.	D				
Henrya goldmani Bartsch, 1947		D	D		
Family Calyptraeidae Blainville, 1824					
Crepidula convexa Say, 1822	D	58	48	D	106
Crepidula fornicata (Linne', 1758)	D	D			
Crepidula plana Say, 1822	D				
Family Strombidae Rafinesque, 1815					
Strombus alatus Gmelin, 1791	D				
Family Ovulidae Gray, 1853					
Simnialena marferula Cate, 1973	D				
Family Atlantidae Wiegmann and Ruthe, 1832					
Atlanta brunnea Gray, 1840	D				
Family Naticidae Gray, 1840					
Polinices duplicatus (Say, 1822)	7		D		7
Sigatica semisulcata (Gray, 1839)	D				
Natica canrena (Linne', 1758)	D				
Natica pusilla Say, 1822	140	D			140
Sinum perspectivum (Say, 1831)	1				1
Family Cymatiidae Iredale, 1913					
Cymatium cingulatum (Lamarck, 1822)	D				
Family Tonnidae Peile, 1926					
Tonna galea (Linne', 1758)	D				
Family Muricidae da Costa, 1776					
Murex fulvescens Sowerby, 1834	D				
Thais haemastoma (Linne', 1767)	D				
Family Columbellidae Swainson, 1815					
Costoanachis cf. *C. avara* (Say, 1821)		12	21		33
Costoanachis lafresnayi (Fischer and Bernardi, 1856)	1				1
Cosmioconcha calliglypta (Dall and Simpson, 1901)	D				
Suturoglypta iontha (Ravenel, 1861)	2				2
Parvanachis obesa (C. B. Adams, 1845)	9				9
Parvanachis ostreicola (Melvill, 1881)	D	2			2
Mitrella lunata (Say, 1826)	D	25	28	13	66
Family Buccinidae Rafinesque, 1815					
Cantharus cancellarius (Conrad, 1846)	12				12
Family Melongenidae Gill, 1867					
Busycon perversum (Linne', 1758)	D				
Busycon spiratum (Lamarck, 1816)	D				
Family Nassariidae Iredale, 1916					
Nassarius acutus (Say, 1822)	14	4			18
Nassarius vibex (Say, 1822)	D	D	2		2
Family Fasciolariidae Gray, 1853					
Fasciolaria lilium G. Fischer, 1807	D				
Family Olividae Latreille, 1825					
Oliva sayana Ravenel, 1834	10				10
Olivella dealbata (Reeve, 1850)	6				6
Olivella minuta (Link, 1807)	1				1
Family Cancellariidae Forbes and Hanley, 1853					

Species	S	L	B	A	Total
Trigonostoma rugosum (Lamarck, 1822)	D				
Family Marginellidae Fleming, 1828					
Prunum apicina (Menke, 1828)	D	D			
Family Terebridae H. and A. Adams, 1854					
Terebra concava Say, 1827	D				
Terebra dislocata (Say, 1822)	D				
Terebra protexta Conrad, 1845	50				50
Hastula salleana Deshayes, 1859	D				
Family Turridae Swainson, 1840					
Splendrillia (Syntomodrillia) woodringi (Bartsch, 1934)	D				
Pilsbryspira albocincta (C. B. Adams, 1845)	D				
Kurtziella rubella (Kurtz and Stimpson, 1851)	D				
Cryoturris cf. *C. cerinella* (Dall, 1889)	D				
Kurtziella dorvilliae (Reeve, 1845)	D				
Kurtziella fargoi (McGinty, 1955)	4				4
Cryoturris serga (Dall, 1881)	D				
Cryoturris adamsi (E. A. Smith, 1884)	D				
Ithycythara lanceolata (C. B. Adams, 1850)	1				1
Nannodiella vespuciana (Orbigny, 1842)	D				
Nannodiella oxia (Bush, 1885)	D				
Agathotoma metria (Dall, 1903)	D				
Pyrgocythara plicosa (C. B. Adams, 1850)		D			
Family Pyramidellidae Gray, 1840					
Pyramidella crenulata (Holmes, 1859)	D		D		
Fargoa bushiana Bartsch, 1909	D				
Fargoa dianthophila (Wells and Wells, 1961)	D	D			
Odostomia gibbosa Bush, 1909	D	24	11	5	40
Boonea impressa (Say, 1821)	D	D	1	D	1
Boonea seminuda (C. B. Adams, 1839)	D	D			
Sayella cf. *S. livida* Rehder, 1935	D	17	64	1	82
Sayella cf. *S. crosseana* (Dall, 1885)		14	14	D	28
Eulimastoma cf. *E. canaliculata* (C. B. Adams, 1850)	D	2			2
Eulimastoma engonia (Bush, 1885)	1	D			1
Eulimastoma harbisonae Bartsch, 1955	D	14	5	D	19
Eulimastoma weberi (Morrison, 1965)	D	D	D	D	
Peristichia toreta Dall, 1889	D				
Turbonilla unilirata Bush, 1899	D				
Turbonilla (Chemnitzia) sp. A	3				3
Turbonilla (C) sp. B	D	D			
Turbonilla (C) sp. C	D				
Turbonilla (C) sp. D	D				
Turbonilla (C) sp. F	2				2
Turbonilla elegans *(Orbigny, 1842)*	D	D			
Turbonilla (Pyrgiscus) sp. B	5	19	D		24
Turbonilla (P) sp. C	D	17			17
Turbonilla (P) sp. D	2				2
Turbonilla (P) sp. F	4	1			5
Turbonilla (P) sp. I	D				
Turbonilla (P) sp. ?	D				
Turbonilla (Strioturbonilla) sp. A	1				1
Turbonilla (S) sp. B	19				19
Turbonilla (S) sp. D	7				7
Turbonilla (cf. *Turbonilla*) sp. A	1				1
Cyclostremella humilis Bush, 1897	D				
Family Acteonidae Orbigny, 1842					
Acteon punctostriatus (C. B. Adams, 1840)	16	5	61	12	94
Family Acteocinidae Pilsbry, 1921					
Acteocina canaliculata (Say, 1822)	5	69	48	15	137
Family Cylichnidae A. Adams, 1850					
Cylichnella bidentata (Orbigny, 1841)	D	D			
Family Philinidae Gray, 1850					
Philine sp.	D				
Family Doridiidae Gray, 1847					
cf. *Doridium* sp. A	1				1
Family Bullidae Rafinesque, 1815					
Bulla striata Bruguière, 1792	D	D			
Family Haminoeidae Pilsbry, 1895					
Atys riiseana Mörch, 1875	D				
Haminoea antillarum (Orbigny, 1841)		D	D		
Haminoea succinea (Conrad, 1846)	D	4			4
Family Retusidae Thiele, 1926					
Pyrunculus caelatus (Bush, 1885)	D				
Volvulella persimilis Mörch, 1875	2				2
Volvulella texasiana Harry, 1967	11				11
Family Cuvieridae Gray, 1840					
Creseis acicula (Rang, 1828)	D				
Cavolina longirostris (Blainville, 1821)	D				
Family Arminidae Rafinesque, 1814					
Armina tigrina Rafinesque, 1814	1				1
Family Favorinidae Bergh, 1889					
cf. *Cratena kaoruae* Marcus, 1957		1			1

Species	S	L	B	A	Total
Class Bivalvia Linné, 1758					
Family Nuculidae Gray, 1824					
Nucula proxima Say, 1822	11				11
Family Nuculanidae Meek, 1864					
Nuculana acuta (Conrad, 1831)	2	266			268
Nuculana concentrica (Say, 1824)	15				15
Family Arcidae Lamarck, 1809					
Arca imbricata Bruguière, 1789	D				
Barbatia domingensis (Lamarck, 1819)	D				
Anadara brasiliana (Lamarck, 1819)	D	D	D		
Anadara transversa (Say, 1822)	9	D			9
Lunarca ovalis (Bruguière, 1789)	D	D			
Family Noetiidae Stewart, 1930					
Noetia ponderosa (Say, 1822)	2	D			2
Family Mytilidae Rafinesque, 1815					
Brachidontes exustus (Linné, 1758)	D	30	82	73	185
Lioberis castaneus (Say, 1822)	1				1
Musculus lateralis (Say, 1822)	1				1
Amygdalum papyrium (Conrad, 1846)		78	73	13	164
Family Pinnidae Leach, 1819					
Atrina serrata (Sowerby, 1825)	D				
Family Pectinidae Rafinesque, 1815					
Aequipecten muscosus (Wood, 1828)	D				
Argopecten gibbus (Linné, 1758)	D				
Argopecten irradians amplicostatus Dall, 1898		15	D		15
Family Plicatulidae Watson, 1930					
Plicatula gibbosa Lamarck, 1801	D				
Family Anomiidae Rafinesque, 1815					
Anomia simplex Orbigny, 1842	D				
Family Limidae Rafinesque, 1815					
Lima cf. *L. locklini* McGinty, 1955	D				
Family Ostreidae Rafinesque, 1815					
Ostreola equestris (Say, 1834)	D	D			
Crassostrea virginica (Gmelin, 1791)	D	D			
Family Lucinidae Fleming, 1828					
Linga amiantus (Dall, 1901)	110	D			110
Parvilucina multilineata (Tuomey and Holmes, 1857)	102	D	D	D	102
Lucina pectinata (Gmelin, 1791)		D			
Anodontia alba Link, 1807	D	D			
Divaricella quadrisulcata (Orbigny, 1842)	D				
Family Ungulinidae H. and A. Adams, 1857					
Diplodonta semiaspera (Philippi, 1836)	D				
Diplodonta soror C. B. Adams, 1852	38				38
Family Chamidae Lamarck, 1809					
Chama congregata Conrad, 1833	2				2
Chama macerophylla (Gmelin, 1791)	D				
Arcinella cornuta Conrad, 1866	D				
Family Kelliidae Forbes and Hanley, 1848					
Aligena texasiana Harry, 1969	D	9	D		9
Family Leptonidae Gray, 1847					
Lepton cf. *L. lepidum* Say, 1826	D				
Family Montacutidae Clark, 1855					
Mysella planulata (Stimpson, 1857)	2	77	10	27	116
Family Sportellidae Dall, 1899					
Ensitellops sp.	D				
Family Carditidae Fleming, 1820					
Carditamera floridana Conrad, 1838	D	D	D		
Family Crassatellidae Férussac, 1822					
Crassinella lunulata (Conrad, 1834)	6				6
Family Cardiidae Oken, 1818					
Trachycardium muricatum (Linné, 1758)	D	D			
Laevicardium laevigatum (Linné, 1758)	D				
Laevicardium mortoni (Conrad, 1830)	D	48	15	D	63
Dinocardium robustum (Lightfoot, 1786)	D				
Family Mactridae Lamarck, 1809					
Mactra fragilis Gmelin, 1791	D	D	D		
Mulinia lateralis (Say, 1822)	3	183	213	86	485
Rangia flexuosa (Conrad, 1839)	D	D			
Anatina anatina (Spengler, 1802)	2				2
Raeta plicatella (Lamarck, 1818)	D				
Family Mesodesmatidae Gray, 1839					
Ervilia concentrica (Holmes, 1860)	D				
Family Solenidae Lamarck, 1809					

Species	S	L	B	A	Total
Solen viridis	20				20
Say, 1821					
Ensis minor		74	D		74
Dall, 1900					
Family Tellinidae					
Blainville, 1814					
Tellina aequistriata	1				1
Say, 1824					
Tellina alternata	8				8
Say, 1822					
Tellina iris	13				13
Say, 1822					
Tellina tampaensis		37	4	D	41
Conrad, 1866					
Tellina texana		188	7	D	195
Dall, 1900					
Tellina versicolor	46				46
DeKay, 1843					
Tellidora cristata	1				1
(Récluz, 1842)					
Strigilla mirabilis	D				
(Philippi, 1841)					
Macoma tageliformis	1				1
Dall, 1900					
Macoma tenta	D	1	D		1
(Say, 1834)					
Family Donacidae					
Fleming, 1828					
Donax variabilis	D	D			
Say, 1822					
Family Semelidae					
Schumacher, 1817					
Semele bellastriata	D				
(Conrad, 1837)					
Semele nuculoides	5				5
(Conrad, 1841)					
Semele proficua	D				
(Pulteney, 1799)					
Cumingia tellinoides		35	1		36
(Conrad, 1831)					
Abra aequalis	511				511
(Say, 1822)					
Family Solecurtidae					
Orbigny, 1846					
Solecurtus cumingianus	D				
Dunker, 1861					
Tagelus divisus		4	D		4
(Spengler, 1794)					
Tagelus plebeius	D	7	163	11	181
(Lightfoot, 1786)					
Family Dreissenidae					
Gray, 1840					
Mytilopsis leucophaeata		D			
(Conrad, 1831)					
Family Corbiculidae					
Gray, 1847					
Polymesoda maritima		20			20
(Orbigny, 1842)					
Family Veneridae					
Rafinesque, 1815					
Mercenaria campechiensis	D				
(Gmelin, 1791)					
Chione cancellata	D	4	2		6
(Linné, 1767)					
Chione clenchi	3				3
Pulley, 1952					
Chione grus	D				
(Holmes, 1858)					
Chione intapurpurea	D				
(Conrad, 1849)					
Anomalocardia auberiana	D	7	3	D	10
(Orbigny, 1842)					
Gouldia cerina	D				
(C. B. Adams, 1845)					
Pitar sp.	D				
Agriopoma texasiana	2				2
(Dall, 1892)					
Dosinia discus	4				4
(Reeve, 1850)					
Dosinia elegans	1				1
Conrad, 1846					
Cyclinella tenuis	D	1			1
(Récluz, 1852)					
Family Petricolidae					
Deshayes, 1831					
Petricola pholadiformis		D			
(Lamarck, 1818)					
Family Myidae					
Lamarck, 1809					
Paramya subovata	D				
(Conrad, 1845)					
Family Corbulidae					
Lamarck, 1818					
Varicorbula operculata	D				
(Philippi, 1848)					
Corbula caribaea	2	D			2
Orbigny, 1842					
Corbula contracta	11				11
Say, 1822					
Corbula dietziana	D				
C. B. Adams, 1852					
Family Gastrochaenidae					
Gray, 1840					
Gastrochaena hians	D				
(Gmelin, 1791)					
Family Hiatellidae					
Gray, 1824					
Hiatella arctica	D				
(Linné, 1767)					
Family Pholadidae					
Lamarck, 1809					
Martesia cuneiformis	D				
(Say, 1822)					
Family Lyonsiidae					
Fischer, 1887					
Lyonsia hyalina floridana		161	28	5	194
Conrad, 1849					
Family Pandoridae					
Rafinesque, 1815					
Pandora bushiana	D				
Dall, 1886					
Pandora trilineata	D				
Say, 1822					
Family Periplomatidae					
Dall, 1895					
Periploma margaritaceum	27				27
(Lamarck, 1801)					
Periploma orbiculare	D				
Guppy, 1878					
Periploma sp.	1				1
Family Cuspidariidae					
Dall, 1886					
Cardiomya ornatissima	D				
(Orbigny, 1842)					
Class Scaphopoda					
Bronn, 1862					
Family Dentaliidae					
Gray, 1834					
Dentalium eboreum	9				9
Conrad, 1846					
Dentalium texasianum	7	D			7
Philippi, 1848					
Family Siphonodentaliidae					
Simroth, 1894					
Cadulus carolinensis	37				37
Bush, 1885					

Distribution of Polychaete Species

Species	S	L	B	A	Total
Phylum Annelida					
Class Polychaeta					
Family Spionidae Grube, 1850	16				16
Paraprionospio pinnata (Ehlers, 1901)	1,005	6	16	16	1,043
Apoprionospio pygmaea (Hartman, 1961)	380				380
Spiophanes bombyx (Claparède, 1870)	218				218
Prionospio heterobranchia Moore, 1907	8	391	186		585
Spio pettiboneae Foster, 1971	2	28	7		37
Scolelepis texana Foster, 1971	2	2	1		5
Streblospio benedicti Webster, 1879		112	20	7	139
Polydora ligni Webster, 1879	4	34	1	6	45
Polydora socialis (Schmarda, 1861)		17	17	6	40
Polydora caulleryi Mesnil, 1897	1				1
Malacoceros vanderhorsti (Augener, 1927)	16				16
Laonice cirrata (Sars, 1851)	1				1
Prionospio steenstrupi Malmgren, 1867	14	3			17
Minuspio cirrifera (Wiren, 1883)	12				12
Minuspio cirrobranchiata (Day, 1961)	10				10
Carazziella hobsonae Blake, 1979	2	11			13
Prionospio cristata Foster, 1971	17				17
Scolelepis squamata (Müller, 1806)		2			2
Minuspio sp.	7	1			8
Scolelepis sp.		4	2		6
Prionospio sp.	11	1			12
Polydora sp.	3	1	3		7
Malacoceros sp.	3				3
Prionospio cf. *P. steenstrupi*	1				1
Polydora cf. *P. concharum* Verrill, 1880			19		19
Polydora cf. *P. aggregata* Blake, 1969	2				2
Polydora cf. *P. quadrilobata*	1				1
Spiophanes sp. A.	3				3
Family Nereidae Johnston, 1845					
Platynereis dumerilii (Audouin and Milne Edwards, 1833)		60	5	1	66
Nereis succinea Frey and Leuckart, 1847	9	1	46	6	62
Nereis micromma Harper, 1979	227				227
Nereis lamellosa Ehlers, 1868	1				1
Nereis falsa Quatrefages, 1865	1				1
Ceratocephale oculata Banse, 1977	10				10
Ceratonereis irritabilis (Webster, 1879)		10			10
Family Capitellidae Grube, 1862		2			2
Capitella capitata (Fabricius, 1780)		43	34	25	102
Mediomastus californiensis Hartman, 1944	254	388	84	16	742
Heteromastus filiformis (Claparède, 1864)		82	3		85
Notomastus hemipodus Hartman, 1945	30	2			32
Notomastus latericeus Sars, 1851	22	6			28
Notomastus americanus Day, 1973	8				8
Notomastus cf. *N. latericeus*	2				2
Notomastus cf. *N. daueri* Ewing, 1982	7				7
Notomastus sp.	12	2			14
Notomastus cf. *N. lobatus* Hartman, 1947	2				2
Capitomastus sp.		2			2
Family Lumbrineridae Malmgren, 1867					
Ninoë cf. *N. nigripes* Verrill, 1873	32				32
Lumbrineris verrilli Perkins, 1979	912				912
Lumbrineris ernesti Perkins, 1979	84				84
Lumbrineris januarii (Grube, 1878)	36				36
Lumbrineris cf. *L. magalhaensis* Kinberg, 1865	1				1
Lumbrineris tenuis Verrill, 1873	32				32
Lumbrineris sp.	7				7
Lumbrinerides sp.	1				1
Family Paraonidae Cerruti, 1909					
Aricidea taylori Pettibone, 1965	403				403
Aricidea fragilis Webster, 1879	52				52
Tauberia gracilis (Tauber, 1879)	27				27
Aricidea wassi Pettibone, 1965	43				43
Cirrophorus branchiatus Ehlers, 1908	4				4
Cirrophorus sp.	74				74
Aricidea sp.	46				46
Aricidea cf. *A. wassi*	2				2
Aricidea (Acesta) sp.	8				8
Family Maldanidae Malmgren, 1867					
Clymenella torquata (Leidy, 1855)	16	29	1		46
Asychis elongatus (Verrill, 1873)	1	13			14
Asychis sp.	59	4			63
Euclymene lombricoides (Quatrefages, 1865)	2	4			6
Axiothella mucosa (Andrews, 1891)	1	45	7		53
Euclymene sp. A		11			11

S = Inner Shelf; L = Laguna Madre (including Intracoastal Waterway); B = Baffin Bay; A = Alazan Bay

Species	S	L	B	A	Total
Euclymeninae	2	1			3
Euclymene sp.	24	14			38
Axiothella sp.	5				5
Family Oweniidae Rioja, 1917					
Owenia fusiformis Delle Chiaje, 1844	283				283
Family Goniadidae Kinberg, 1866					
Glycinde solitaria (Webster, 1879)		37	14		51
Glycinde cf. *G. nordmanni* (Malmgren, 1865)		12	4		16
Glycinde sp.	2	2		1	5
Goniada teres Treadwell, 1931	2				2
Goniada littorea Hartman, 1950	10				10
Goniada sp.	2				2
Family Cossuridae Day, 1963					
Cossura delta Reish, 1958	249				249
Family Amphinomidae Savigny, 1818					
Pseudeurythoe ambigua (Monro, 1933)	35	1			36
Family Onuphidae Kinberg, 1865					
Diopatra cuprea (Bosc, 1802)	90	18	8	2	118
Onuphis eremita oculata Hartman, 1951	24				24
Onuphis texana Fauchald, 1982	91				91
Kinbergonuphis virgata (Fauchald, 1980)	13				13
Kinbergonuphis sp. A	2				2
Onuphis sp.	3				3
Family Pilargidae Saint-Joseph, 1899					
Sigambra tentaculata (Treadwell, 1941)	48				48
Litocorsa antennata Wolf, 1986	42				42
Cabira pilargiformis (Uschakov and Wu, 1962)	3	1			4
Ancistrosyllis commensalis Gardiner, 1975	1	6			7
Ancistrosyllis jonesi Pettibone, 1966	7	2			9
Cabira incerta Webster, 1879	4				4
Pilargis berkeleyae Monro, 1933	1				1
Pilargis sp.	1				1
Cabira sp.	1				1
Pilargis cf. *P. berkeleyae*	1				1
Ancistrosyllis sp.	3	1			4
Family Glyceridae Grube, 1850					
Glycera americana Leidy, 1855	20	7			27
Glycera cf. *G. oxycephala* Ehlers, 1887	1				1
Glycera sp.	12	1			13
Ophioglycera sp.	2				2
Family Pectinariidae					
Pectinaria gouldii (Verrill, 1873)	2	3	16	3	24
Pectinaria cf. *P. meredithi* Long, 1973			1		1
Pectinaria sp.	1				1

Species	S	L	B	A	Total
Family Orbiniidae Hartman, 1942					
Scoloplos fragilis (Verrill, 1873)	8	1	1		10
Scoloplos foliosus Hartman, 1951	170	5			175
Scoloplos rubra (Webster, 1879)	21	9	1		31
Scoloplos robustus (Verrill, 1873)		2			2
Scoloplos sp.	14		1		15
Naineris laevigata (Grube, 1856)		22			22
Family Nephtyidae Grube, 1850					
Aglaophamus verrilli (McIntosh, 1885)	222				222
Nephtys incisa Malmgren, 1865	45				45
Nephtys bucera Ehlers, 1868	14				14
Nephtys picta Ehlers, 1868	2				2
Family Sigalionidae Malmgren, 1867					
Sthenelais boa (Johnston, 1833)	50				50
Sthenolepis sp.	2				2
Family Dorvilleidae Chamberlin, 1919					
Protodorvillea kefersteini (McIntosh, 1869)		1			1
Schistomeringos rudolphi (Delle Chiaje, 1828)	3	21	9	3	36
Family Polynoidae Malmgren, 1867					
Harmothoe imbricata (Linné, 1767)	1				1
Lepidonotus sublevis Verrill, 1873	5				5
Lepidasthenia sp.	11				11
Gattyana sp.	1				1
Eunoe sp.	1	6			7
Polynoid sp. C	1				1
Harmothoe-Eunoe sp.	3				3
Lepidametria commensalis Webster, 1879			1		1
Family Cirratulidae Carus, 1863					
Tharyx marioni (Saint-Joseph, 1894)	160	2			162
Tharyx setigera Hartman, 1845	11				11
Cirratulus hedgpethi Hartman, 1951	2				2
Chaetozone setosa Malmgren, 1867	4				4
Family Polyodontidae Buchanan, 1894					
Polyodontes lupinus (Stimpson, 1856)	2				2
Eupanthalis kinbergi McIntosh, 1876	1				1
Eupanthalis sp. A	2				2
Family Magelonidae Cunningham and Ramage, 1888					
Magelona pettiboneae Jones, 1963	196	53	1		250
Magelona riojai Jones, 1963	32				32
Magelona sp. A	57	1			58
Magelona cf. *M. phyllisae* Jones, 1963	2,120				2,120

Species	S	L	B	A	Total
Magelona sp. C	2				2
Magelona cf. *M. riojai*	6				6
Magelona sp.	1				1
Magelona polydentata Jones, 1963		1			1
Family Phyllodocidae Williams, 1851		1			1
Eteone heteropoda Hartman, 1951	6	34	16	1	57
Eteone lactea Claparède, 1868	1	1			2
Genetyllis castanea (Marenzeller, 1879)		1	1		2
Anaitides mucosa Oersted, 1843	1	1			2
Eumida sanguinea Oersted, 1843		9	2		11
cf. *Protomystides*			4		4
Phyllodoce sp.	4				4
Family Arabellidae Hartman, 1944					
Arabella iricolor (Montagu, 1804)	6				6
Drilonereis magna Webster and Benedict, 1887	8				8
Family Hesionidae Sars, 1862	11				11
Podarkeopsis levifuscina Perkins, 1984	12	16	1	2	31
Podarke obscura Verrill, 1873		9			9
Parahesione luteola (Webster, 1880)		1			1
Heteropodarke lyonsi Perkins, 1984	11				11
Family Eulepethidae Chamberlin, 1919					
Grubeulepis mexicana (Berkeley and Berkeley, 1939)	11				11
Grubeulepis cf. *G. ecuadorensis* Pettibone, 1969	1				1
Family Sabellidae Malmgren, 1867	1				1
Potamilla reniformis (Müller, 1771)		36			36
Megalomma pigmentum Reish, 1963			1		1
Chone duneri Malmgren, 1867	25	367	7		399
Sabella micropthalma Verrill, 1873		2			2
Family Syllidae Grube, 1850					
Exogone dispar Webster, 1879	3	158	51		212
Typosyllis (Langerhansia) sp.		223	94		317
Sphaerosyllis taylori Perkins, 1980	4	10			14
Brania sp.		1		1	2
Streptosyllis arenae (Webster and Benedict, 1884)	1				1
Syllis sp.	1				1
Autolytus sp.	1				1
Family Chaetopteridae Malmgren, 1867					

Species	S	L	B	A	Total
Spiochaetopterus c. oculatus Webster, 1879	18	9			27
Family Trichobranchidae Malmgren, 1866					
Terebellides stroemi Sars, 1835	39				39
Family Chrysopetalidae Ehlers, 1864					
Bhawania heteroseta (Hartman, 1945)	9				9
Family Ampharetidae Malmgren, 1867					
Melinna maculata Webster, 1879	10	267	1		278
Isolda pulchella Müller, 1858	41				41
Ampharete parvidentata Day, 1973		1			1
Ampharete cf. *A. americana* Day, 1973	1				1
Family Terebellidae Malmgren, 1867					
Loimia medusa (Savigny, 1818)	4	3			7
Pista palmata (Verrill, 1873)	4	33	2		39
Pista quadrilobata (Augener, 1918)	4		8	33	45
Polycirrus sp.	2				2
Pista cf. *P. brevibranchia* Caullery, 1915	1				1
Pista cristata (Müller, 1776)	2				2
Amaeana trilobata (Sars, 1863)	4				4
Pista brevibranchia Caullery, 1915		6			6
Pista sp.			1		1
Family Serpulidae Johnston, 1865	1				1
Hydroides dianthus (Verrill, 1873)		8			8
Spirorbis corrugatus (Montagu, 1803)		89			89
Serpula sp.		1			1
Spirorbis spirillum Linné, 1767			2		2
Family Eunicidae Savigny, 1818					
Marphysa sanguinea (Montagu, 1815)	5	2			7
Family Opheliidae Malmgren, 1867					
Armandia agilis (Andrews, 1891)	136				136
Armandia maculata (Webster, 1884)	19	7			26
Family Arenicolidae Johnston, 1835					
Arenicola cristata Stimpson, 1956		3			3
Family Flabelligeridae Saint-Joseph, 1894					
Piromis cf. *P. roberti* (Hartman, 1951)	1				1

Distribution of Crustacean Species

Species	S	L	B	A	Total
Phylum Arthropoda					
Class Crustacea					
Order Mysidacea					
Bowmaniella cf. *B. dissimilis* Coifmann, 1937			2		2
Mysidopsis almyra Bowman, 1964	2	1			3
Order Cumacea					
Cyclaspis varians Calman, 1912	4	7	31	9	51
Eudorella monodon Calman, 1912	1				1
Oxyurostylis salinoi Da Silva Brum, 1966	14	250	26		290
Order Apseudidae					
Apseudes sp.	54				54
Order Tanaidacea					
Hargeria rapax (Harger, 1879)		8	10		18
Order Isopoda					
Ancinus depressus (Say, 1818)	8				8
Edotea montosa (Stimpson, 1853)	2	11	10	21	44
Erichsonella filiformis isabellensis Menzies, 1951		8			8
Erichsonella attenuata (Harger, 1873)		14	17	2	33
Harrieta faxoni (Richardson, 1905)		63	145	61	269
Xenanthura brevitelson Barnard, 1925	33				33
Anthelura sp.	9				9
Order Amphipoda					
Family Ampeliscidae					
Ampelisca abdita Mills, 1964		152	1,238	102	1,492
Ampelisca agassizi (Judd, 1896)	1,642				1,642
Ampelisca verrilli Mills, 1967	153				153
Ampelisca sp.	8	2	1		11
Family Ampithoidae					
Cymadusa compta (Smith, 1873)	1	19	44	4	68
Family Aoridae					
Grandidierella bonnieroides Stephensen, 1848		32	277	85	394
Lembos cf. *L. processifer* (Pirlot, 1938)		3			3
Unciola irrorata Say, 1818	27				27
Family Corophiidae					
Cerapus tubularis Say, 1817	7	35	14		56
Corophium acherusicum Costa, 1857	1	2	10		13
Ericthonius brasiliensis (Dana, 1853)	10	29	5		44
Family Haustoriidae					
Acanthohaustorius sp.	59				59
Protohaustorius cf. *P. bousfieldi* Robertson and Shelton, 1978	5				5
Platyschnopus sp.	110				110

S = Inner Shelf; L = Laguna Madre (including Intracoastal Waterway); B = Baffin Bay; A = Alazan Bay

Species	S	L	B	A	Total
Family Liljeborgiidae					
Listriella bahia McKinney, 1979		4			4
Listriella barnardi Wigley, 1973	8				8
Family Melitidae					
Melita nitida Smith, 1873			4		4
Elasmopus levis (Smith, 1873)		46	22	21	89
Netamelita barnardi McKinney, Kalke, and Holland, 1978	7				7
Family Oedicerotidae					
Monoculodes cf. *M. nyei* Shoemaker, 1935	54	1			55
Synchelidium americanum Bousfield, 1973	8				8
Family Phoxocephalidae					
Trichophoxus floridanus (Shoemaker, 1933)	149				149
Family Pontogeneiidae					
Pontogeneia cf. *P. bartschi* (Shoemaker, 1948)	1	17	25		43
Family Gammaridae					
Gammarus mucronatus (Say, 1818)		2			2
Family Amphilochidae					
Gitanopsis laguna McKinney, 1978	4		8		12
Gitanopsis sp.	2				2
Family Isaidae					
Microprotopus raneyi Wigley, 1966	5				5
Photis macromanus McKinney, Kalke, and Holland, 1978	9				9
Photis sp.	11		2		13
Family Synopiidae					
Tiron tropakis Barnard, 1972	2				2
Family Stenethoidae					
Parametopella texensis McKinney, Kalke, and Holland, 1978	2				2
Family Bateadae					
Batea catharinensis Müller, 1865	1				1
Suborder Caprellidea		39	8	3	50
Suborder Hyperiidea	3				3
Order Stomatopoda					
Family Squillidae					
Squilla empusa Say, 1818	1				1
Order Decapoda					
Family Sergestidae					
Acetes americanus Ortmann, 1893	6				6
Family Pasaphaeidae					
Leptochela serratorbita Bate, 1888	5				5
Family Alpheidae					
Alpheus floridanus Kingsley, 1878	1				1
Alpheus heterochaelus Say, 1818			1		1
Automate cf. *A. evermanni* Rathbun, 1901	4				4

Species	S	L	B	A	Total
Family Thalassinidae					
Callianassa latispina Dawson, 1967	1				1
Family Paguridae					
Pagurus sp.	17				17
Pagurus longicarpus Say, 1817	7				7
Pagurus bullisi Wass, 1963	1				1
Family Albuneidae					
Albunea paretii Guérin, 1853	11				11
Family Portunidae					
Portunus cf. *P. ventralis* (A. Milne-Edwards, 1879)	3				3
Family Xanthidae					
Panopeus herbstii H. Milne-Edwards, 1834	2				2
Pilumnus sp.	1				1
Rhithropanopeus harrisii (Gould, 1941)	5	10	5		20
Neopanope texana (Stimpson, 1859)	3		1		4
Eurypanopeus depressus (Smith, 1869)	3				3
Micropanope cf. *M. sculptipes* Stimpson, 1871			1		1

Species	S	L	B	A	Total
Platypodiella cf. *P. spectabilis* (Herbst, 1794)	2				2
Family Goneplacidae					
Speocarcinus lobatus Guinot, 1969	3				3
Family Pinnotheridae					
Pinnixa cf. *P. chaetopterana* Stimpson, 1860	2				2
Pinnixa cf. *P. retinens* Rathbun, 1918		1			1
Pinnixa sayana Stimpson, 1860	6	5	1		12
Family Dromiidae					
Hypoconcha spinosissima Rathbun, 1933	1				1
Family Porcellanidae					
Euceramus praelongus Stimpson, 1860	15				15
Family Penaeidae					
Trachypeneus constrictus (Stimpson, 1871)	5				5
Family Palaemonidae					
Palaemonetes pugio Holthuis, 1949		1			1
Pereclimenes cf. *P. longicaudatus* (Stimpson, 1860)	4				4
Order Pycnogonidea		1			1

Distribution of Other Phyla

Species	S	L	B	A	Total
Phylum Cnidaria					
Class Anthozoa					
Order Actiniaria	10	9		83	102
Order Zoanthidea					
cf. *Palythoa texaensis* Carlgren and Hedgpeth, 1952	218				218
Order Pennatulacea					
Family Renillidae					
Renilla mülleri Kölliker, 1872	1				1
Family Pennatulacea	9				9
Class Hydrozoa					
Hydroid polyps	*				
Phylum Platyhelminthes					
Class Turbellaria					
Order Polycladida	3	37			40
Phylum Nemertinea					
Nemerteans (unidentified)	212	33	38	10	293
Phylum Aschelminthes					
Class Nematoda	14	1	2		17
Phylum Chaetognatha					
Chaetognaths (unidentified)	4				4
Phylum Bryozoa					
Bryozoans (unidentified)	*				
Phylum Phoronida					
Phoronis architecta Andrews, 1890	23	5	1		29
Phylum Annelida					
Class Oligochaeta		5	11		16

Species	S	L	B	A	Total
Phylum Sipunculida					
Phascolion strombi (Montagu, 1804)	24	142			166
Family Aspidosiphonidae	13				13
Phylum Echinodermata					
Class Ophiuroidea					
Hemipholis elongata (Say, 1825)	2	1			3
Microphiopholis atra (Stimpson, 1852)	7	18			25
Brittlestars (unidentified)	15				15
Class Holothuroidea					
Leptosynapta crassipatina Clark, 1924		16			16
Pentamera pulcherrima Ayres, 1854		27			27
cf. *Thyone* sp.	1				1
Class Asteroidea					
Luidia alternata (Say, 1825)	1				1
Phylum Hemichordata					
Class Enteropneusta	40				40
Phylum Chordata					
Subphylum Cephalochordata					
Branchiostoma sp.	6				6
Subphylum Vertebrata					
Juvenile fish	4	1			5
Family Ophichthidae					
Myrophis punctatus Lütken	3				3

S = Inner Shelf; L = Laguna Madre (including Intracoastal Waterway);
B = Baffin Bay; A = Alazan Bay
*Present (not counted)