SUBMERGED LANDS OF TEXAS, BROWNSVILLE-HARLINGEN AREA: SEDIMENTS, GEOCHEMISTRY, BENTHIC MACROINVERTEBRATES, AND ASSOCIATED WETLANDS

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PREFACE

The utility of the Bureau of Economic Geology's Environmental Geologic Atlas series (1972-1980) in providing 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 on the Galveston-Houston area is the second of seven atlases that will 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, the number of applications processed by the General Land Office of Texas for various types of easements and permits within submerged and associated State coastal lands approximates 1,000 a year. Consolidated tonnage handled by Texas ports increased from about 193 million tons in 1970 to more than 347 million tons in 1979. In 1976-77, commercial and sports fishing activities, together, produced more than $550 million in gross business (direct and indirect) as well as more than $150 million annually in personal income in Texas. Mineral receipts by the State of Texas from coastal lands in FY 1980 were in excess of $200 million and in FY 1982 totaled about $277 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 natural processes, climatic conditions, and human activities. Geologically, the bay-estuary-lagoon and inner-shelf systems, which comprise 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, humans and their activities are so much a part of the system that they, too, must be considered integrally connected to it. Human activities can have a significant and often immediate effect on both a local and sometimes regional scale. Investigating and understanding the resulting cause and effect relationships is 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 of sediment textural parameters, sediment geochemistry, benthic macroinvertebrates, and associated wetlands. Identifying, mapping, and characterizing these essential components of nearshore coastal environments provide important baseline information in 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 new atlas series was designed, in part, to complement the Bureau's Environmental Geological 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, and lagoons, and the inner continental shelf. In one area of Laguna Madre samples were collected at 0.5-mi (0.8-km) intervals. In addition, the distribution of wetlands in adjacent areas was mapped using color infrared photographs taken primarily in 1979.

Textural maps of the Brownsville-Harlingen area show that sand and muddy sand, having a mean grain size of between 2.5ϕ and 5ϕ, are the dominant sediment types in bay-estuary-lagoon and inner-shelf areas. Generally, in Laguna Madre sands occur on the barrier island side of the lagoon, whereas muddier sediments are more abundant along the mainland side and in deeper areas. Muddy sand is dominant in the relatively wide southern end of Laguna Madre, and sand is dominant along the narrower, northern two-thirds of the lagoon where broad sandy wind-tidal flats on Padre Island grade into shallow subaqueous lagoon sands. Dominantly sand-sized sediments blanket most of the inner shelf and extend about 10 mi (16 km) offshore from Padre Island. The greatest extent of sand is associated with marine reworked late Pleistocene fluvial-deltaic deposits that underlie much of the inner shelf. Water depths average about 90 ft (30 m) at the outer limits of this sand-rich area. A nearshore patch of mud occurs near the mouth of the Rio Grande and represents the most recent deposition of the river. To the east and north the mud grades into muddy sand that represents a mixture of relict shelf sands and more modern fluvial muds.

Of approximately 30 major and trace elements analyzed, 12 were selected to show the concentrations of metals and other chemical components in the sediments. Selected were 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 texture: concentrations are generally highest where fine-grained sediments (muds)

are most abundant and lowest where sand is abundant. Exceptions occur on the inner shelf where chromium, iron, and manganese concentrations are highest in sandy sediments presumably as a result of associated heavy minerals. In sediments composed predominantly of mud (>75% silt and clay), the mean concentrations of boron, barium, chromium, copper, iron, manganese, and zinc are higher in shelf sediments than in bay sediments. The mean concentration of lead is approximately the same in bay and shelf muds. Total organic carbon is more abundant in bay sediments than shelf sediments. Scattergrams in which the concentrations of the different chemical elements are plotted against mud percent, provide a method of isolating samples containing anomalously high trace metal concentrations. Many of these higher than normal concentrations are attributed to anthropogenic contributions.

Benthic macroinvertebrates found in the sediments of the lagoon and inner shelf were primarily polychaetes, bivalves, gastropods, and crustaceans. Polychaetes were the most numerous species, followed by mollusks and crustaceans. On the inner shelf, highest species counts occurred in the northern half of the map area. In lower Laguna Madre, species counts were highest at grassflat stations near Brazos Santiago Pass. Distributions of the macroinvertebrates were related to bathymetry and sediment type. The average number of species per station on the inner shelf was generally highest in a depth range of 48 to 72 ft (14.6 to 21.9 m). On the inner shelf, the highest species counts generally occurred in the 60 to 100 percent sand range. Diversity values on the inner shelf were uniformly very high. In lower Laguna Madre, diversity values were lowest in the middle and northern parts of the lagoon and highest at grassflat stations in the southern section. Using cluster analyses, three macroinvertebrate assemblages were delineated on the inner shelf and six were delineated in the bays.

Wetlands 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 Brownsville-Harlingen area, 18 map units, including 3 marsh categories were used to delineate wetlands. Marshes and wind-tidal flats were subdivided into "high" and "low" categories according to moisture conditions and vegetation reflected in 1979 photographs.

Among the most extensive mapped environments outside the marine grassflats in Laguna Madre, are broad wind-tidal flats that flank the lagoon and also comprise a significant part of the Holocene-Modern deltaic system. Absent in this semiarid region are the extensive proximal salt-water marshes that characterize the intertidal areas along the upper Texas coast. Topographically low, vegetated saline flats are areally significant environments. Collectively, numerous small to moderate sized brackish-water and inland fresh-water marshes and water bodies comprise an important resource in the Brownsville-Harlingen area. Mapped wetlands were compared with those of the Environmental Geologic Atlas of the Texas Coastal Zone (mapped on 1960 photographs). The comparison suggests that some changes, such as the spread, locally, of marine grasses may, in part, be related to compactional subsidence and relative sea-level rise.

THE STATE SUBMERGED LANDS 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 below waters of the Gulf of Mexico, where they extend from the Gulf shoreline to a distance of 10.3 mi (16.6 km) on the inner continental shelf (fig. 1). The importance of these lands and their overlying waters to the abundant flora and fauna that are so dependent on them is well known and documented through numerous studies. Equally, the importance of these lands and their resources to people is well known and documented in part by the concentration of more than one-third of the state's population within an area of the Coastal Zone that is only about one-sixteenth of the state's land area. Present and future interactions of people and their 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 to a large degree on a detailed inventory of the basic components of these lands. The State Submerged Lands Project was designed in part to accomplish this objective (McGowen and Morton, 1979).

Initiated in 1975, the State Submerged Lands Project is based primarily on an intensive sampling program in which approximately 6,700 surficial bottom samples were collected at regularly spaced intervals 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 will be published as a series of seven atlases of the Texas coast, divided into areas (fig. 1) similar to those

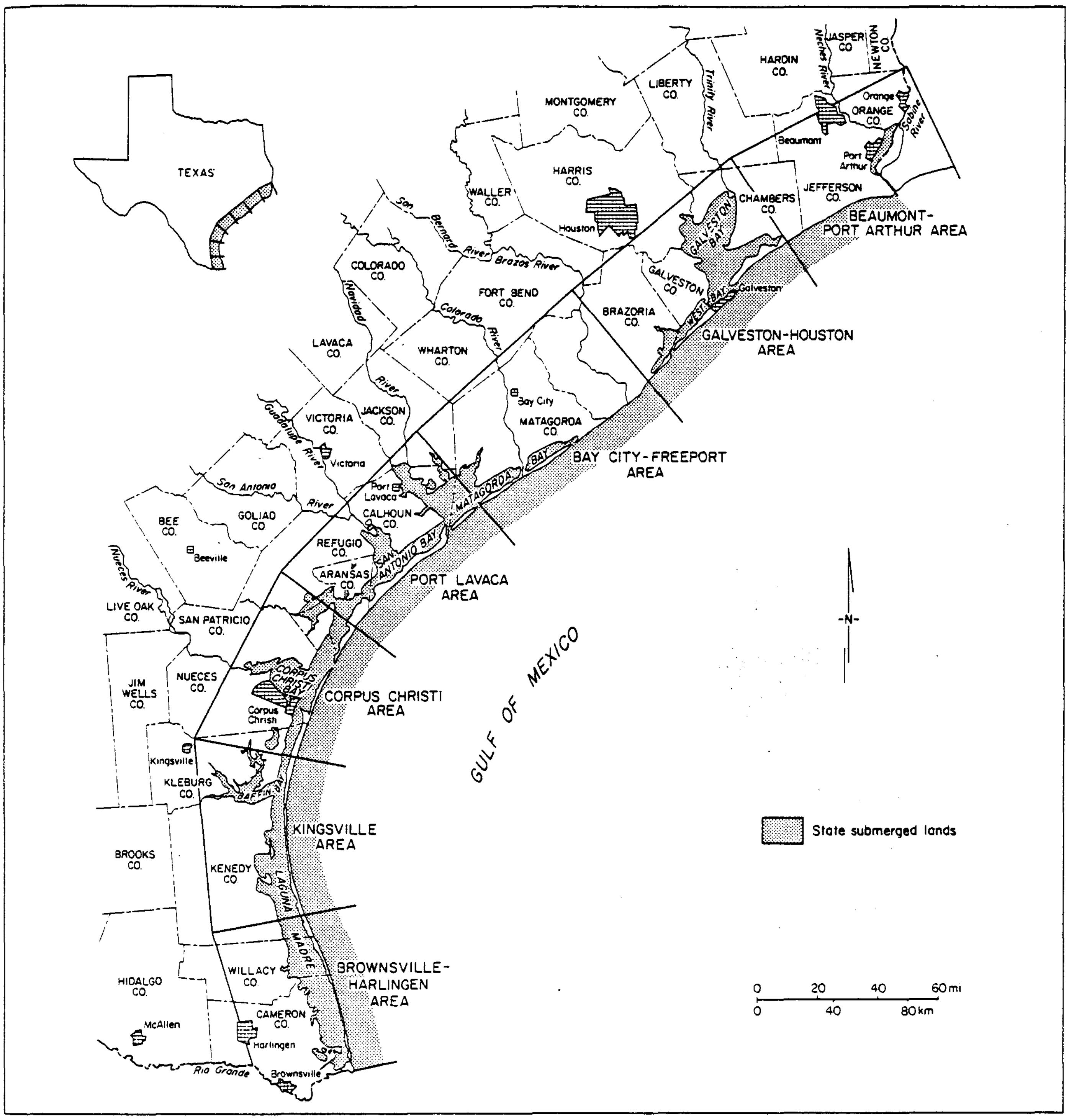

Figure 1. Index map showing seven area maps that cover the submerged coastal lands of Texas (modified from McGowen and Morton, 1979, and Brown, 1972-80).

defined in the Bureau's Environmental Geologic Atlases (Brown, 1972-1980) and in a special report on submerged lands (McGowen and Morton, 1979). Each of the submerged lands atlases will include 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 state-owned submerged lands series followed by one of the Galveston-Houston area (White and others, in preparation); this atlas of the Brownsville - Harlingen area is the third in the series.

Data Acquisition and Analyses

Surficial sediment samples analyzed for this study 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 (.0018 m^3), were used in the bay system, and Smith-McIntyre samplers having a capacity of 0.46 ft^3 (.013 m^3) were used on the shelf. Sediment penetration depths ranged between 1.5 and 3 in (4 and 7 cm). Samples were described at the time of collection in terms of sediment type, color, and other visual characteristics (McGowen and Morton, 1979), and then subsampled and stored in containers for more quantitative sedimentological, geochemical, and biological analyses in the laboratory. Although acquired data are considered comparable for the entire study area, different types of equipment and techniques were used in the bays and on the inner shelf. This was primarily because of differences in water depths and wave heights between the two systems, which influenced the effectiveness of different sampling techniques. Navigation techniques used to determine sample localities, for example, involved precision radio-navigation equipment on the shelf, whereas in the bays, less accurate triangulation and dead-reckoning navigation were used. In addition, in sampling bay sediments composed of sand, more than one grab was usually necessary to obtain enough sediment for processing.

Bathymetric and geophysical data were also collected during the sampling phase of the submerged lands program (McGowen and Morton, 1979).

The wetlands study was begun after submerged lands sampling ended. The purpose was to provide updated 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.

Below 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 Brownsville-Harlingen area are found in a later section.

Sediments

Textural analyses provided the primary sediment data on the submerged lands. Analyses were performed by the Bureau of Economic Geology's Sedimentology Laboratory except for samples from the southern half of the inner shelf on the Brownsville-Harlingen map sheet (fig. 1), which were analyzed by the U.S. Geological Survey. 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); in the mud (silt and clay) fraction, a Coulter Counter was used (Shideler, 1976).

Sediment types are classified on the basis of their 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. 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, and the second map shows the distribution of sand, silt, and clay. A third map showing the distribution of sand (percent sand map) and a fourth depicting the

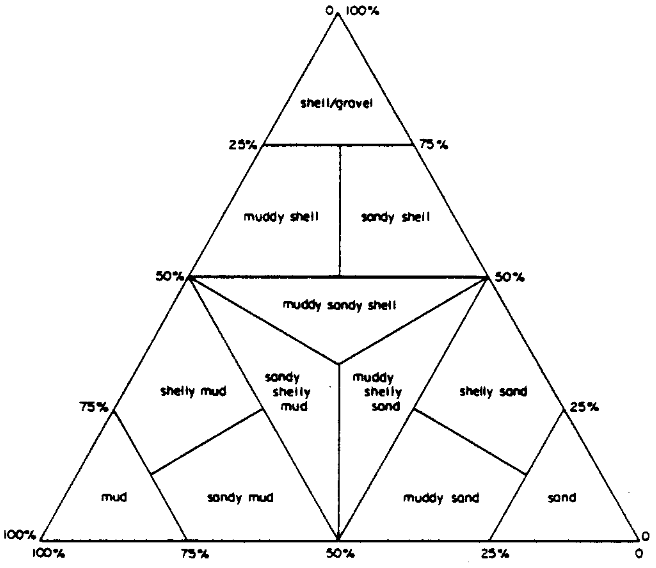

Figure 2. Classification of sediment types: shell(gravel)-sand-mud, submerged lands of Texas (from McGowen and Morton, 1979).

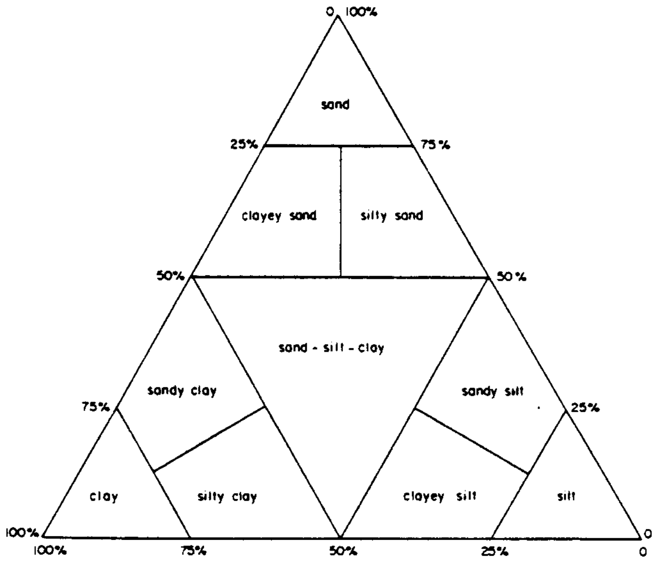

Figure 3. Classification of sediment types: sand-silt-clay, submerged lands of Texas (modified from Shepard and Moore, 1955).

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 for 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, but more importantly, 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 the Bureau's Mineral Studies Laboratory, using a wet-combustion technique (Jackson, 1958). Fewer samples (approximately 3,800) were analyzed for trace and major element concentrations. The U.S. Geological Survey performed most of these analyses using an emission spectrograph (Grimes and Marranzino, 1968), which provides semiquantitative results (relative standard deviation for each reported concentration being plus 50 percent and minus 33 percent).

Supplementary quantitative analyses of chemical elements for selected samples were conducted by the Bureau's Mineral Studies Laboratory, using an inductively coupled plasma atomic emission spectrometer (ICP-AES). This instrument provides highly reproducible data, as the variability of duplicate analyses is less than 2 percent for most elements. The accuracy of analyses for most common elements ranges from 100 ± 1 percent to 100 ± 5 percent in most cases (depending on the element), if the concentration levels fall within the optimal range for quantitative measurement; the optimal range is from 5 times to 10^4 times the detection limit of each element (C. L. Ho and S. Tweedy, personal communication, 1982). Because of the two different methods of chemical element analyses--the 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 graphs and tables.

Samples were scanned for about 30 elements. Twelve elements, including TOC, were selected for mapping purposes. They are 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 Galveston-Houston area, discussed in detail in a later section, are shown on plates II, III, and IV.

Benthic Macroinvertebrates

A total of 1,600 benthic samples, consisting of 1,050 from the bay-estuary-lagoon system and 550 from the inner shelf, were examined in this study. Live macroinvertebrates were identified to species level when possible and counted. Dead mollusks were also identified, but individual counts of the dead species were taken only in the Corpus Christi and Galveston areas (fig. 1).

Processing the biological samples for analysis included a "shipboard" phase and a laboratory phase. On the inner shelf, samples were washed through a 0.5-mm or 1-mm screen and, narcotized with a solution of propylene phenoxytol. In the bays, 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 placed in 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 dead pelecypod valves were counted as one; unpaired valves were counted as one-half.

Each major invertebrate group (Mollusca, Polychaeta, and Crustacea) is discussed individually and its distribution is related to sediment 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 macroinvertebrate assemblages section.

Wetlands

Wetlands were interpreted and delineated using National Aeronautics and Space Administration (NASA) stereoscopic, color-infrared positive transparencies taken in 1979, at a scale of approximately 1:66,000. Mapping procedures were similar to those used in preparing the Environmental Geologic Atlas series (Brown, 1972-1980): mapping "involved extensive aerial photographic interpretation, field work, aerial reconnaissance, 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 center on the following: (1) the photographs used (1979 color-infrared stereopair), were a major improvement over the late 1950's - early 1960's black-and-white photomosaics used in the earlier atlases and allowed a more accurate and detailed subdivision of map units; (2) more emphasis was placed on detailed subdivision and mapping of the wetlands by focusing specifically on wetlands and excluding the classification of upland areas; (3) the additional field observations made in selected areas after the original atlases were prepared provided a more detailed picture of the distribution of plant assemblages in many areas; and (4) improved photographic quality and cartographic capability permitted smaller map areas to be shown than were possible on the earlier atlas maps. These smaller map units provide the necessary detail for users who need to enlarge the maps for various purposes.

The distribution 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). Shoreline features such as spoil islands, navigation channels, and so on, 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 updated using county road maps published in 1979 by the Texas

Department of Highways and Public Transportation. A much more detailed discussion of wetlands is presented in a later section of this report.

BROWNSVILLE - HARLINGEN AREA

The Brownsville-Harlingen map area, as defined in figure 1 and plates I through VI, encompasses a long narrow lagoon system composed principally of Laguna Madre and small South Bay, separated from the Gulf of Mexico and the inner shelf by a modern barrier-island complex composed of Padre and Brazos Islands (fig. 4). Tidal exchange between marine and lagoon systems occurs at (1) Brazos Santiago Pass, a tidal inlet between Padre and Brazos Islands, and (2) Port Mansfield Channel, a dredged channel/inlet complex that connects to the Intracoastal Waterway and Port Mansfield. The lagoon system is connected to broad wind-tidal flats along Padre Island and the mainland, and to numerous smaller lagoons and embayments, such as Laguna Larga, Bahia Grande, and San Martin Lake. Near the center of the map area, about 4 mi (6.5 km) inland from the Laguna Madre, is Laguna Atascosa, which before its impoundment was connected to Laguna Madre through Cayo Atascosa.

The Rio Grande, which marks the southern boundary of the map area, discharges into the Gulf of Mexico. Previous courses of the Rio Grande are manifested in numerous meandering abandoned water- and marsh-filled channels. One deeply entrenched channel--Arroyo Colorado--is connected to Laguna Madre and the Intracoastal Waterway primarily via a cutoff, which is the gulfward extension of a dredged channel (barge canal) that connects to the Port of Harlingen (fig. 4). The Arroyo Colorado and the North Floodway are the principal drainage systems that contribute limited fresh-water inflows to Laguna Madre.

Cities in the map area include Brownsville, Harlingen, Rio Hondo, Raymondville, and Port Isabel. Navigation channels include (1) Brownsville and Port Isabel Ship Channels, which connect to the Gulf of Mexico through Brazos Santiago Pass, (2) the Intracoastal Waterway, which extends the entire length of Laguna Madre, and (3) Port Mansfield and Port of Harlingen Channels. Dredged spoil has been placed along most of the channels (Brown and others, 1980).

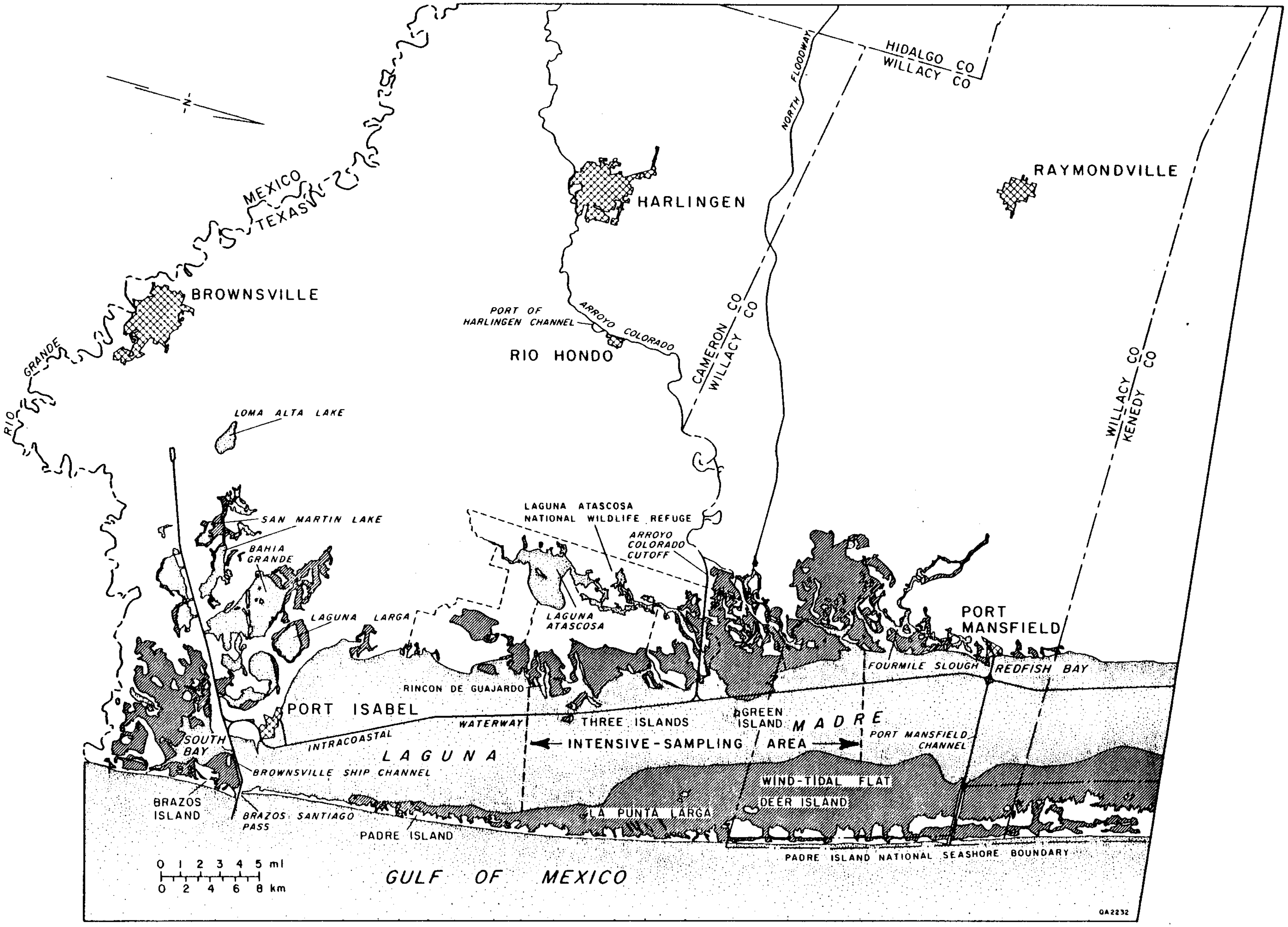

Figure 4. Index map of the Brownsville-Harlingen area.

Climate

Climate in the Brownsville-Harlingen area is semiarid (Thornthwaite, 1948) (table 1). Average annual rainfall for the period 1941-1970 was between 25 and 26 inches (63 to 66 cm). Along the coastline in the Brownsville area, the annual rainfall ranges from 28.0 inches (71.1 cm) in the north to about 26.0 inches (66 cm) in the south (Brown and others, 1980). Between 1931 and 1960, the average annual evaporation and plant transpiration exceeded precipitation by approximately 23 to 31 inches (58 to 79 cm) (fig. 5).

Precipitation levels in the Brownsville-Harlingen area during recent years are shown in figures 6, 7, and 8. The low annual rainfall budget coupled with relatively nonuniform rainfall distribution throughout the year are characteristics very different from areas on the northeast Texas coast (Brown and others, 1980). Between 1931 and 1960, the average annual mean free-air temperature in the Brownsville area was 73.5°F (23.1°C). In the summer the daily highs are in the lower 90's (°F) (near 32°C). And the lows are in the middle 70's (°F) (near 24°C). Average daily winter temperature ranges from a low in the 50's (°F) (10°C) to a high in the 70's (°F) (21°C) (Herber, 1981).

Two principal wind regimes dominate the Brownsville-Harlingen area: persistent, southeasterly winds from March through November and short-lived but strong northerly winds from December through February (Brown and others, 1980). Cold fronts, while causing an abrupt drop in air temperature, cumulatively cause a drop in temperature of bay waters.

Active Processes and Natural Systems

Submerged lands and wetlands are affected by a variety of natural, physical processes that include the action of rivers, streams, and surface runoff, astronomical and wind-generated tides, waves and currents, tropical storms and hurricanes, and eolian activity, as well as subsidence, faulting, and relative sea-level rise. Sources of fresh-water inflows into the bay-estuary-lagoon system include streams and runoff, municipal, industrial, and agricultural return

Table 1. Generalized characteristics of active coastal processes and conditions in the Brownsville-Harlingen area.

Climatic zone: Semiarid (Thornthwaite, 1948)

Mean annual precipitation: 25-26 inches (63-66 cm) (U.S. Department of Commerce, 1982)

Dominant wind direction: southeast, north (Brown and others, 1980)

Average annual wind speed (Brownsville): Prevailing south to southeasterly - 11.8 mph; north winds reach velocities of 26 mph (Espey, Huston and Associates, Inc., 1981)

Direction of net sand transport by winds: Northwestward (Brown and others, 1980)

Astronomical tidal range:
  Gulf shoreline
    Diurnal range: 1.4 ft (0.4 m) (U.S. Department of Commerce, 1978)
    Mean: 0.7 ft (0.2 m) (U.S. Department of Commerce, 1978)
  Lower Laguna Madre shoreline (mean): 1 ft (0.3 m) (Diener, 1975)

Tidal current velocities:
  Brazos Santiago Pass
    Average peak flood: 0.94 knots (1.74 km/hr)
      (Espey, Huston and Associates, Inc., 1981)
    Average peak ebb: 0.73 knots (1.35 km/hr)
      (Espey, Huston and Associates, Inc., 1981)
Wave height (Gulf):
  Usual height: 2.5 to 3.5 ft (0.8 to 1.1 m) (U.S. Army Corps of Engineers, 1956)
Longshore current velocities (Gulf):
  Up to 3 knots (5.6 km/hr) (Lohse, 1952)

Direction of net longshore sediment transport: Northward (Brown and others, 1980)
Net rate of Gulf shoreline erosion over period of about 120 years (South Padre Island):
  < 1 to 13 ft (.02 to 4.0 m) per year (Morton and Pieper, 1975)
Estimated peak hurricane surge height at Port Isabel: 11 ft (3.4 m) MSL (Bodine, 1969)

Hurricane frequency:
  Probability of occurrence along 50-mi (80.5 km) segment of coast in Brownsville-Harlingen area: 8% in any one year (Simpson and Lawrence, 1971)

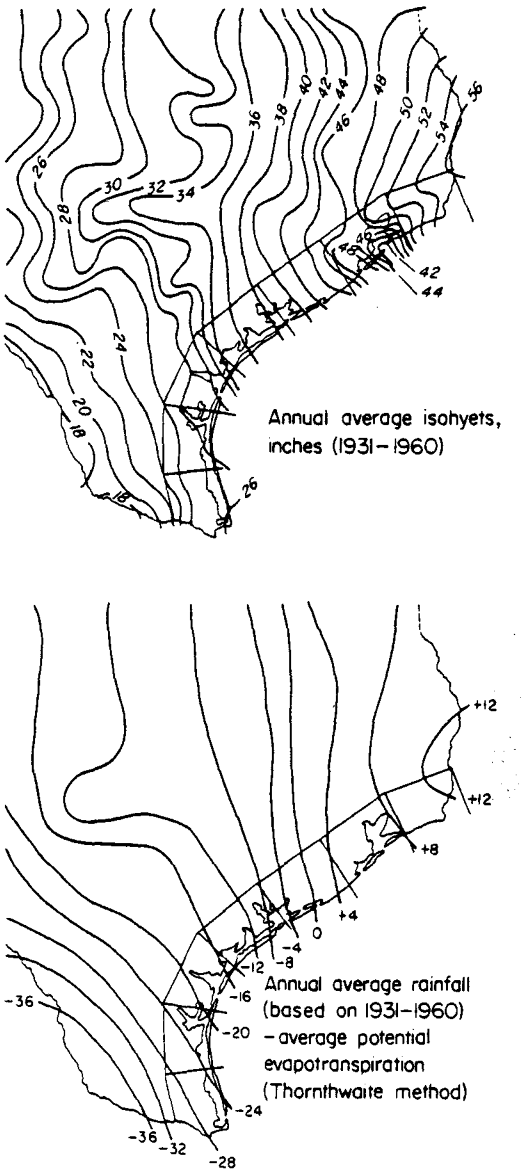

Figure 5. Regional climate data, Texas Coastal Zone (after Brown and others, 1976). Calculations of average potential evapotranspiration from Thornthwaite and Mather, 1957.

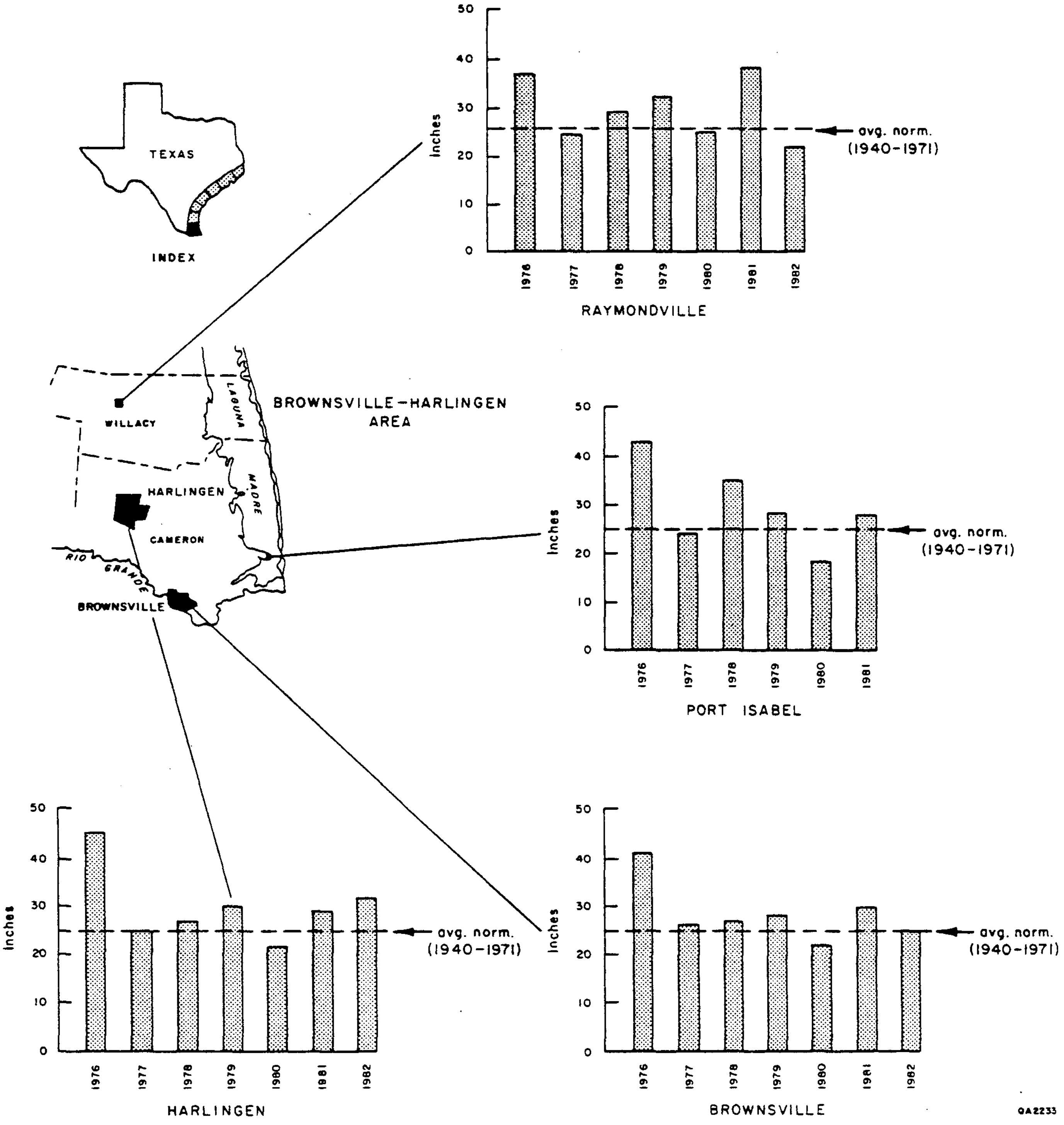

Figure 6. Annual precipitation of Brownsville, Harlingen, Port Isabel, and Raymondville, Texas, 1976-1982. Compiled from records of the National Weather Service, U.S. Department of Commerce.

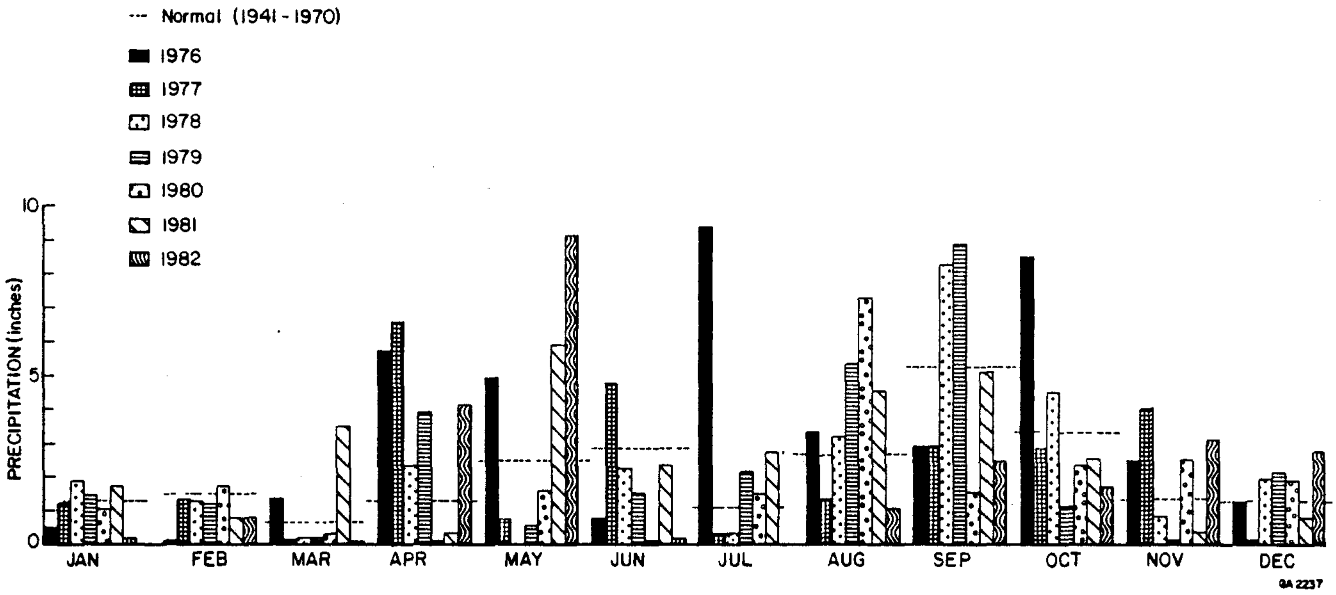

Figure 7. Monthly precipitation for Brownsville, Texas, 1976-1982. Compiled from records of the National Weather Service, U.S. Department of Commerce.

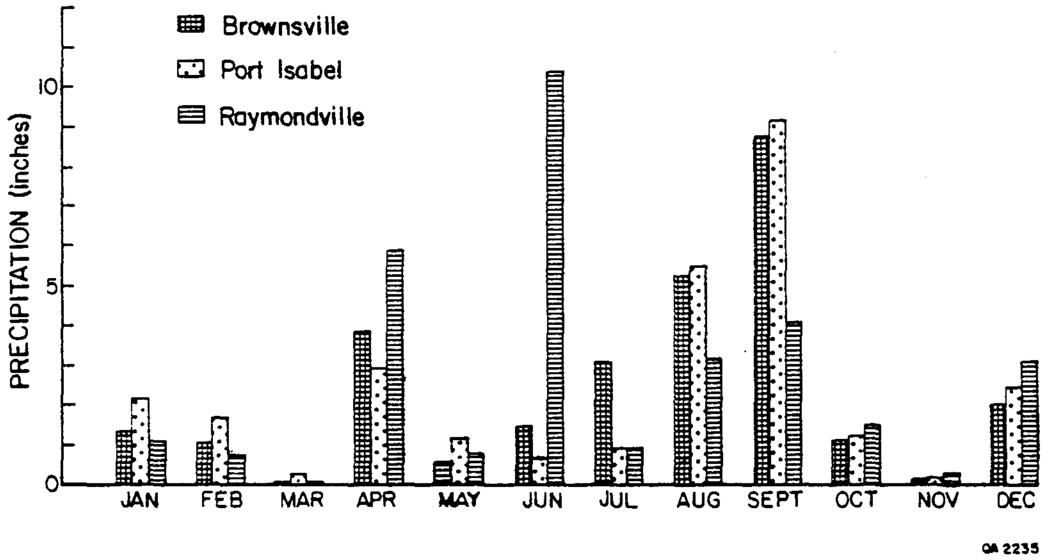

Figure 8. Monthly precipitation for Brownsville, Port Isabel, and Raymondville, 1979. Compiled from records of the National Weather Service, U.S. Department of Commerce.

flows, and direct precipitation. From 1941 through 1976, annual average gaged fresh-water inflows (excludes ungaged inflows, diversions, and direct precipitation) were about 335,000 acre-ft (411 million m^3) for the Laguna Madre-Baffin Bay System (fig. 1; Texas Department of Water Resources, 1983). The low inflows in this semiarid region are in marked contrast to estuaries along the upper Texas coast where, for example, annual gaged inflows for the Trinity estuary in the Galveston-Houston area (fig. 1) are about 16 times higher. A difference in these two areas besides variations in climatic conditions, however, is that the Trinity River discharges directly into Trinity Bay, but the Rio Grande discharges into the Gulf of Mexico. Thus, the Rio Grande does not contribute fresh water to Laguna Madre except during floods and through water-diversion programs. Gaged inflows that enter Laguna Madre are (1) from creeks that flow into Baffin Bay north of the Brownsville-Harlingen area, and (2) from the Arroyo Colorado and North Floodway, both of which receive flood water as well as water diverted for various uses from the Rio Grande. Gaged inflows into Laguna Madre and Baffin Bay account for only 17 percent of the total fresh-water inflows; ungaged runoff and return flows account for 18 percent and direct precipitation supplies the rest (65 percent) (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 and lagoon environments and have produced extensive wind-tidal flats and less extensive marshes (discussed in the wetlands section). Other processes affecting environments in the bays and along the inner shelf are listed in table 1.

Active processes are integral components of the natural systems that have operated along the coast during the Pleistocene and Holocene-Modern epochs. These natural systems (fig. 9), defined and mapped by Brown and others (1980), reflect natural and genetic associations and include: (1) the offshore system, consisting of the inner continental shelf and barrier-island shoreface located seaward of the Gulf beaches, (2) the barrier system, consisting of the modern barrier islands, (3) the bay-estuary-lagoon system, consisting of submerged estuarine environ-

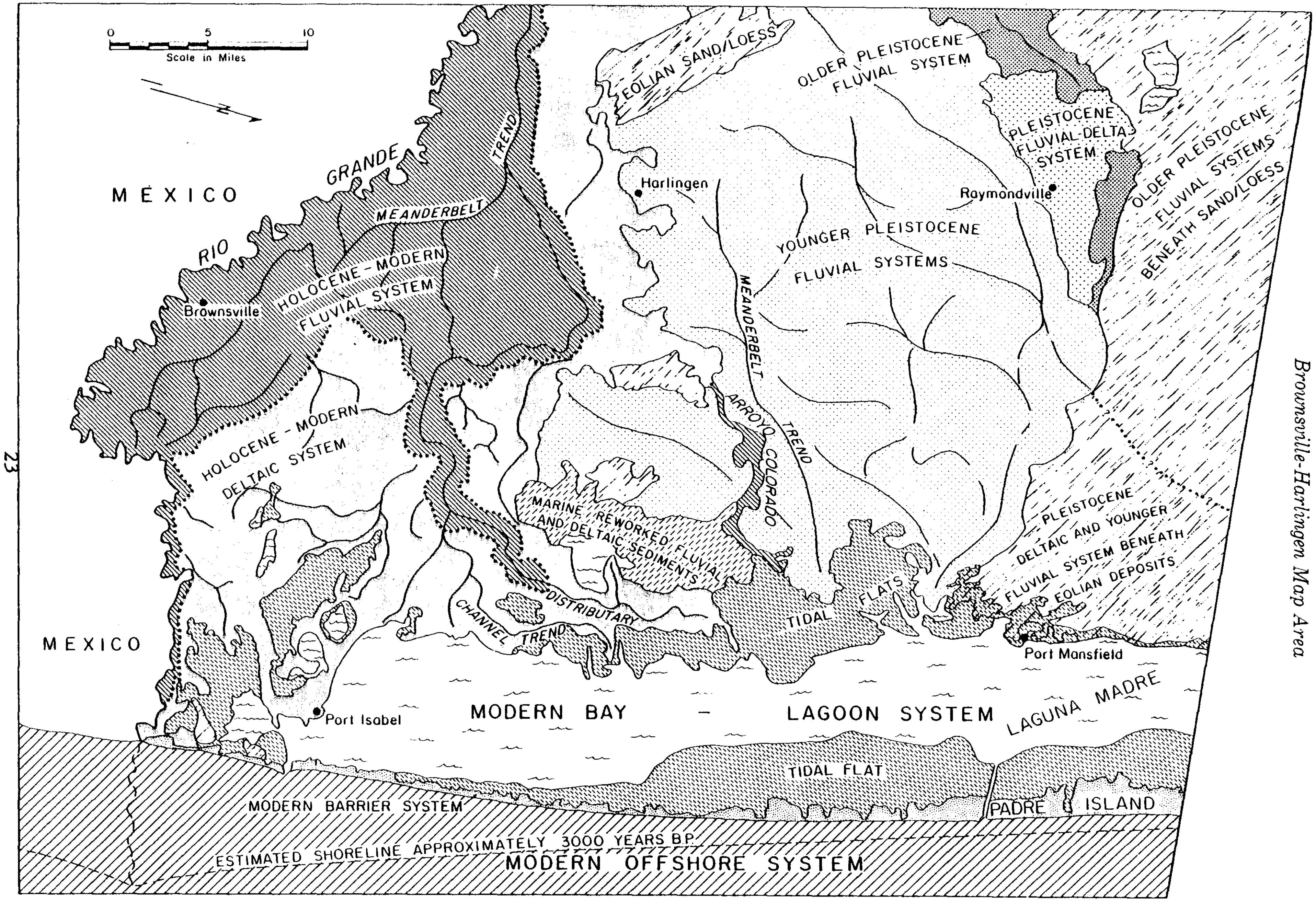

Figure 9. Natural systems defined by environmental mapping in the Brownsville-Harlingen area.

ments and extensive wind-tidal flats, (4) the fluvial-deltaic system, consisting of the relict and modern environments formed by ancient (Pleistocene) and modern rivers and deltas, (5) the eolian system, consisting of deflation flats or depressions, dune complexes, and loess sheets, and (6) the marsh system, consisting of the various permanently to intermittently wet environments occurring both in low-lying coastal areas and in association with most of the above-mentioned systems. Natural systems in the Brownsville-Harlingen area are discussed in a later section of this report in conjunction with wetlands, and a more in-depth discussion is presented by Brown and others (1980).

Bathymetry

Bathymetry is an important parameter because it 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 program by measuring water depth at each sampling site (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).

Lower Laguna Madre is characterized by broad wind-tidal flats stretching from the north map boundary southward to the vicinity of La Punta Larga (fig. 4). In general, water depths are shallowest where wind-tidal flats are broadest (McGowen and Morton, 1979). North of the Port Mansfield Channel, maximum depth of Redfish Bay is about 8 ft (2.4 m). Depths of 8 ft (2.4 m) are also present in a small area near Brazos Santiago Pass. The lagoon between Three Islands and Port Mansfield Channel is generally less than 2 ft (0.6 m) deep. South of Three Islands the lagoon becomes broader and depths increase to about 4 ft (1.2 m). Measured depths in South Bay range from 0.5 to 3 ft (0.1 to .9 m) with an average depth of less than 1 ft (0.3 m).

Channels maintained by dredging have the greatest depths in lower Laguna Madre. Depths in these channels are: Brownsville Ship Channel, 38 ft (11.6 m) in the entrance channel and 36 ft (11 m) in all inland channels (Espey, Huston and Associates, Inc., 1981); Intracoastal Waterway, 12 ft (3.7 m) (Breuer, 1962); and Port Mansfield Channel, 12 ft (3.7 m) (Breuer, 1962).

Shelf bathymetry near the Gulf shoreline is characterized by a relatively steep slope (approximately 30 ft/mi or 6 m/km), which becomes more gradual beyond a distance of about 1 mi (1.6 km) offshore. At approximately 10 mi (16 km) offshore, the slope decreases to about 9 to 12 ft/mi (1.8 to 2.4 m/km) and depths along the southeast edge of the map sheet exceed 96 ft (29.3 m) (pl. V).

Salinity

Salinity is an important parameter because it affects the distribution of marsh vegetation and the distribution of benthic macroinvertebrates. Water salinities in the bay-estuary-lagoon system in the Brownsville-Harlingen area vary across the entire system in part because of the regional variations both in fresh-water inflows from rivers and streams and in salt-water interchange from tidal passes (Brazos Santiago Pass and Port Mansfield Channel). 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. Salinities reported by the Texas Parks and Wildlife Department (Martinez, 1973, 1974, 1975) for lower Laguna Madre and South Bay provide some salinity data during the 1970's. Sediment samples were collected in the Brownsville-Harlingen area in 1976 and 1977.

Salinities in lower Laguna Madre are generally highest in July or August and lowest in January or February (fig. 10). In 1973, low salinity averages also occur in March, July, and November. Monthly salinity averages range from 19 parts per thousand (ppt) in January, 1975 to 37 ppt in August, 1974. Salinities taken at different stations in a single month may vary considerably. For example, salinities taken in January, 1974 range from 25 to 55 ppt, and in July, 1973, from 8 to 32 ppt.

Salinities generally increase from the southern end at Port Isabel to north of Port Mansfield (Brown and others, 1980 and Espey, Huston and Associates, Inc., 1981). Salinities in the Port Isabel area range from 23 to 36 ppt and are influenced by the exchange of Gulf water (32 to 35 ppt) through Brazos Santiago Pass (Espey, Huston and Associates, Inc., 1981). Salinity concentrations at the northern end of Laguna Madre range from 20 to 40 ppt, with an average of about 38 ppt.

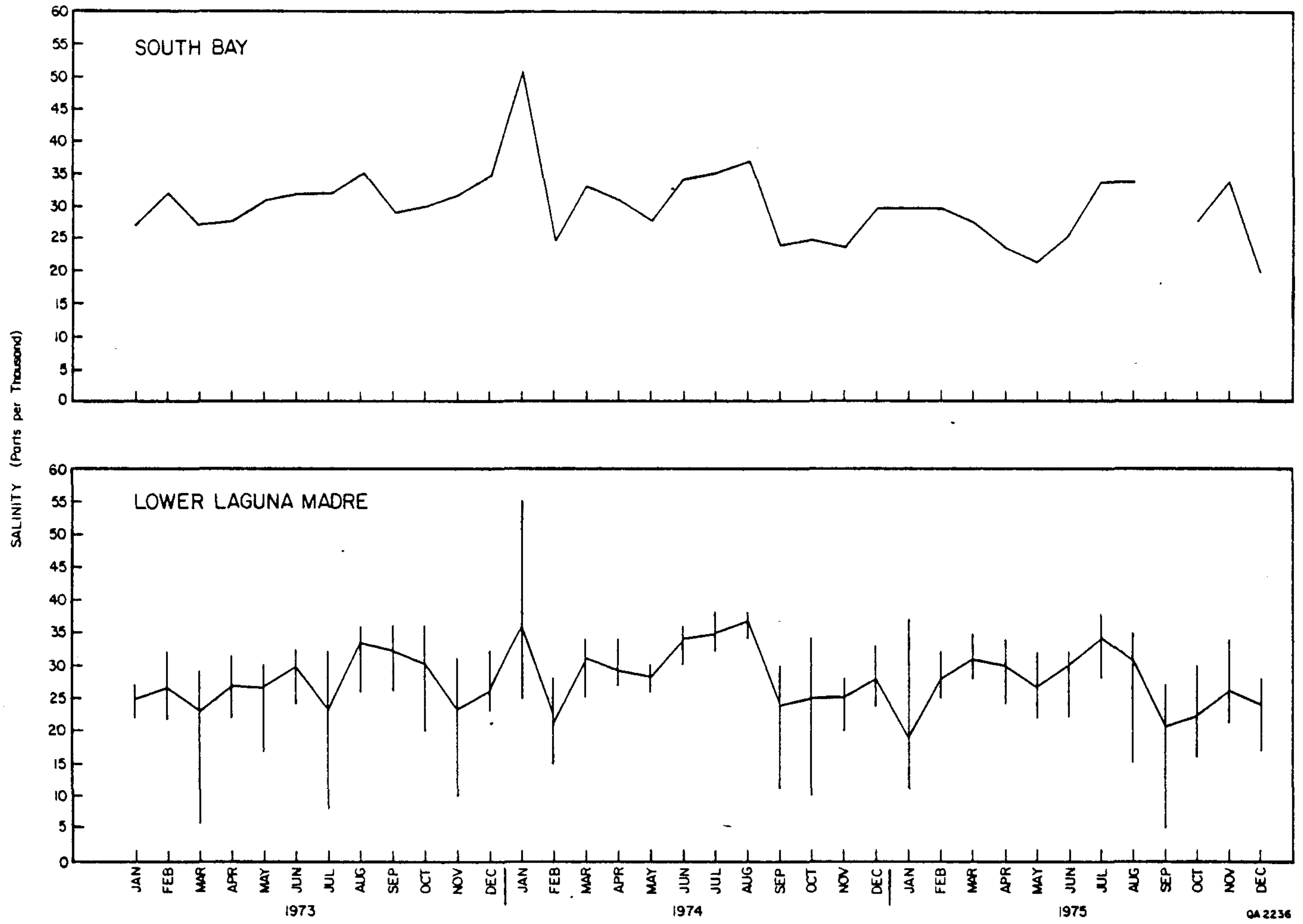

Figure 10. Monthly means and ranges in salinities in South Bay and lower Laguna Madre, Brownsville-Harlingen area. (Compiled from Martinez, 1973, 1974, 1975.)

Salinity measurements taken at one station in South Bay range from 20 ppt in December, 1975 to 51 ppt in January, 1974; however, most measurements are between 25 and 35 ppt.

Distribution of Marine Grasses

The seagrass meadow is a complex assemblage that fills multiple functional roles in coastal ecosystems, providing habitat and protection for many faunal species, including juvenile forms and substrate for epifauna and epiphytes (Orth, 1973; and Stoner, 1980). Seagrasses serve as a primary food source for some animals including migratory waterfowl (Cornelius, 1975). Also, the roots of the plants help stabilize the substrate and the leaves have a baffling effect (Ginsburg and Lowenstam, 1958). Through their sediment trapping and binding ability, thick tracts of grass can develop banks that have topographic relief. Also, nutrient exchange studies of seagrasses under laboratory conditions show that organic compounds are exported under active growth conditions (Armstrong and Gordon, 1979). The exchange rates measured by Armstrong and Gordon are, in general, higher than those measured in previous studies for emergent marsh systems indicating the importance of seagrass systems to nutrient budgets of estuaries. This highly productive environment is tenuously balanced by such conditions as salinity, temperature, turbidity, and water depth. An increase in turbidity resulting from spoil disposal or other man-induced development may be sufficient to destroy or severely restrict the grassflat environment (Brown and others, 1980).

All five marine spermatophytes found on the Texas Gulf Coast occur in lower Laguna Madre. Halodule beaudettei (previously Halodule wrightii), Ruppia maritima, Cymodocea filiformis (previously Syringodium filiforme), and Halophila engelmannii are the most abundant. Thalassia testudinum is relatively rare, growing primarily at the south end of Laguna Madre and in South Bay (Brown and others, 1980). Halodule and Cymodocea are the two most common grasses, occurring over much of the grassflat environments. Halophila occurs sparingly in various parts of the lagoon, and Ruppia is found primarily along the Intracoastal Canal adjacent to spoil mounds and along the perimeters of natural islands (Breuer, 1962; Cornelius, 1975; and Brown and others, 1980).

The plants generally consist of branched, underground rhizomes which produce erect shoots and roots (Edwards, 1977). The erect shoot consists of a very short, basal stalk which bears the leaves. Most species generally grow only during the warmer months, and their leaves are lost in winter. Reproduction takes place sexually by seed formation or vegetatively by the production of new shoots on the elongating rhizome.

The five seagrass species found in lower Laguna Madre have varying physical requirements and limitations. Substrate in which the grasses are rooted vary from sand and muddy shelly sand to muddy sand and sandy mud (Brown and others, 1980). Salinity tolerance is probably the most significant environmental factor controlling seagrass ecology. McMillan and Moseley (1967) and McMahan (1968) have indicated the general salinity limits for the various species. Halodule beaudettei was successfully grown in salinities of 60 ppt, with an optimum salinity of 44 ppt. Cymodocea growth responses suggested it had the least salinity tolerance of the five seagrasses; growth terminated at 45 ppt in a controlled room situation. Chin (unpublished manuscript) citing McMillan and Moseley (1967), ranked the various grasses according to salinity tolerance from most tolerant to least tolerant: Halodule, Thalassia, Ruppia and Cymodocea. Studies of Halophila's tolerance were inconclusive, but it is suspected to be between Halodule and Cymodocea.

Chin (unpublished manuscript) conducted a detailed analysis of the distribution of marine grasses over an area of approximately 80 sq. miles (129 sq. km) centered roughly on the mouth of the Arroyo Colorado Cutoff (figs. 11 and 12). Thalassia was the only marine grass not present in the study area when the sampling was conducted in 1977. Comparative mapping of 1977 seagrass distribution with that of previous studies, primarily maps available from the Texas Parks and Wildlife Department for the years 1961, 1965, and 1966, revealed significant changes in species distribution and density, including (1) the grassflat environment has expansioned overall, (2) Halodule total bottom cover has decreased as has its distribution and

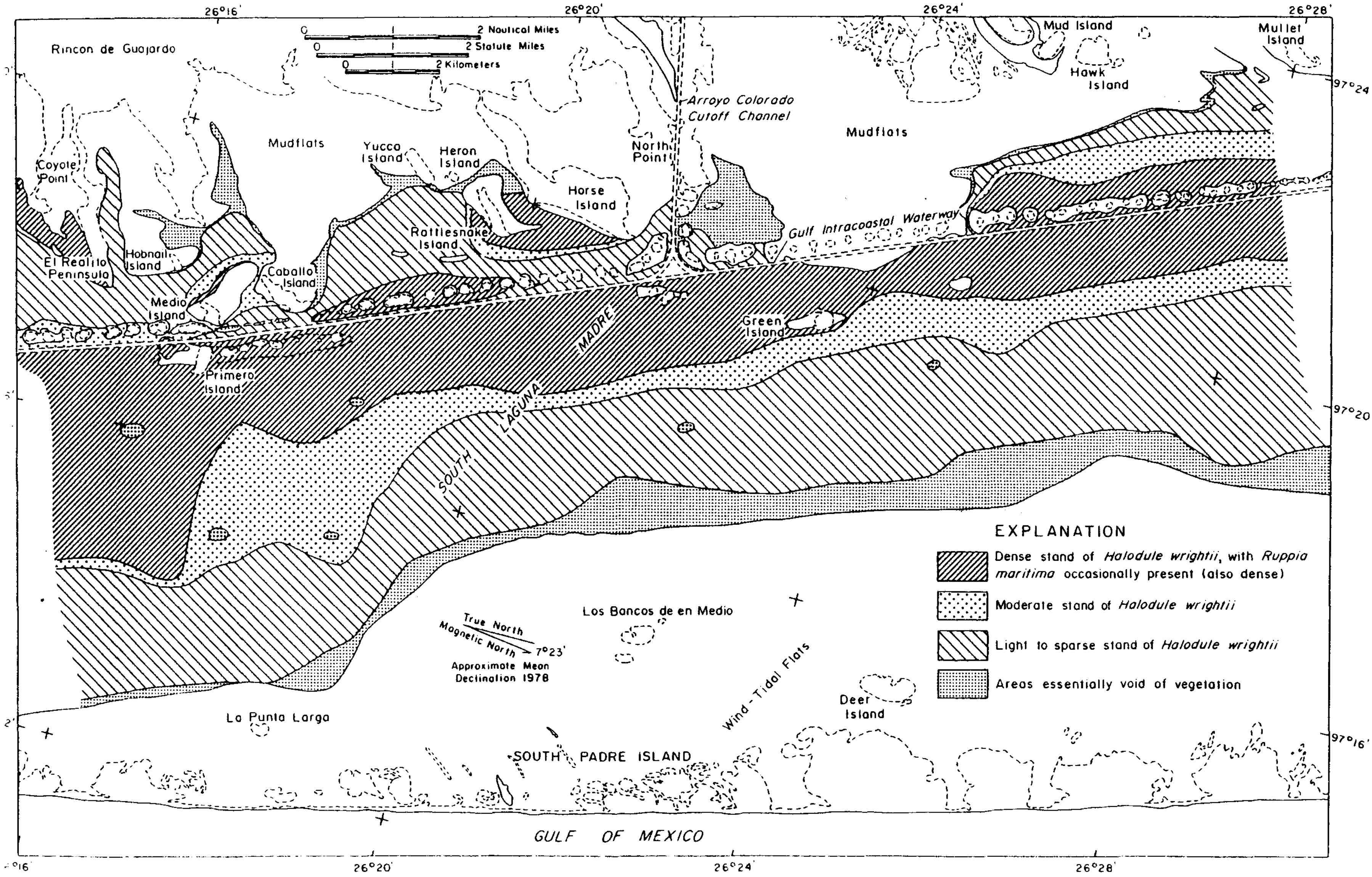

Figure 11. Distribution of Halodule and Ruppia for a segment of Laguna Madre, Brownsville-Harlingen area (after Chin, unpublished manuscript).

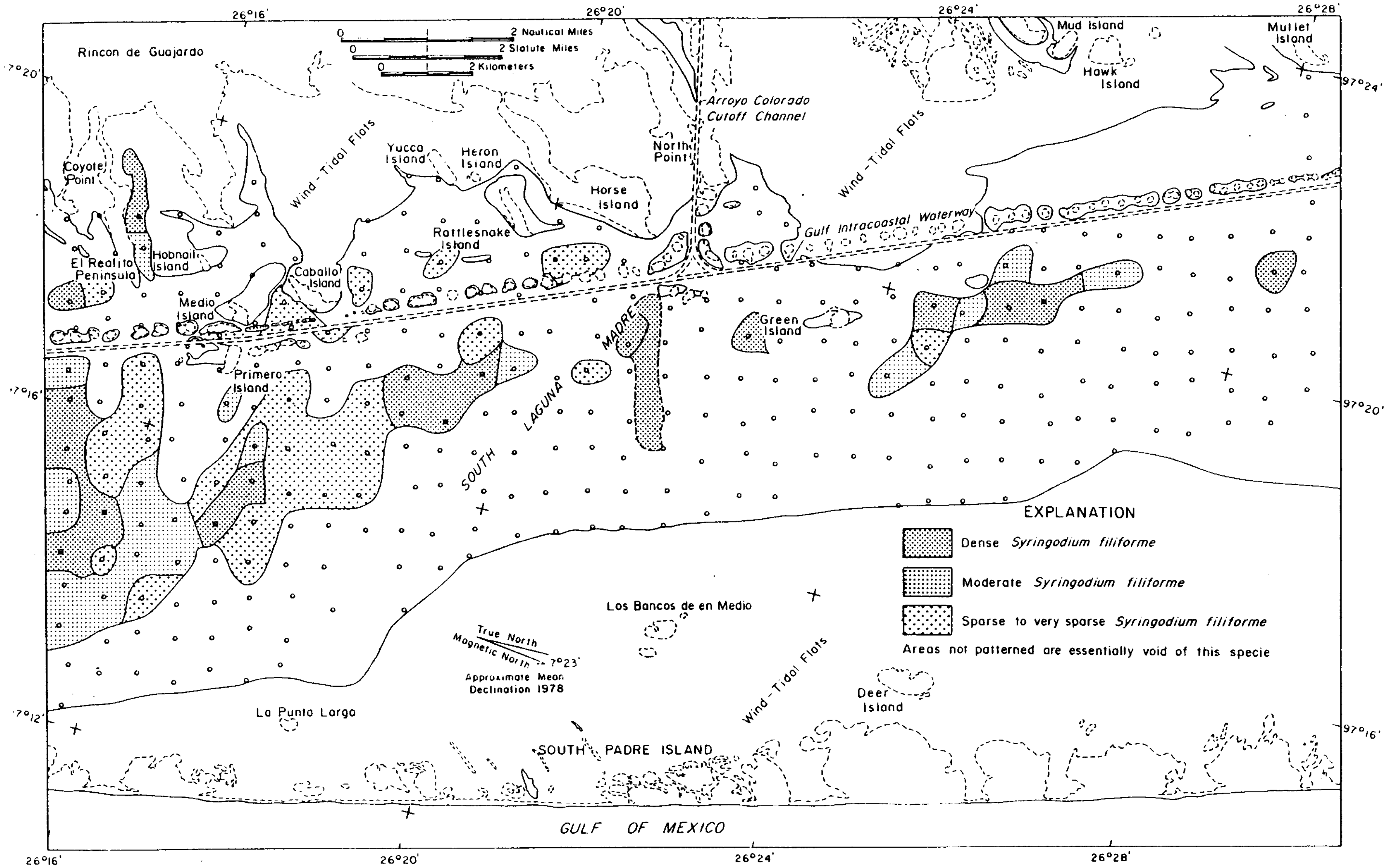

Figure 12. Distribution of Syringodium (Cymodocea) for a segment of Laguna Madre, Brownsville-Harlingen area (after Chin, unpublished manuscript).

density from 1961 to 1977, (3) Cymodocea has not only encroached upon formerly pure Halodule stands, but in places it has totally replaced it as the dominant vegetative type, (4) Ruppia has decreased in its distribution, occurrence, and density. Chin speculated that conditions contributing to the expansion of the grassflat environments included (1) stabilization of salinity and other physical factors, caused partly by the construction of the Intracoastal Waterway and Port Mansfield Channel; and (2) natural subsidence from compaction of ancient deposits (Fisk, 1959) resulting in increased lagoonal bottom and water depth.

Sample Collection and Analysis

A total of 1,193 sediment samples were collected from State-owned submerged lands in the Brownsville-Harlingen area (pl. VI and table 2). Of those collected and stored almost all of them (1,185) were analyzed for total organic carbon; 423 were analyzed for textural properties; 216 for benthic macroinvertebrates; and 457 for selected trace and major elements (table 2). The numbers and locations of samples analyzed were determined, in part, by the requirement to establish an adequate data base for mapping and interpretive purposes, but also by the requirement to consider time and costs of the various types of analyses. Methods of analysis are presented in the section on data acquisition and analyses. Dates of collection are given in table 3. All sample locations and identifying numbers are shown on plate VI. Results of the various textural and geochemical analyses for each station are presented in tabular form in appendix B. Data on benthic macroinvertebrates are presented in appendix C.

It should be noted that along the central segment of Laguna Madre in the Brownsville-Harlingen area, samples were collected on a 0.5-mi (0.8-km) spacing rather than the usual 1-mi (1.6-km) spacing. This segment of Laguna Madre called the "intensive sampling area" is shown on figure 4 and plate VI. Samples were collected over shorter distances in this area to satisfy requirements of a related Bureau project (McGowen and others, 1977).

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

Location	Number of samples collected	Number of samples analyzed			
		Texture	TOC	Chemical elements	Benthic macroinvertebrates
Lower Laguna Madre	500	157	492	224	79
Port Isabel Channel	4	0	4	2	0
Arroyo Colorado	30	30	30	30	1
South Bay	10	10	10	4	10
Port Mansfield Channel	13	9	13	6	6
Brownsville Ship Channel	14	9	14	8	3
Intracoastal Waterway	46	24	46	31	4
Bay-Estuary-Lagoon Totals	617	239	609	305	103
Inner Shelf Totals	576	184	576	152	113
Submerged Lands Totals	1193	423	1185	457	216

Table 3. Sample collection dates for bays and inner shelf.

Location	Sample Collection Dates
Lower Laguna Madre	Feb. 16 to Apr. 25, 1977*
Intensive sampling area	Mar. 4 to Apr. 25, 1977**
Port Mansfield Channel	Mar. 20, 1977
Intracoastal waterway	Mar. 1 to Mar. 20, 1977
Arroyo Colorado	Mar. 3, 1977***
South Bay	Mar. 22, 1977
Brownsville Ship Channel	Mar. 22, 1977
Inner shelf	Apr. 22 to Apr. 26, 1976

* Stations 210 to 217 collected Nov. 10 to Nov. 11, 1977; stations 163, 190, 191, 208 collected Dec. 13 to Dec. 14, 1977

** Station 31 collected July 29, 1977

*** Stations 297, 298, 301, 302, 319, 320, 321 collected July 29, 1977; stations 243 to 264 collected Nov. 6, 1977

SEDIMENTS AND GEOCHEMISTRY

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Late Quaternary Geologic History

Major depositional and erosional events during the past 150,000 years were responsible for the distribution of surface sediment types found on the inner shelf and in Laguna Madre. These events, which were principally controlled by glacio-eustatic changes in sea level (Rusnak, 1960; Brown and others, 1980), are recorded as aggradational and progradational coastal plain deposits that accumulated during periods of high sea level, and erosional unconformities that formed at times of extremely low sea level or acutely diminished sediment supply.

The oldest surficial sediments exposed in the Brownsville-Harlingen study area were deposited by a large, late Pleistocene river and delta mapped by Brown and others (1980) as the Raymondville fluvial system and Atascosa deltaic-marine system (fig. 13). Sediments of both systems are composed mainly of sand that respectively originated as meanderbelt and strandplain deposits. Correlative fluvial-deltaic sands form the seafloor over most of the inner shelf of the Brownsville-Harlingen area. These tan and gray silty fine sands grade downward into stiff tan and gray silty clay and shelly clay. Measurements from soil borings and high resolution seismic profiles indicate that the overall upward coarsening sequence is 50 to 180 ft thick with thicknesses increasing offshore and toward the fluvial axis (fig. 14a and 14b). The strike-aligned isopach patterns at the seaward limit of seismic control and lateral continuity of sand (Fulton, 1975; Morton and McGowen, 1980; Morton and others, 1983) are typical characteristics of wave-dominated deltas. A strong reflector seen on seismic profiles corresponds closely to the base of the progradational sequence (fig. 14b and 14c). Offlapping

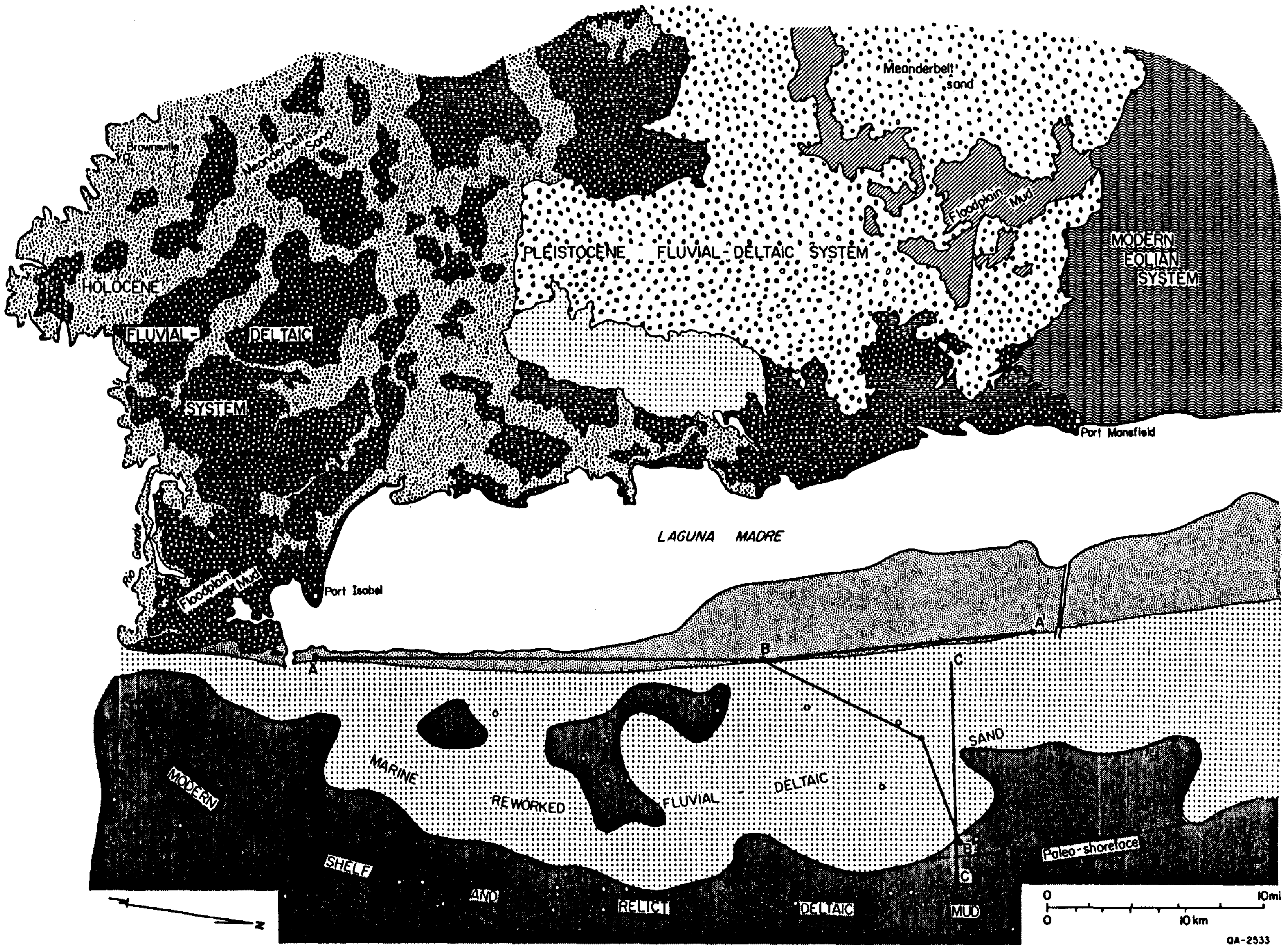


Figure 13. Distribution of late Quaternary fluvial-deltaic systems deposited by the Rio Grande during sea-level highstands. The axis of the entrenched valley eroded during the Wisconsinan sea-level lowstand is probably located in northern Mexico.

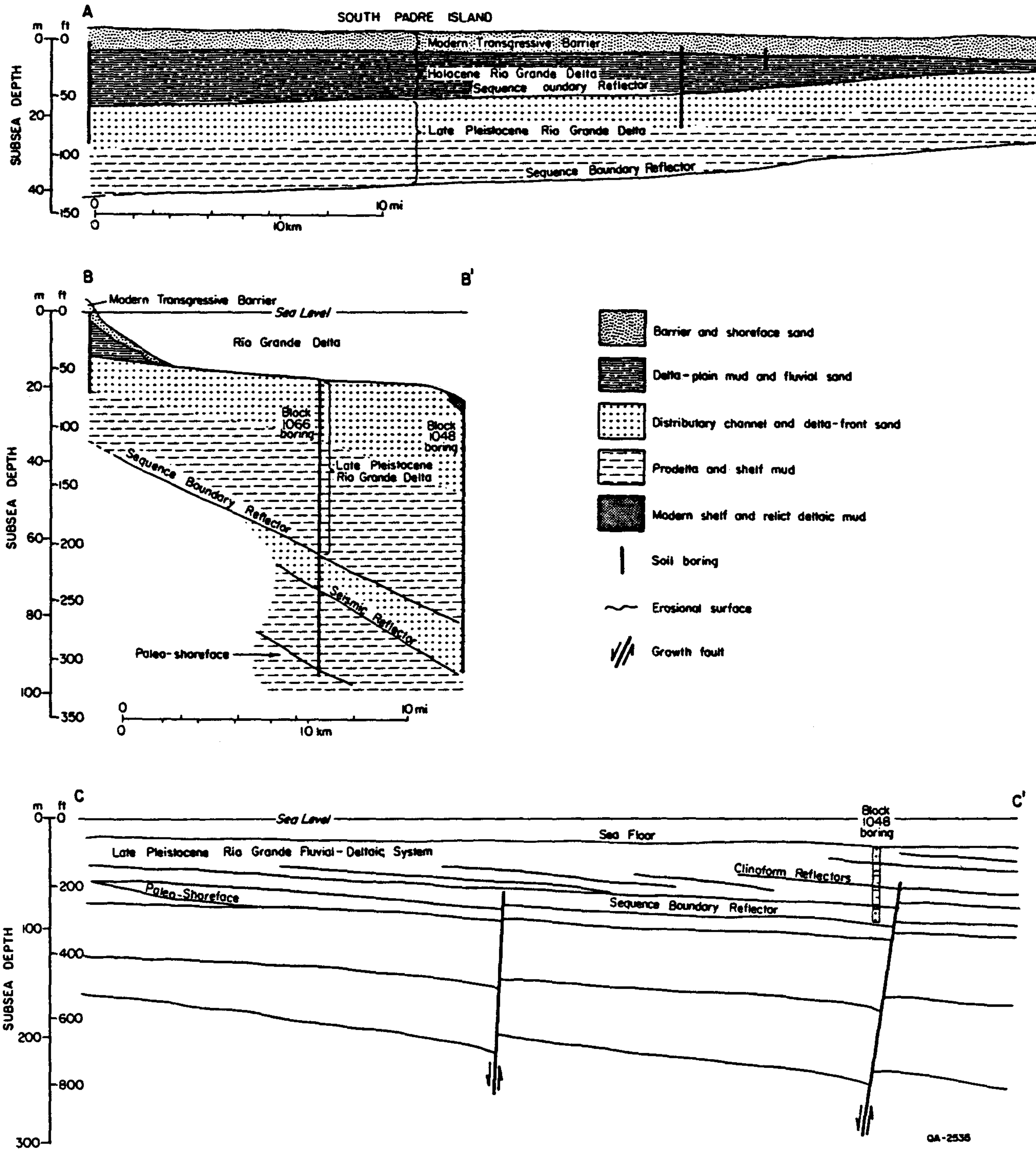


Figure 14. Late Quaternary facies relationships near South Padre Island shown by a (A) stratigraphic strike section, (B) stratigraphic dip section, and (C) high-resolution seismic profile. Locations of diagrams shown on figure 13. Stratigraphic cross sections based on published data (U.S. Army Corps of Engineers, 1958; Fulton, 1975; Morton and McGowen, 1980; Morton and other, 1983) as well as unpublished soil borings.

relationships above the sequence boundary, which can be mapped beneath much of the inner shelf, record the last Pleistocene depositional event (Winker, 1979). The top of the sand lithofacies also represents a sequence boundary that corresponds to the Holocene-Pleistocene unconformity and is recorded in the subsurface as a lithologic boundary and a strong seismic reflector near the Rio Grande (fig. 14a and 14b). This surface formed as sea level fell about 50,000 years ago and was modified during the Holocene rise in sea level which began about 18,000 years ago. As the former coastal plain and entrenched valleys were transgressed, the upper surface of the sand lithofacies was reworked by nearshore processes that introduced a marine fauna into sediments that were originally thick channel and shoreface sands interbedded with thin floodbasin and delta-plain muds (Morton and McGowen, 1980).

The Holocene-Pleistocene contact (fig. 14a and 14b) coincides with the base of the youngest progradational sequence in the Rio Grande Embayment. Overlying Holocene fluvial-deltaic sediments can be subdivided into four lithofacies that together constitute a major offlapping sequence. Brown to gray clays of prodelta origin compose the basal lithofacies which is 20 to 35 ft thick. This unit grades upward into thin gray sands interbedded with sediments similar to the prodelta muds. These alternating sands and muds (second lithofacies) comprise the delta-front deposits that are up to 25 ft thick. Sediments above the delta-front deposits are relatively thick (35 ft) and composed either of brown to gray sandy clay and organic-rich clay or gray fine sand and sandy silt. These two lithofacies, which were respectively deposited in delta plain and active fluvial channel environments, account for most of the Holocene Rio Grande fluvial-deltaic system. The thin prodelta and delta-front deposits and thick channel-fill and delta-plain deposits are typical of fluvially-dominated, stable-platform delta systems.

Holocene sediments derived from the Rio Grande range in thickness from 5 ft (fig. 14a) to nearly 100 ft (Fulton, 1975). Thickness increases toward the river mouth (fig. 14a) where subsidence was greatest and where the entrenched valley is deeper. Aggradation of the upper delta plain and fluvial channels accompanied valley filling and delta progradation across the inner shelf about 4,000 to 7,000 years ago (Fulton, 1975; Morton and McGowen, 1980) when the rate of sea-level rise diminished.

Morphological and sedimentological evidence suggests that the modern Rio Grande delta was located about 15 to 25 mi seaward of its current position (Price, 1954; Morton and Winker, 1979). However, reductions in sediment load and discharge associated with climatic changes caused subsequent delta abandonment and headland retreat that is manifested as shoreline erosion along Brazos Island and South Padre Island (Morton and Pieper, 1975). Delta abandonment was accompanied by subsidence which in turn promoted the formation of Laguna Madre and the adjacent wind-tidal flats about 2,000 years ago (Rusnak, 1960; Morton and McGowen, 1980).

Paleo-shorefaces representing brief pauses in shoreline retreat accompanying the relative rise in sea level are preserved as increases in shelf gradient with arcuate shapes (fig. 15). These former strandlines are part of the lobate pattern delineated by mapping coarse biogenic detritus and rock fragments on the inner shelf (Morton and Winker, 1979). Other slope changes that trend oblique to the shoreline (fig. 15) are caused by indurated sandstones and mudstones that form bathymetric highs (McGowen and Morton, 1979). Many of the seafloor ridges coincide with the surface expression of deep-seated (early Miocene) faults (figs. 14c and 15) that were reactivated and served as pathways for ground-water movement and subsequent cementation of adjacent sediments.

Sediments

Sediment Sources and Texture--Bay-Estuary-Lagoon System

Modern sediments in the bay-estuary-lagoon system are derived from several sources including (1) suspended and bed-load materials of rivers and streams, (2) erosional products from bay-margin shores, where upland areas include clay dunes and modern and Pleistocene barriers and deltas, (3) Gulf sediments transported through tidal passes and across barrier islands through washover channels, (4) sediment transported across the barriers by eolian processes,

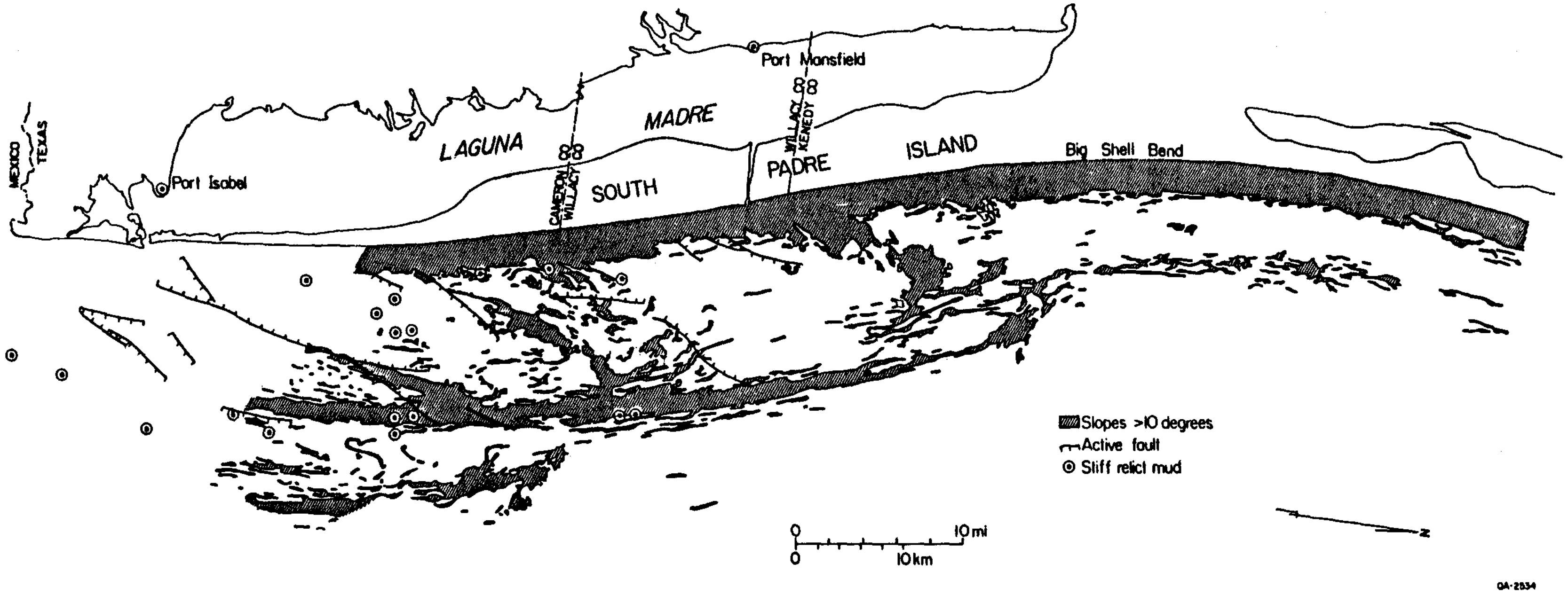


Figure 15. Slope map of the inner shelf off South Padre Island showing the relationship among seafloor gradient and active faults or paleo-strandlines. Also shown is the distribution of relict stiff muds from McGowen and Morton (1979).

(5) nonterrestrial biogenic materials, composed primarily of shells of benthic invertebrates, and (6) spoil placed on submerged lands along dredged channels. 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 bay shorelines is largely determined by prevailing and dominant wind directions, fetch, orientation of the 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 sources including (1) river deposition, (2) Gulf shoreline and shoreface erosion, (3) redistribution of modern shelf and bay-lagoon sediments, and (4) reworking of relict sediments exposed on the seafloor. During the past few thousand years these processes have supplied sediment to the inner shelf near Brownsville. The influence of rivers on shelf sedimentation in this area has been substantial because Quaternary and modern Rio Grande fluvial systems occupied the southern extremity of the area. Because net movement of littoral drift is to the north, coarse sediment (sand) deposited by the river is transported toward South Padre Island; fine-grained suspended sediment (mud) is deposited near the river mouth or in deep water on the continental shelf.

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 Brazos and Colorado Rivers. Erosion and redistribution of fluvial-deltaic deposits of the ancestral Rio Grande were significant sources of shelf sediment for the Brownsville-Harlingen area shortly after sea level reached its present position several thousand years ago. However, the volume of sediment supplied to the shelf by shoreline and shoreface erosion has greatly decreased with time. This decrease was caused by straightening the shoreline and developing an equilibrium profile for the shoreface and inner shelf.

Studies indicate that the main processes responsible for shelf sedimentation near Brownsville today are (1) suspension and redistribution of preexisting shelf and shoreface sediments during storms and (2) deposition of suspended sediment near the mouth of the Rio Grande. Insignificant quantities of sediment are probably transported onto the shelf through Brazos Santiago Pass. The "new" sediment introduced from the bay-lagoon system may include suspended fluvial sediment passing through the lagoon system or suspended sediment derived from bay shoreline erosion and erosion of bay-margin and bay-center sediments. What portion the preexisting shelf or bay sediments contribute is essentially impossible to determine because of the physical and biological mixing that occurs continuously. Wind-driven shelf currents and wave activity are responsible for the mechanical mixing, whereas burrowing organisms create additional heterogeneity after the sediments are deposited.

Sediments of the Texas inner shelf span three grain sizes--gravel, sand, and mud. The gravel-sized fraction, which is minor, is composed predominantly of shell of inner shelf species 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.

Gravel-size fragments of calcareous sandstone are common in shelf sediments off South Padre Island. They occur along subparallel linear trends that are oblique to the shoreline and form a broad arcuate trend extending from stations 385 to 503 (pl. IA and pl. VI). Morton and Winker (1979) interpreted the gravel as relict beach deposits associated with transgression of the ancestral Rio Grande delta. Shell concentrations are generally greatest along these same trends where rock fragments are present. Together the shells and rock fragments generally constitute from 2 to 8 percent of the sediment volumes at the stations where the coarse fraction is abnormally high; a few samples contain as much as 26 percent gravel.

Within the Brownsville-Harlingen region, composition of the sand fraction varies substantially both alongshore and offshore. Major components of the sand fraction and their average percentages are quartz (80 percent), feldspar (7 percent), rock fragments (6 percent), and accessory minerals, including glauconite (6 percent). Black opaques account for nearly 85 percent of the heavy mineral population; other heavy minerals in decreasing order of abundance are: pyroxenes (6 to 30 percent), basaltic hornblende (5 to 26 percent), tourmaline (3 to 14 percent), rutile (2 to 6 percent), and zircon (2 to 46 percent). Chlorite and the micas (muscovite and biotite) account for about 2 and 1 percent, respectively. Trends of sand composition show an overall decrease in quartz and increase in accessory minerals in both offshore and southwestward directions. Furthermore, relict sands exposed at the seafloor are mineralogically different from nearshore sands by having lower concentrations of hornblende, tourmaline, rutile, and mica and higher concentrations of zircon and garnet.

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. The composition and the relative abundance of clay minerals in the coastal area are similar to those in the source areas, thus indicating that neither authigenic mineral formation nor diagenetic alteration is significant in these shallow marine sediments.

Surface Sediment Type and Distribution Patterns

Sediment type 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. Users of the maps should be aware that lines denoting the contacts of the various map units are interpretations based on the given data points. Other interpretations using the same data points but slightly altering the position of boundary lines, or isoliths, are possible.

Disagreement between the mapped distribution of shell-sand-mud in this report and the earlier submerged lands report 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 the quantitative mapping effort resulting in more extensive interpretation or extrapolation between data points.

Bay-Estuary-Lagoon System

Shell(gravel)-sand-mud.--The most abundant sediment types in the bay-estuary-lagoon system are sand and muddy sand (pl. IA). In the northern half of Laguna Madre, a broad belt of sand occurs adjacent to wind-tidal flats that characterize the back-island area of Padre Island north of La Punta Larga. The sand extends from the margin of the tidal flats to more than halfway across the lagoon where it grades along a sinuous boundary into muddy sand (pl. IA). In this area, muddy sand occurs in slightly deeper water along much of the mainland half of the lagoon. Farther south the distribution of muddy sand broadens and covers more than 75 percent of the deeper southern end of the lagoon. Sand is less abundant in this area of Laguna Madre; it occurs in a narrow band fringing Padre Island, and at a few stations near the center of the lagoon along the Intracoastal Waterway (pl. IA). Other occurrences of sand are along the mainland margin of Redfish Bay near Port Mansfield.

Sandy mud occurs in several patches along the mainland shore of Laguna Madre. Two of the largest patches occur (1) centered on the mouth of the Arroyo Colorado cutoff, and (2) in the area of Laguna Vista cove (pl. IA). Also, sandy mud is the predominant sediment type in South Bay.

Although mud (silt and clay) is the most abundant sediment type in dredged channels such as the Intracoastal Waterway, Brownsville Ship Channel, and the Arroyo Colorado (Harlingen Channel), its occurrence in the bay and lagoon sediments outside of channels is limited to four sample stations, most of which are scattered in the southern part of the lagoon (pl. IA). Muddy shelly sand, shelly sand, and sandy shelly mud have a very limited distribution, occurring in a total of five sample stations. Muddy shelly sand is most abundant; it occurs in three stations in the vicinity of Port Isabel.

Sand-silt-clay.--The map depicting the distribution of sand, silt, and clay, and various ratios thereof (pl. IB) provides a more detailed picture of the distribution of mud constituents--silt and clay. Gravel is ignored in computing and mapping the relative percentages of the finer grained sediments that this map represents. Removal of gravel percentages from the calculations elevates sand concentrations above 75 percent for some samples, thus explaining the slightly larger distribution of sand on the sand-silt-clay map (pl. IB) when compared to the shell(gravel)-sand-mud map (pl. IA). This difference can be seen by comparing sand distribution shown on the two maps for the south-central part of Laguña Madre.

In the mud fraction, silt is generally more abundant than clay. This relationship is shown by the wide distribution of silty sand over most of the southern part of Laguna Madre as well as over the mainland half of the lagoon to the north (pl. IB). Clayey sand is rare and occurs at only four sample stations along the margins of Padre Island. (The predominance of silt over clay in the lagoons and bays as well as in muds in deeper areas of the inner shelf, may be in part a reflection of the method of the textural analysis used; see app. A.)

While clayey silt is abundant in channels, such as the Brownsville Ship Channel and the Intracoastal Waterway, it occurs in only five sample stations outside of the channels. Sandy silt is even less abundant, occurring in only two sample stations, one located near Horse Island along the mainland shoreline, and the other along the margin of South Bay. Mixtures of sand, silt, and clay, where no single sediment fraction exceeds 50 percent, are found in patches along the lagoon margins and in much of South Bay.

Percent sand.--The sand-percent map (pl. IC), can be used with other sediment maps to provide a more complete picture of the textural variations in the bay-estuary-lagoon system.

Overall, in Laguna Madre the highest percentage of sand occurs in sediments adjacent to Padre Island wind-tidal flats and the lowest percentages in sediments next to the mainland (pl. IC).

The lagoon can be subdivided from north to south into three segments based on sand-percent distribution patterns. In the northern segment sand is relatively abundant throughout the lagoon and ranges from 80 to 100% in sediments adjacent to the wind-tidal flats, decreasing to 60 to 80% in the western half of the lagoon. Sediment distribution patterns near Port Mansfield Channel have apparently been altered by dredged spoil dumped along the channel.

The central or middle segment of Laguna Madre, which corresponds generally with an area of intensive sampling (sample stations spaced 0.5 mi or 0.8 km apart--see pl. VI) is characterized by sediments with decreasing percentages of sand from the margin of Padre Island to the mainland shores. Sediments containing from 80 to 100 percent sand grade landward into a belt of sediment containing 60 to 80 percent sand, which in turn grades into an area of sediment made up of 40 to 60 percent sand. Patches of sediment containing less than 40% sand also occur along the mainland.

In the southern segment south of La Punta Larga, the width of Laguna Madre increases and sediment distribution patterns are more irregular. A narrow strip of sediment with high sand content (80-100 percent) fringes Padre Island and grades lagoonward into broad and intertonguing areas of sediment containing 60 to 80 percent and 40 to 60 percent sand. Although there are exceptions, sediments near the mainland generally have lower percentages of sand (pl. IC).

In the sediments of South Bay, sand ranges from 75 percent at a station along the bay margin to a low of 9 percent in bay center. Most sediments have a sand content of between 40 and 60 percent.

Generally, dredged channels such as Brownsville Ship Channel, Harlingen Channel (Arroyo Colorado), and the Intracoastal Waterway, contain sediments with low sand percentage (less than 20 percent). Sediments containing high concentrations of sand such as stations 9, 13, and 19, along the Harlingen Channel (Arroyo Colorado) (pl. IC and app. B), were usually taken along the channel margins in shallow water where waves and currents winnow out silt and clay and concentrate sand.

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 equivalent to the negative logarithm to the base 2 of particle diameter (Krumbein, 1934). In the phi scale, the larger the number, the finer is the grain size. Gravel was excluded in the mean-grain-size determinations (app. A).

Distribution patterns of mean grain sizes in the bay-estuary-lagoon system generally follow those depicted on the other textural maps; however, the mean-grain-size data provide a more detailed subdivision of sediments. The coarsest sediment--with a mean grain size of fine sand (2ϕ to 3ϕ)--is broadly distributed adjacent to back-island wind-tidal flats from near La Punta Larga northward. Outside of this broad belt, sediments with a mean grain size of less than 3ϕ are limited to about eight sample stations, four of which are located near the mainland margin around Redfish Bay, and four are located in the southern end of Laguna Madre. Sediment with the coarsest mean grain size (1.1ϕ) was collected at sample station 176 in Redfish Bay (pl. VI). This particular station coincides with an area of oolite shoals mapped by Brown and others (1980); the coarseness of the sediment is attributed mainly to abundant shell hash.

In the central part of Laguna Madre (area of intensive sampling--pl. VI) the broad belt of fine sand (2ϕ to 3ϕ) extending from Padre Island tidal flats grades lagoonward into very fine sand (3ϕ to 4ϕ), which grades into coarse silt (4ϕ to 5ϕ) toward the mainland. Locally, such as near the mouth of the Arroyo Colorado Cutoff, lobes of sediment with a mean grain size of medium silt (5ϕ to 6ϕ) occur.

In the southern part of Laguna Madre, south of La Punta Larga, much of the lagoon is floored with sediment having a mean grain size of coarse silt (4ϕ to 5ϕ), which surrounds a relatively large centrally located arcuate band of very fine sand (3ϕ to 4ϕ). Along the mainland margin, between Laguna Vista Cove and the Laguna Atascosa National Wildlife Refuge, sediments with a mean grain size of medium silt occur. The finest grained sediment (mean grain size of 7.4ϕ) was collected at sample station 393 near the south end of Padre Island.

In South Bay sediments with a mean grain size of coarse silt (4ϕ to 5ϕ) extend from the margin of Brazos Island near Brazos Santiago Pass, toward the bay center, which is characterized by medium to fine silt (5ϕ to 7ϕ). Sediment with the coarsest mean grain size (3.2ϕ or very fine sand) was collected at sample station 6 (pl. ID and pl. VI).

Dredged channels, such as Brownsville Ship Channel and the Intracoastal Waterway, are characterized by fine-grained sediments typically ranging from 5ϕ to 8ϕ. Port Mansfield Channel, which cuts through sand-rich Padre Island, contains relatively coarse sediments ranging from 2ϕ to 4ϕ (fine to very fine sand) gulfward of the Intracoastal Waterway. Landward of the Intracoastal, the mean grain size is much finer, exceeding 7ϕ (fine silt).

Inner-Shelf System

Shell(gravel)-sand-mud.--Less than one half of the 12 possible sediment types are represented on the shelf portion of plate IA because shell material in the sediments is less abundant than terrigenous clastic material. Even though shelf sediments are composed essentially of sand and mud, the whole-sample classification, including shell, (pl. IA) shows certain features that are not apparent on the other maps depicting sedimentological characteristics.

The use of shell content to classify shelf sediments mainly influences the sand/mud ratio. Only two analyzed samples (363, 364) have sufficient quantities of the three sediment types to plot within the fields of muddy, shelly sand. 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 sedimentation and eustatic sea-level changes that influenced the area during the late Quaternary period. Dominantly sand-sized sediments blanket most of the inner shelf and extend about 10 mi (16 km) offshore from South Padre Island. Water depths average about 90 ft

(30 m) at the outer limits of this sand-rich area. The greatest extent of sand is associated with the marine reworked late Pleistocene fluvial-deltaic deposits that underly much of the inner shelf because they were never buried or younger muddy sediments were removed by erosion.

Overall, the highest concentration of sand parallels the coastline. An exception is the arcuate trend of muddy sand of variable width that lies seaward of the nearshore sand zone and extends to the seaward limits of the study area off Mansfield Channel. This trend curves toward the shoreline and merges with a nearshore patch of mud near the Texas-Mexico border. The nearshore patch of mud (stations 3 to 64) represents the most recent Rio Grande deposition whereas the muddy sand to the east and north represents a mixture of relict shelf sands and more modern fluvial muds. Together these palimpsest sediments delineate the retreat path of the mouth of the Rio Grande and suggest that the river has been contributing primarily fine-grained suspended sediment to the Texas shelf for the past few thousand years. Nearshore patches of muddy sand (stations 157 to 179 and 249 to 308) possibly represent erosional remnants of relatively young Rio Grande flood basin deposits dated from nearby core samples at 5,000 yr BP by Fulton (1975). Deposition of modern mud away from the river mouth is limited to relatively deep water because of higher wave energy and steeper seafloor gradient as compared to other segments of the Texas inner shelf. The reentrant of muddy sand between stations 423 and 534 occupies an area of relatively gentle slopes (fig. 15) immediately landward of steeper slopes that probably represent a submerged Holocene shoreface.

Sand-silt-clay.--Although subdivision of the shelf mud fraction into silt and clay provides a greater definition of sediment size (pl. IB) the overall pattern is essentially the same as that seen on the gravel-sand-mud map (pl. IA). The most noticeable difference is delineation of sediments composed of clayey sand within the muddy sand trend. The cause of this unusual mixture is unclear although it appears to be gradational with surrounding silty sand.

Sediments in the transition zone near the three-league line consist of nearly equal amounts of sand and silt. These sediments, which are slightly coarser than adjacent (seaward) muds, owe their distinctive characteristics to physical and biological processes that together have created a mixture of sand and mud along and seaward of a former strandline. 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 backfilling in burrows. Others, however, in the transition and offshore mud zone, remain undisturbed and are preserved as graded sand layers within shelf mud (Morton, 1981).

Inner shelf sediments of the Brownsville-Harlingen area are actually more heterogeneous than is suggested by either Plates IA or IB. Relict stiff muds mapped by McGowen and Morton (1979) are widely scattered but apparently do not greatly influence the composition of less cohesive overlying sediments. However, the relict muds generally coincide with patches of finer-grained sediment within the sand sheet or along the former strandline.

Percent sand.--Sand is an economic mineral resource as well as a useful indicator of physical processes that can be used to interpret the geologic history of an area. Therefore it is instructive to know the relative proportions of sand and mud occurring in the shelf sediments. Sand constitutes from 2 to 98 percent of the inner-shelf sediments (pl. IC), depending partly on water depth and concomitant distance from the shoreline and mouth of the Rio Grande. Areas containing the highest proportions of sand are adjacent to the beaches of South Padre and Brazos Island. In these areas concentrations of sand greater than 80 percent generally extend at least 5 mi offshore, except near the mouth of the Rio Grande. An oblique sand-rich trend (stations 137 to 295) corresponds to a fault-controlled ridge that owes its topographic relief to differential erosion of calcite-cemented Holocene sandstone and mudstone. The steeper slopes (fig. 15) and surface elevations prevent deposition of mud and promote preservation of the winnowed fine-grained sand.

Thickness and lateral extent of the nearshore sand along Padre Island are partly related to the late Pleistocene Rio Grande delta (figs. 13 and 14) and partly to the influence of shelf gradients (fig. 15). Lower gradients and or deeper water are preferred sites of mud accumulation and lower sand percents. Holocene and Modern sediments generally contain more mud than Pleistocene sediments. Numerous borings indicate that Holocene sediments along South Padre Island thicken towards Brazos Santiago Pass (fig. 14a) which overlies the former entrenched valley margin cut by the Rio Grande system when sea level was lowered during Wisconsin glaciation (Brown and others, 1980). Maximum thickness of Holocene sediments near the Rio Grande is uncertain, but they appear to be greater than 100 ft thick within the valley axis. In contrast, Holocene sediments are only a few inches to a few feet thick (fig. 14b) over much of the inner shelf.

Mean grain size.--Inner shelf sediments are characterized by average textures that range from 2.4ϕ to 8.2ϕ, or fine sand to coarse clay (pl. ID). As with other sedimentological properties, mean-grain sizes either decrease offshore with trends roughly parallel or slightly oblique to the shoreline or are irregular and patchy. Sediments with textures of very fine sand are areally more extensive than the other grain sizes. Fine sand and coarse silt are also abundant, whereas grain sizes finer than medium silt are least abundant. The inner-shelf sediments with the finest textures have mean grain sizes between 6ϕ and 8ϕ (fine silt to coarse clay). The fact that these sediments are comparable in size to sediments found in Laguna Madre suggests a common source.

The coarsest textures (<3ϕ or fine sand) are attributed to reworked late Pleistocene fluvial sands that were washed over South Padre Island or partially buried beneath modern finer-grained sands transported to the North by longshore and inner shelf currents. In contrast, the finest textures are associated with modern mud sinks near the Rio Grande and along the seaward margin of the former strandline (fig. 13).

Gross Changes in Sediment Distribution (1927-1974), Brazos Santiago Pass

Jetty construction and frequent channel dredging over the past 50 years have greatly influenced bathymetry and sediment volumes but not sediment textures at the Gulf entrance to Brazos Santiago Pass. These bathymetric and sediment changes were primarily associated with modification of the ebb-tidal delta. Shallow borings made by the U.S. Army Corps of Engineers before channel modification (Morton and McGowen, 1980) show that sand blanketed the inner shelf near Brazos Santiago Pass. These ebb-tidal delta deposits contributed to the beach accretion on Brazos and South Padre Islands (Morton and Pieper, 1975) and to aggradation of the inner shelf after the jetties were constructed in 1927 (Morton, 1977).

Although inlet depths were greatly increased and shelf depths adjacent to the jetties decreased, the sediment composition and grain size were not appreciably affected in comparison to normal sandy shoreface deposits (Pl. IA, IB, IC, ID).

Bathymetry and Sediment Distribution

The 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. The larger bays along the central and upper Texas coast are generally characterized by sandy bay margins that reflect not only sand sources, but also 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.

This relationship between bathymetry and texture, which is apparent for the larger, deeper bays such as Corpus Christi and Trinity Bays to the north, is not as well defined in relatively shallow, narrow south Laguna Madre in the Brownsville-Harlingen area. Factors besides bathymetry such as lithology of lagoon margins, erosional and depositional patterns, wind and current directions, location of storm washover areas, occurrence of marine grasses, and location of dredged spoil deposits, also have a significant effect on textural distribution.

A comparison of the distribution of sand (pl. IC) with water depth (pl. V) reveals that sediments with the highest percentages of sand are not necessarily related to areas of shallow water. While the broad belt of sediments with high sand percentages (>80 percent sand) adjacent to wind-tidal flats in the northern half of Laguna Madre do occur in shallow water

(< 2 ft or 0.6 m deep), sand content in Redfish Bay, which is about 8 ft or 2.4 m deep, is also relatively high (>60 percent sand). This is in contrast to shallow mainland margin environments south of the Cameron and Willacy County line where submerged lands less than 2 ft (0.6 m) deep are typically composed of sediments with less than 60 percent sand and in some areas less than 40 percent sand.

Expectably, sand increases toward Padre Island particularly north of La Punta Larga where onshore winds and numerous hurricane washover channels supply sand to broad wind-tidal flats and adjacent shallow submerged lands. Across the lagoon in the vicinity of Port Mansfield, mainland depositional facies include sand-rich Pleistocene deltas and fluvial deposits and eolian sands (fig. 9). Southward, the abundance of muddy sediments increases along the mainland shore reflecting sources of mud such as Arroyo Colorado, drainage canals, and importantly, numerous clay sand dunes, such as Horse Island, from which silt and clay (mud) are eroded.

Along the margin of Padre Island south of La Punta Larga, wind-tidal flats are narrow and the slope of the lagoon margin is much steeper than that farther north as denoted by the 2 ft (0.6 m) bathymetric line (pl. V) that occurs relatively close to shore. Marine grasses in this broader southern stretch of Laguna Madre trap mud, contributing to extensive areas of muddy sand (pl. IA). Coarser sediment occurs along the Intracoastal Waterway in bay center as a result of dredged spoil deposits and associated erosional products that include sand.

Shallow, small South Bay, which is less than 2 ft (0.6 m) deep and is characterized by relatively fine-grained sediment, is perhaps a sink for clay and silt in part derived from adjacent tidal flats and associated clay-sand dunes that are scattered across the flats. The clay dunes are topographically high features that are easily identified from contour lines shown on plate V.

The distribution of terrigenous sediment on the inner shelf is only partly controlled by water depth and distance from the shoreline. Muddy sediments are less abundant than sandy sediments, although mud covers the slopes of the inner shelf. The transition zones between sand and mud, or zones of greatest sediment mixing are well defined and generally correspond to breaks in shelf gradient as they do in other areas. The overall shelf gradient is fairly uniform in a northeasterly direction but steeper slopes (fig. 15) attributed to recent fault movement and submerged Holocene shorefaces occur within the generally seaward gradient. The steepest gradients occur off the Rio Grande where water depths approaching 100 ft are encountered within the study area.

Data from the Gulf of Mexico and elsewhere suggest that the shoreface sands and interlaminated sands and muds of the transition zone exhibit physical sedimentary structures. In contrast, the offshore muds deposited in deeper water are extensively bioturbated and biogenic structures are more abundant than physical structures.

Geochemistry

Distribution of Selected Major and Trace Elements

Uniform standards were followed in contouring geochemical data (pls. II, III, and 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. In reality, this "bull's-eye" effect, which can cover a relatively large area around the point, may or may not exist. Because the analyses are only semiquantitative, one should interpret the meaning or significance of any single value with caution.

It should be reemphasized that although the majority of sediment samples were analyzed by the U.S. Geological Survey using an emission spectrograph, supplementary analyses of selected samples of bay sediments were analyzed by the Bureau of Economic Geology using an inductively coupled plasma atomic emission spectrometer (ICP-AES) (for additional details about these methods, refer to the section on Geochemistry under Data Acquisition and Analyses). The methods of analysis were similar in that both provide total concentration of the selected elements in each sample. Because the analytical techniques are different, however, the results are not totally comparable. Therefore, on maps (pls. II, III, and IV) and scattergrams, results of the two analytical methods are distinguished from each other so that users can view and judge the trends, accordingly. Trace element distribution patterns and anomalies in some areas may be partly attributed to the different analytical methods.

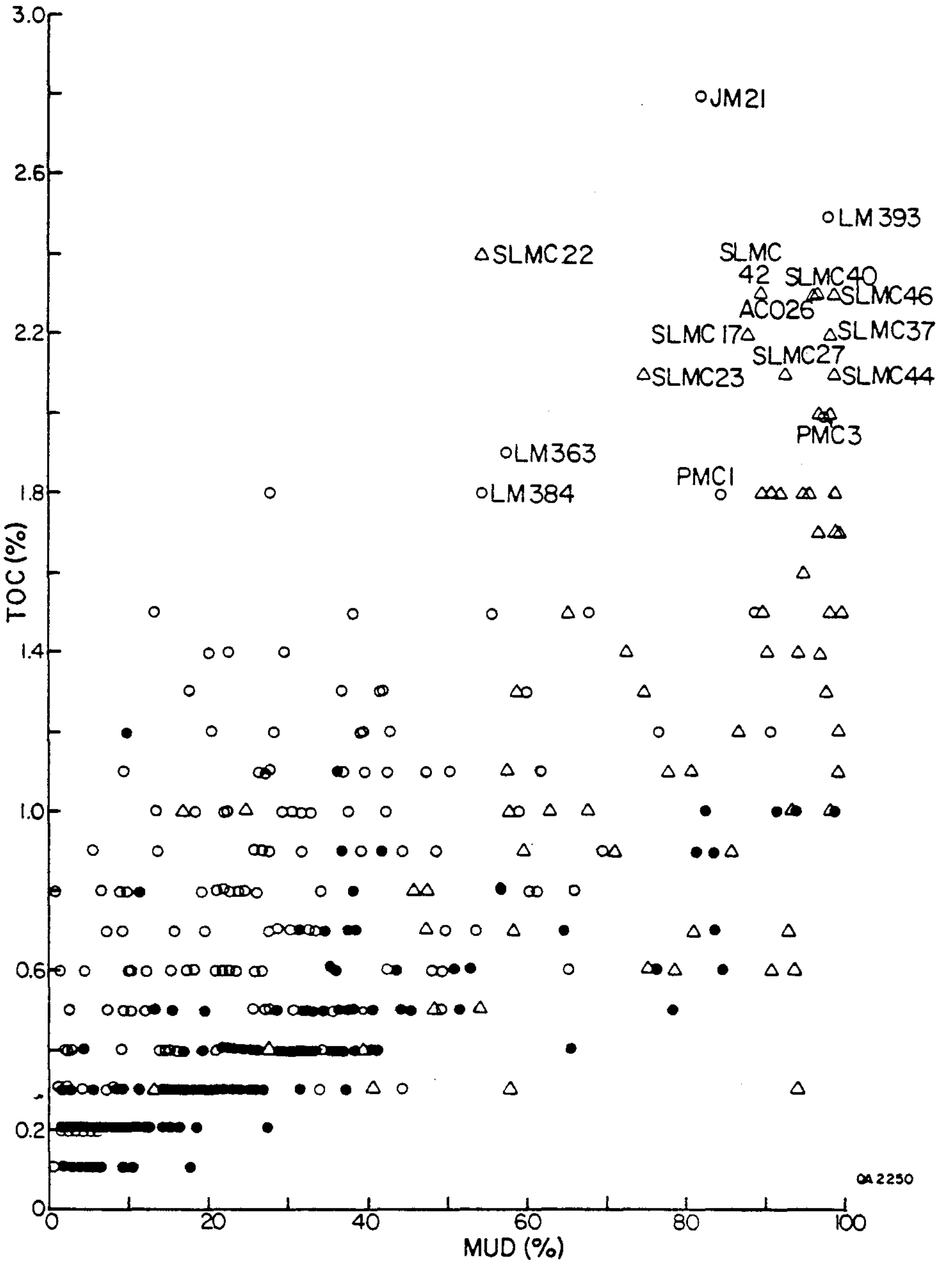
Total Organic Carbon

Bay sediments.--Distribution patterns defined by total organic carbon (TOC) concentrations in submerged land sediments (pl. IIA; app. B) are similar to those shown on textural maps (pl. I). Concentrations of TOC in Laguna Madre range from 0.1 to 2.8 percent. Low values of TOC (less than 0.6 percent) generally correspond to sandy sediments whereas higher values (more than 1.0 percent) are associated with muddier sediments. Such a relationship between TOC and texture, which has been reported in other studies (for example, Shimp and others, 1970), is consistent for most of the lagoon. However, the presence of abundant marine grass at many locations increases the TOC in sandy sediments, which tends to reduce the correlation between TOC and fine-grained sediments. Still, there is a definite positive correlation between TOC and mud (fig. 16).

The relationship between TOC and sediment texture can, also, be seen by comparing the TOC map (pl. IIA) with the sand-percent map (pl. IC). Generally, in northern Laguna Madre (north of the intensive sampling area--fig. 4) where sand percentages are relatively high, TOC concentrations are lower than 0.6 ppm. In southern Laguna Madre, where sand content decreases and mud content increases, TOC is more abundant and much of the area contains sediments with TOC concentrations ranging between 1.0 and 1.5 ppm.

In the middle segment of Laguna Madre (area of intensive sampling, fig. 4), the distribution of TOC is complex and the relationship with texture less apparent. This reflects, in part, the occurrence of marine grasses on sandy substrates in this area.

Shelf sediments.--The general relationship between TOC values and sediment size in bay sediments noted both in this study and in other studies also applies to the inner shelf (pl. IIA, app. B). Accordingly, TOC concentrations exhibit patterns that are similar to the shelf



o Bay sediments
Δ Channel sediments; r (for bay and channel sediments) = 0.655; n = 144
• Shelf sediments; r = 0.830; n = 32

Figure 16. Scattergram of total organic carbon and mud, Brownsville-Harlingen area. (Letters and numbers next to plotted points on the above and succeeding scattergrams are sample station numbers for sediments that plot above the trend set by other sediments--ACO = Arroyo Colorado, BSC = Brownsville Ship Channel, JM = intensive sampling area of Laguna Madre, LM = Laguna Madre, PMC = Port Mansfield Channel, SLMC = Intracoastal Waterway, Z = South Bay; numbers without letter prefixes = shelf stations--see plate VI and appendix B; r = correlation coefficients and n = number of samples.)

sediment patterns (pl. I). Concentrations of TOC in shelf sediments from the Brownsville-Harlingen area are generally extremely low and range from less than 0.1 to 1.2 percent; most samples, however, contain between 0.1 and 0.5 percent TOC. These concentrations (fig. 16) are less than half those measured in sediments from adjacent bays where biological productivity is slightly greater.

Highest values of TOC approximately coincide with mud sinks and lowest values of TOC correspond with shoreface and inner shelf sands. There are, however, many exceptions to the rule. The highest concentrations of TOC on the inner shelf occur in small discontinuous patches, usually reflecting high values at individual stations. The highest measured TOC value (stations 187 and 311) was from a mud and a sand, respectively. These sediment types are typical of many other shelf samples and, therefore, the TOC value is anomalously high in comparison to surrounding sediments. The pattern of TOC values is patchy and complex owing to the high variability of the sediment types. However, transects from the shoreline usually exhibit increases in TOC in an offshore direction.

Barium

Bay sediments.--Concentrations of barium (Ba) in bay sediments range from less than 150 ppm to a high of 1100 ppm; average values are about 300 ppm (pl. IIB). Highest concentrations of barium in lagoon sediments, typically ranging between 400 and 500 ppm, occur at the southern tip of Laguna Madre in the vicinity of Port Isabel, in South Bay, and in patches along the mainland side of Laguna Madre in the area of Laguna Vista Cove, between Rincon de Guajardo and the Arroyo Colorado Cutoff, and in the vicinity of Four Mile Slough south of Port Mansfield. The only anomalous value of barium along the eastern margin (island margin) of Laguna Madre, occurs at station 201 about 1 mi (1.6 km) north of Port Mansfield Channel (pl. IIB and pl. VI). The barium concentration in the predominantly sandy sediments at this site is 457 ppm.

Except for the high value of 1100 ppm occurring in sediment from a station (no. 394) near Port Isabel, the highest concentrations of barium were in sediments collected from the

Brownsville and Port Isabel ship channels. Six of the ten samples analyzed from these channels were above 500 ppm. One sample from the Intracoastal Waterway contained a barium concentration of 600 ppm but the remainder of the samples were below 400 ppm.

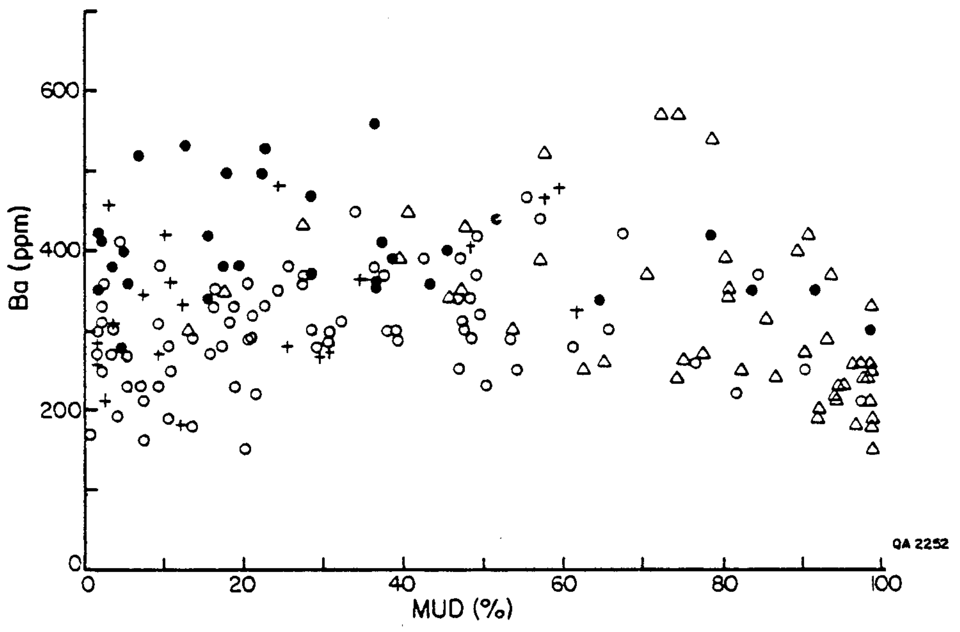
In many bay systems, anomalous occurrences of barium are related to drilling activities and the associated use of barite ($BaSO_4$) in drilling muds. Holmes (1974) reported good correlation between locations of oil and gas wells and high concentrations of barium in Corpus Christi Bay.

Shelf sediments.--Surface sediments of the inner shelf contain barium in quantities ranging from 270 to 600 ppm (pl. IIB, app. C). The maximum concentrations of barium in most shelf sediments are higher than those for sediments in adjacent bays. Also, shelf sediments generally contain more barium than bay sediments having comparable amounts of mud (fig. 17). The lowest and highest amounts of barium occur in irregularly shaped patches rather than in systematic trends that are related to sediment texture or composition. Comparison of maps showing well sites and barium abundance suggests that the patches of high barium are only partly related to drilling activities on the inner shelf. Abnormally high values of barium at individual sample localities are unrelated to well sites. Moreover, some well sites plot within areas of low barium concentration.

Most samples contain between 400 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.

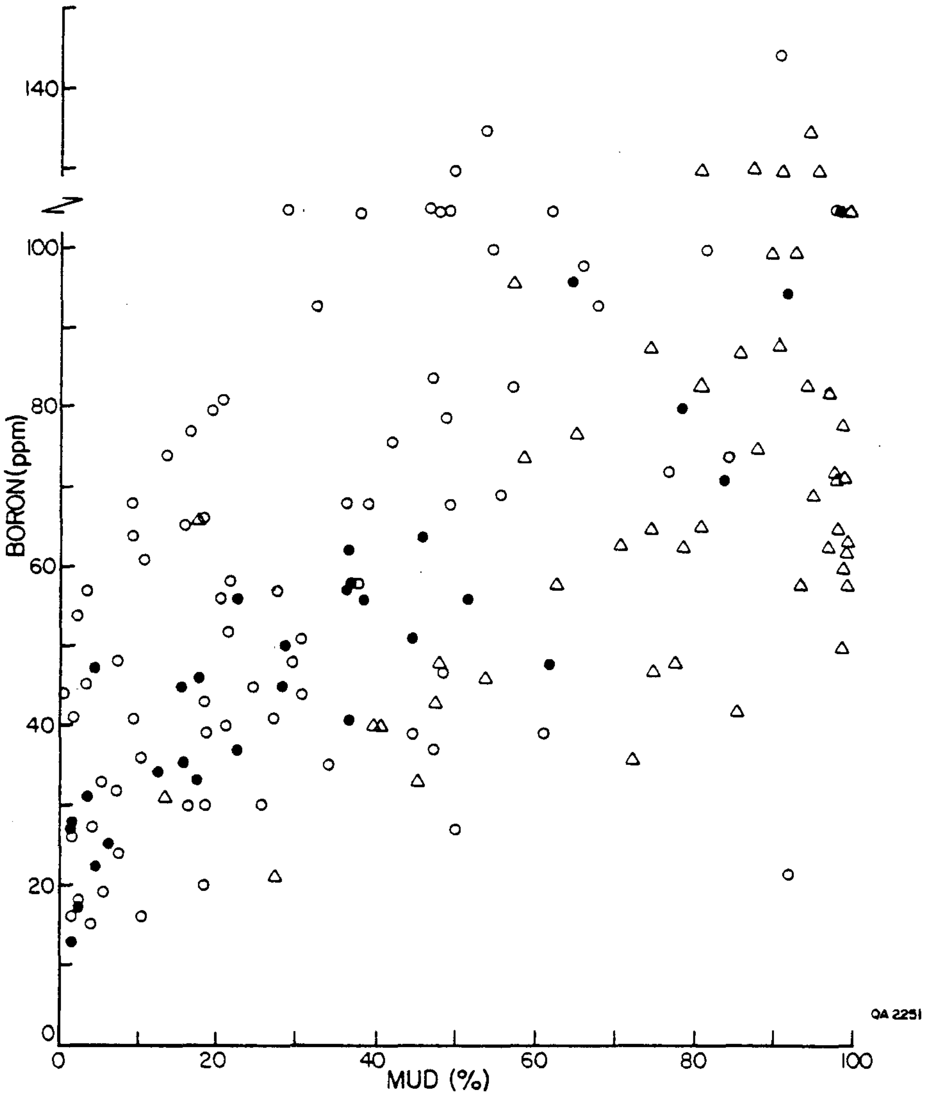
Boron

Bay sediments.--Concentrations of boron (B) range from less than 20 ppm to 220 ppm in Laguna Madre (pl. IIC). The distribution of boron as depicted on Plate IIC follows rather complex patterns and its relationship with sediment texture (pl. I) is not readily apparent. However, there is a positive correlation (correlation coefficient of 0.539) with texture as shown in a scattergram of boron and percent mud (fig. 18).



o Bay sediments; Ba analyses by USGS; r = 0.263; n = 71
+ Bay sediments; Ba analyses by Bureau of Economic Geology; r = 0.424; n = 19
Δ Channel sediments; Ba analyses by USGS
r (for USGS analyzed bay and channel sediments) = -0.048; n = 126
• Shelf sediments; Bay analyses by USGS; r = 0.285; n = 32

Figure 17. Scattergram of barium and mud (r = correlation coefficient; n = number of samples).



o Bay sediments; r = 0.677; n = 71
Δ Channel sediments
r (for bay and channel sediments) = 0.539; n = 126
• Shelf sediments; r = 0.912; n = 32

Figure 18. Scattergram of boron and mud (r = correlation coefficient; n = number of samples).

Highest concentrations of boron ($\geq$ 120 ppm) occur in patches of sediments (1) adjacent to the mainland between Gabrielson Island and Mullet Island, and (2) near Padre Island in the vicinity of La Punta Larga. Although the highest concentration of boron (220 ppm) occurred in lagoon sediments collected adjacent to Yucca Island (pl. IIC), the predominantly muddy sediments from the Intracoastal Waterway contain the next highest concentration of boron--160 ppm. Lowest concentrations of boron (> 40 ppm) are broadly distributed in sands adjacent to wind-tidal flats along the lagoonward side of Padre Island.

Shelf sediments.--Boron concentrations in shelf sediments (pl. IIC, app. B) range from 11 to 130 ppm, a range slightly less than that of nearby bay sediments. Most shelf samples, however, have minor boron concentrations ranging from 11 to 60 ppm (pl. IIC). The correlation between boron and mud (fig. 18) is also similar for both areas with shelf samples having a better correlation than bay samples. The relation of boron to mud in shelf sediments generally corresponds to the mid range of bay sediments (fig. 18) but shelf sediments have more uniform concentrations (less variability) of boron for a given percent mud.

Boron generally increases offshore along South Padre Island; however, the patterns are not systematic and they are not related to water depth although the overall pattern is similar to sediment type (pl. I). Boron concentrations are lowest where sand is abundant. In contrast, highest concentrations of boron are normally limited to isolated sample sites.

Calcium

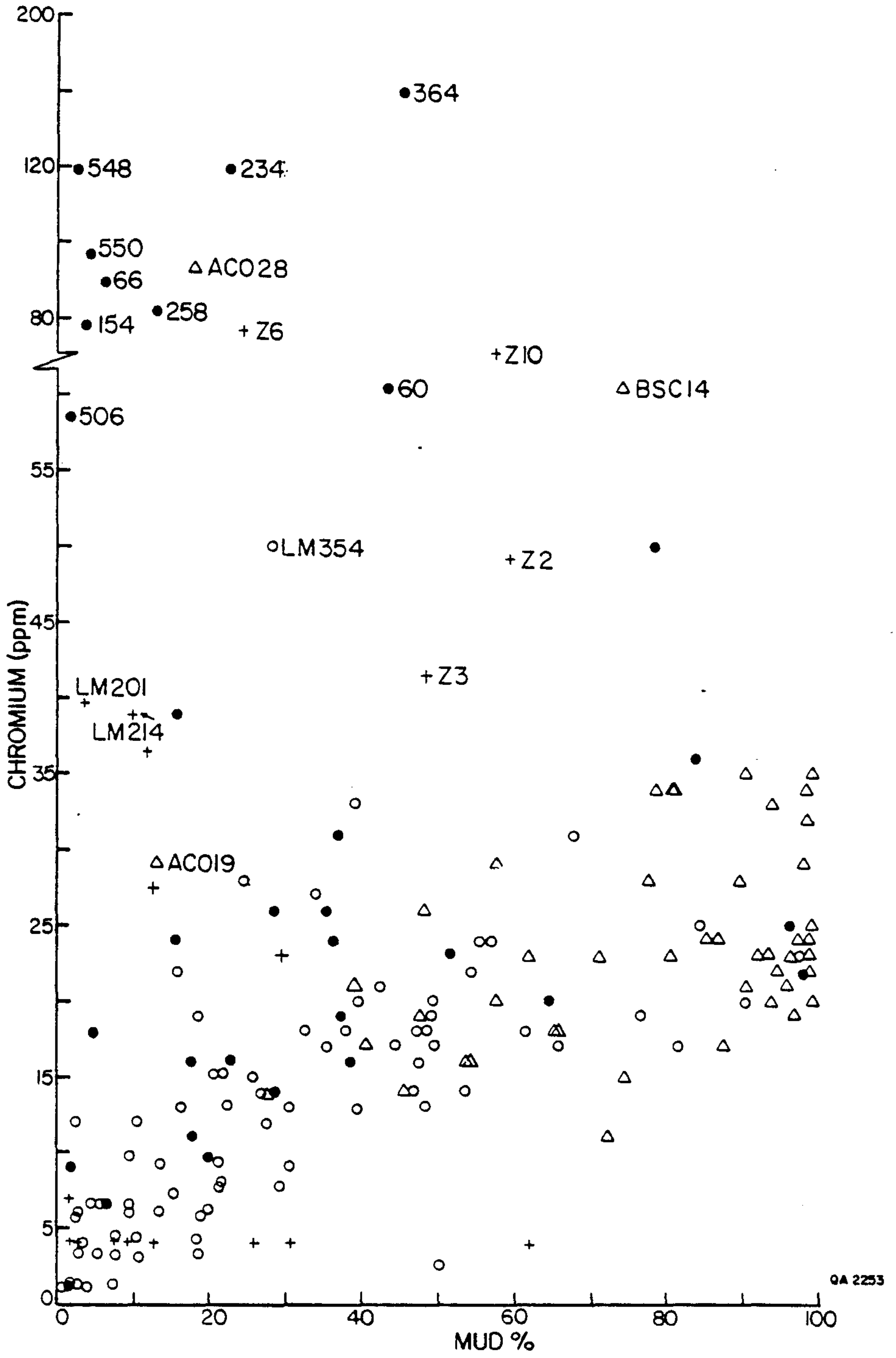
Bay sediments.--Concentrations of calcium (Ca) in the bay-estuary-lagoon sediments range from less than 2 percent (20,000 ppm) near Padre Island, to a high of about 23 percent (230,000 ppm) near the Intracoastal Waterway northeast of Port Mansfield (pl. IID). The mean value for calcium is about 6 percent. Generally, the lowest concentrations of calcium are along the margin of Padre Island on the eastern shore of Laguna Madre. Concentrations increase in central and western parts of the lagoon. In the area of intensive sampling (fig. 4, pl. IID), calcium distribution patterns are complex with several patches of sediment containing more than 9 percent calcium. Shell (gravel) content ranges from less than 1 percent to almost 8 percent and averages about 4 percent in eight lagoon samples that contain calcium concentrations of 11 percent or more. The mean concentration of calcium in channel sediments, which are uniformly fine-grained and devoid of shell, is approximately 5 percent.

Shelf sediments.--Although concentrations of calcium in shelf sediments range from 0.3 to 9 percent, most samples contain less than 3 percent (pl. IIC). Anomalously high concentrations are scattered along the former strandline which also corresponds to a trend of coarser sediment including shells and shell fragments. Muddy sediments are slightly enriched in calcium near the mouth of the Rio Grande. Calcium is generally less abundant on the shelf than in adjacent bays probably because modern shelf sediments normally contain less shell material than do bay sediments.

Chromium

Bay sediments.--Chromium (Cr) in lagoon sediments ranges from less than 1 ppm to 84 ppm (pl. IIIA, app. B) and averages about 10 ppm. Comparison of textural maps (pl. I) with maps showing the distribution of chromium in lagoon sediments indicates that chromium concentrations generally increase as sediment particle sizes decrease. This relationship with texture is shown in the scattergram of chromium and percent mud (fig. 19). Although chromium concentrations in bay sediment are uniformly low, a few anomalous values do stand out in a scattergram (fig. 19). These samples, such as LM 354, contain above normal concentrations of chromium compared to other lagoon sediments with similar amounts of mud.

Shelf sediments.--Chromium concentrations in shelf sediments (pl. IIIA, app. B) 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. 19) shows a scattering of data points similar to that established by data from adjacent bays. Shelf and bay sediments generally contain comparable concentrations of chromium, however, areas of highest chromium values are larger on the shelf than in the bays. Some shelf samples with exceptionally high chromium content, especially given the percent mud, occur as isolated samples (stations 60, 276, 364). Although chromium concentrations range from 1.2 to 160 ppm,



o Bay sediments; Cr analyses by USGS; r = 0.576; n = 70

+ Bay sediments; Cr analyses by Bureau of Economic Geology; r = 0.527; n = 10

Δ Channel sediments; Cr analyses by USGS
r (for USGS analyzed bay and channel sediments) = 0.492; n = 124

• Shelf sediments; Cr analyses by USGS; r = -0.132; n = 32

Figure 19. Scattergram of chromium and mud. (Letters and numbers shown next to plotted points are sample station numbers for sediments that plot above the trend set by other sediments--see figure 16 for explanation; r = correlation coefficient; n = number of samples.)

values between 2 and 30 ppm are most common. Values above 60 ppm only occur at a few sample sites. The poor correlation of chromium with sediment characteristics may be partly attributed to these low concentrations.

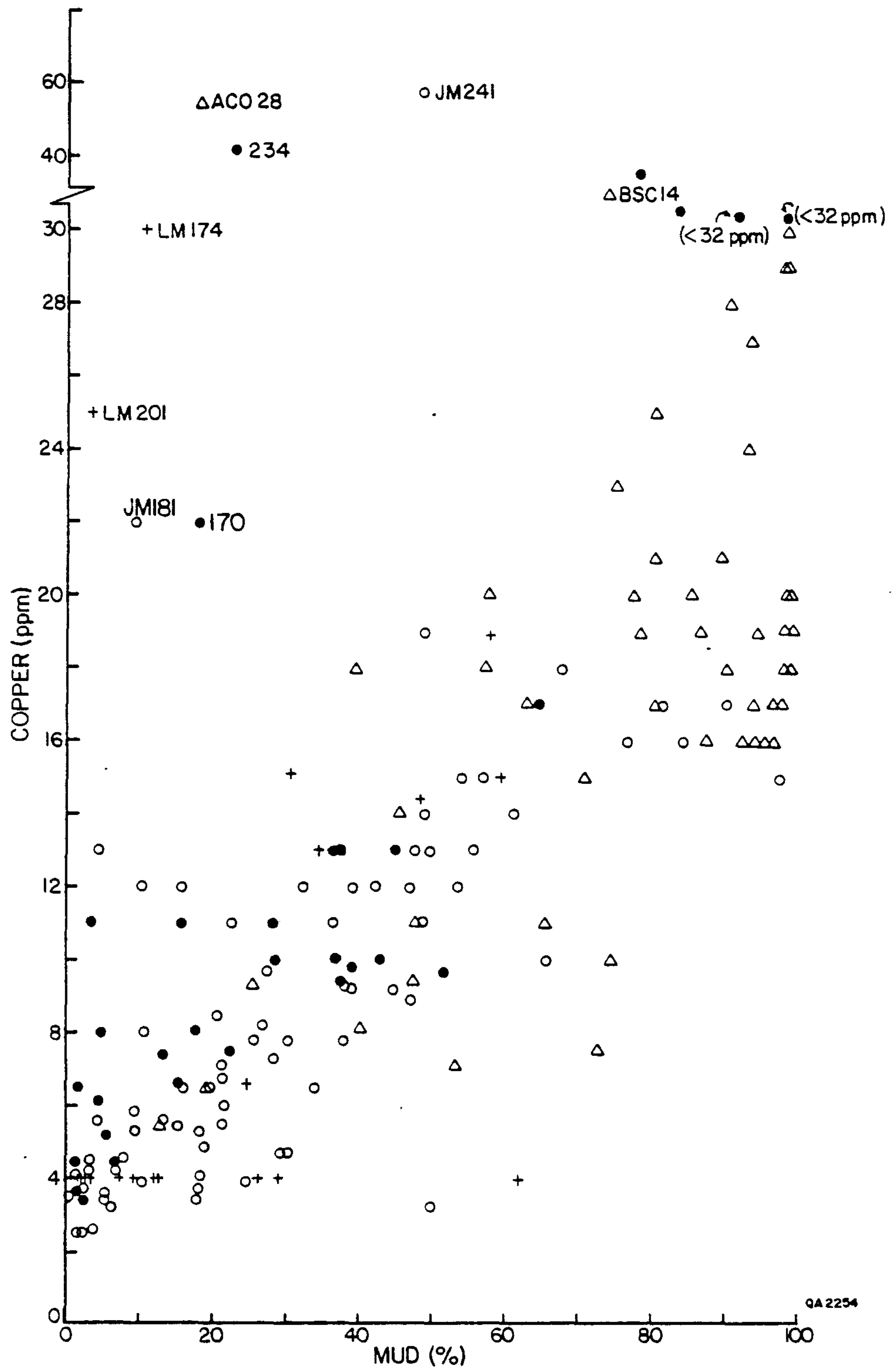
Copper

Bay sediments.--The average concentration of copper (Cu) is about 9 ppm (pl. IIIB). Concentrations range from less than 5 ppm to 84 ppm (app. B). Highest concentrations (greater than 15 ppm) are generally associated with muddier sediments in the western portion of Laguna Madre near the Arroyo Colorado Cutoff or area of intensive sampling (fig. 4; pl. IIIB). Sediments with high sand content typically contain less than 5 ppm copper. The obvious relationship between copper and sediment grain size can be seen in figure 20 and by comparing the distribution of copper (pl. IIIB) with textural distribution (pl. I). Most of the samples that have more than 15 ppm copper contain more than 50 percent mud (fig. 20).

Many of the sediment samples collected from the Brownsville Ship Channel and the Arroyo Colorado (which also serves as the Port Harlingen Channel) contain concentrations of copper greater than 20 ppm. Concentrations of copper generally increase in a landward direction along the Arroyo Colorado, suggesting an inland source of the copper.

Shelf sediments.--Concentrations of copper in shelf sediments range from 3.1 to 63 ppm (pl. IIIB, app. B); however, most shelf sediments contain minor amounts of copper ranging from 3 to 10 ppm. Copper values generally increase offshore; lowest concentrations occur where sand is abundant whereas highest concentrations are generally associated with fine-grained sediments and are commonly restricted to isolated sample sites or small areas such as stations 234, 166, and 168 (pl. VI). The largest area with high copper concentrations is found near the mouth of the Rio Grande.

Copper concentrations in shelf sediments correlate well with percent mud (fig. 20). Concentrations of copper on the shelf are comparable to those in adjacent bays considering the abundance of mud.



o	Bay sediments; Cu analyses by USGS; r = 0.536; n = 71
+	Bay sediments; Cu analyses by Bureau of Economic Geology; r = 0.485; n = 7
Δ	Channel sediments; Cu analyses by USGS r (for USGS analyzed bay and channel sediments) = 0.607; n = 126
•	Shelf sediments; Cu analyses by USGS; r = 0.724; n = 32

Figure 20. Scattergram of copper and mud. (Letters and numbers shown next to plotted points are sample station numbers for sediments that plot above the trend set by other sediments--see figure 16 for explanation; r = correlation coefficient; n = number of samples.)

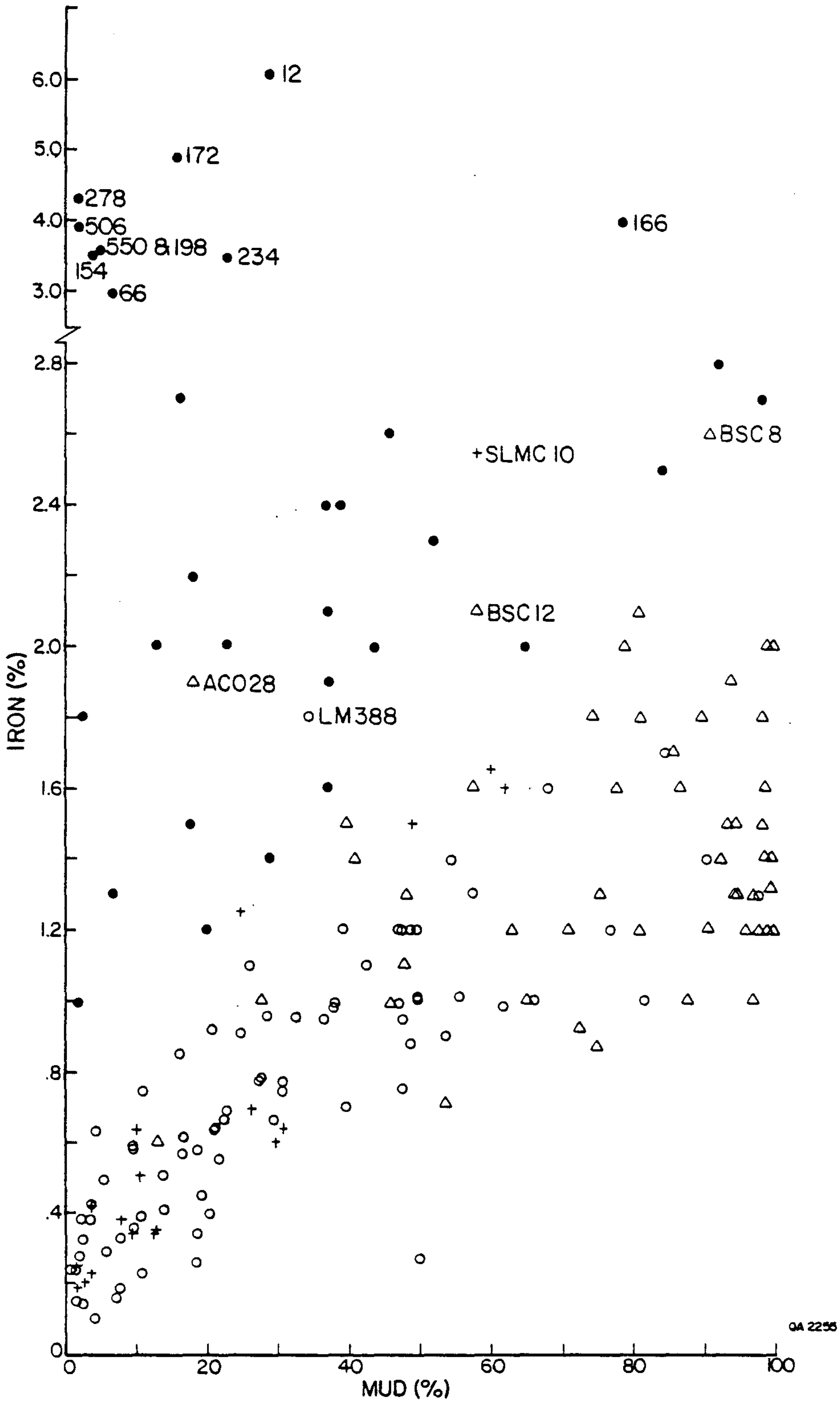
Iron

Bay sediments.--Concentrations of iron (Fe) in bay sediments (pl. IIIC) range from 0.1 percent (1,000 ppm) to 4.3 percent (43,000 ppm), with the latter value occurring in the Intracoastal Waterway (station SLMC14, app. B). Highest measured concentrations of lagoon sediments (excluding channels) occur at a station in South Bay and at a station near Four Mile Slough south of Port Mansfield; concentration of iron at these two stations is 2.6 percent (pl. IIIC). As with trace metals chromium and copper, highest iron percentages are associated with fine-grained sediments. This relationship between texture and iron concentrations is demonstrated in figure 21, a scattergram of percent iron and percent mud. Sediments with high sand content (>75 percent) typically contain iron concentrations of less than 0.7 percent.

Shelf sediments.--The abundance of iron in shelf sediments (pl. IIIC) ranges from 0.5 to 6.2 percent. Highest concentrations occur at isolated sample sites whereas lowest concentrations are widespread and generally coincide with sandy sediments although the empirical correlation is weak. Patterns of iron abundance are simple, and concentrations are normally between 1 and 4 percent. Shelf sediments generally contain more iron than do bay sediments having comparable amounts of mud (fig. 21).

Lead

Bay sediments.--Lead (Pb) concentrations in lagoon sediments range from less than 10 ppm to 27 ppm (pl. IIID). The highest concentrations in the entire bay-estuary-lagoon system, however, occur in dredged channel muds. An extremely high value of 810 ppm occurs in sediments from a station in the Intracoastal Waterway (station number SLMC 14, app. B). This concentration is eight times higher than the next highest concentration of lead (100 ppm), which occurs in sediments at the head of the Brownsville Ship Channel (BSC) (station 14). Sediments from two other channel stations (Arroyo Colorado - ACO 28 and Port Isabel Ship Channel - PIC 3) have lead concentrations of more than 70 ppm, but the remainder fall below 45 ppm. The concentration of lead generally increases up (landward direction) the Arroyo Colorado (Port Harlingen Channel) with a high of 42 ppm near Rio Hondo (pl. IIID).



o Bay sediments; Fe analyses by USGS; r = 0.788; n = 71

+ Bay sediments; Fe analyses by Bureau of Economic Geology; r = 0.910; n = 19

Δ Channel sediments; Fe analyses by USGS
r (for USGS analyzed bay and channel sediments) = 0.776; n = 126

• Shelf sediments; Fe analyses by USGS; r = 0.379; n = 32

Figure 21. Scattergram of iron and mud. (Letters and numbers shown next to plotted points are sample station numbers for sediments that plot above the trend set by other sediments--see figure 16 for explanation; r = correlation coefficient; n = number of samples.)

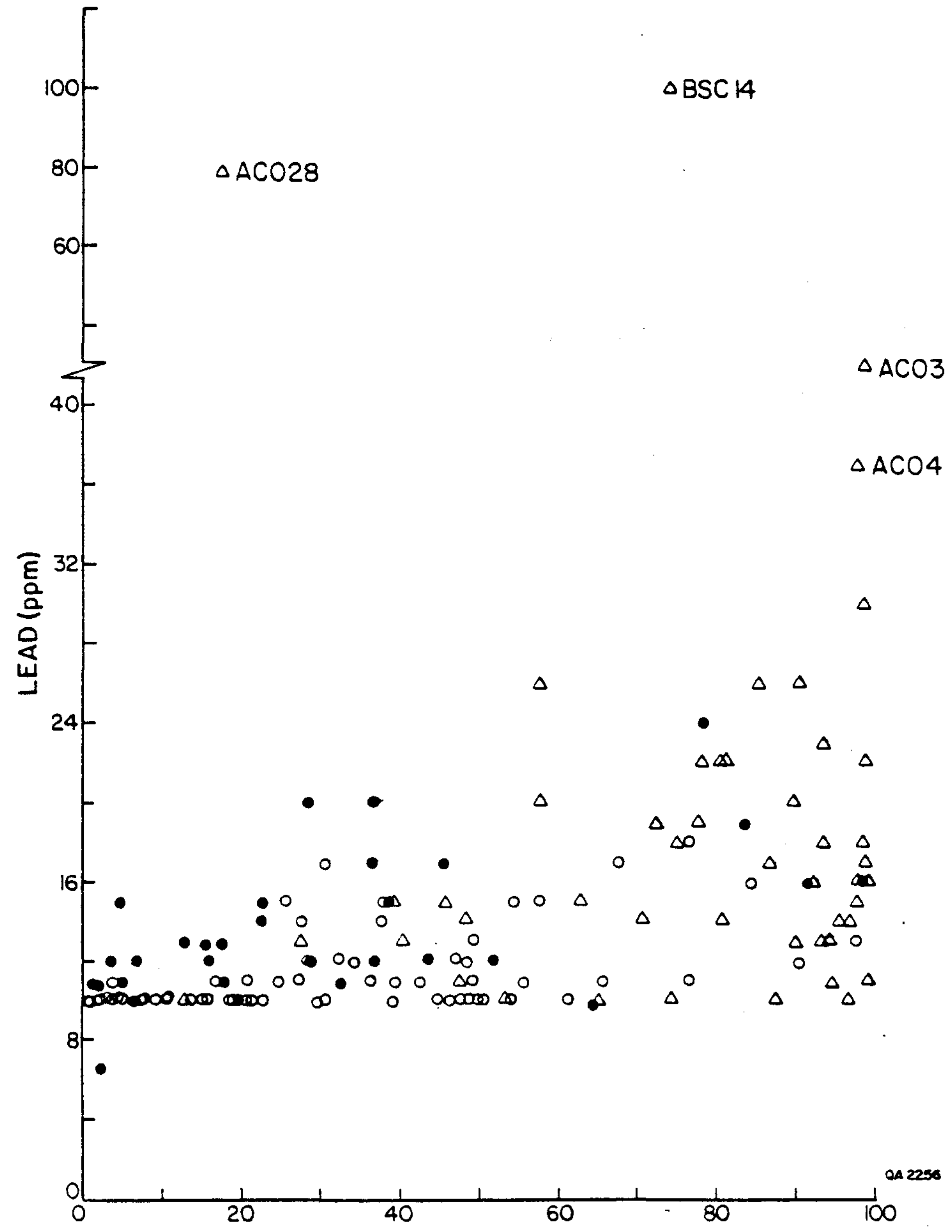
In Laguna Madre, sandier sediments typically contain less than 10 ppm lead, whereas muddy sands and sandy muds (pl. IA) have slightly higher concentrations but generally do not exceed 20 ppm (fig. 22).

Shelf sediments.--Lead in surface sediments of the inner shelf ranges from less than 7 to 24 ppm (pl. IIID); however, most samples contain between 10 and 15 ppm. Lead concentrations are commonly higher in shelf sediments than in bay sediments (fig. 22). Lowest concentrations generally are widespread where sand is abundant whereas highest concentrations occur in patches such as near the mouth of the Rio Grande where other trace metals are also concentrated. Although lead distribution is patchy, abundance generally increases offshore. Lead concentrations greater than 20 ppm occur as a small patch (stations 166 and 188) associated with fine-grained sediments.

Manganese

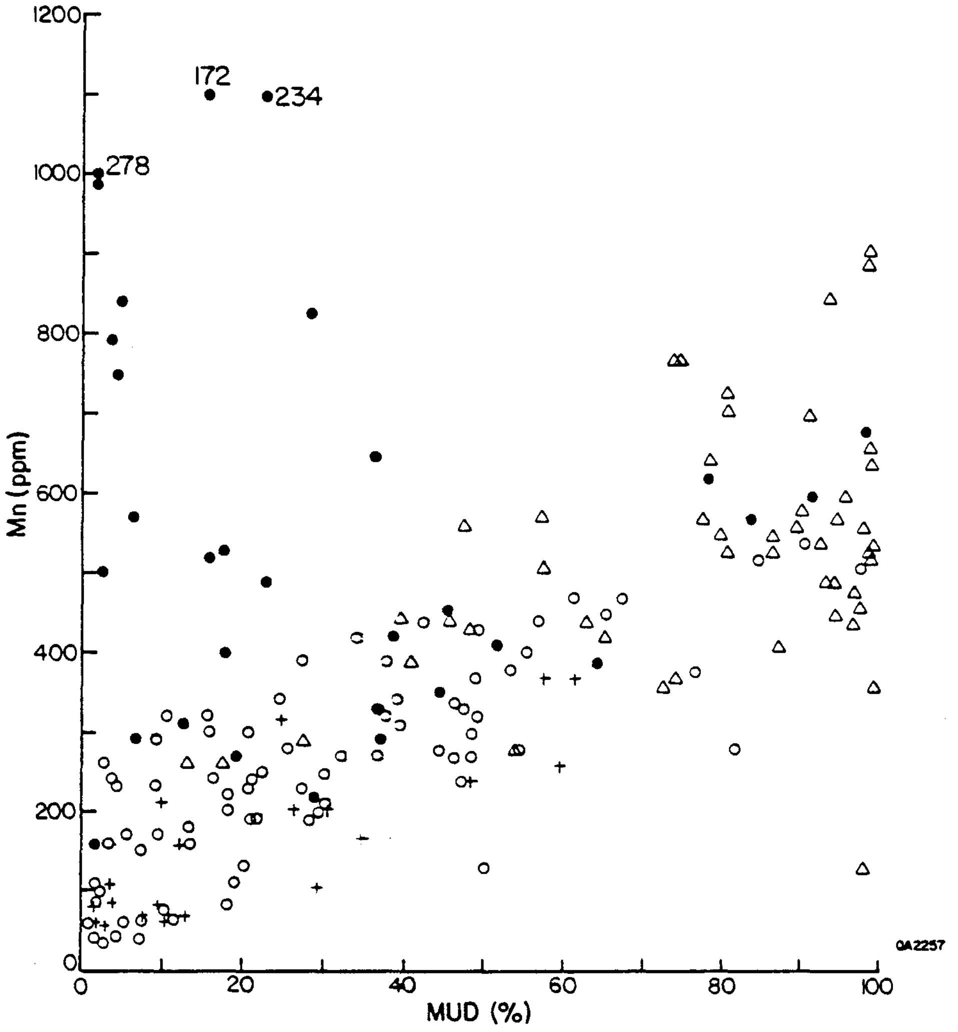
Bay sediments.--Concentrations of manganese (Mn) range from less than 40 ppm to more than 600 ppm in lagoon sediments (pl. IVA). Average concentrations are about 250 ppm. Dredged channel sediments reach considerably higher levels with maximums above 800 ppm occurring in sediments from the Intracoastal Waterway, Arroyo Colorado, and Brownsville Ship Channel. As with other trace metals, high concentrations are commonly associated with muddy sediments and low concentrations with sandy sediments (fig. 23) (correlation coefficient for ppm manganese and percent mud is 0.782).

Broad sandy areas on the east side of Laguna Madre, in the vicinity of La Punta Larga and northward, have manganese concentrations of below 200 ppm, which intergrade toward the west and south into slightly muddier sediments containing manganese concentrations ranging from 200 to 400 ppm. Most of the sediments in the broad southern end of Laguna Madre also contain manganese between 200 and 400 ppm (pl. IVA). Patches of sandy muds (pl. IA) occurring along the mainland shore have manganese levels exceeding 400 ppm. Average concentrations of manganese in the predominantly muddy channel stations is about 550 ppm.



o	Bay sediments; r= 0.479; n = 71
Δ	Channel sediments r (for bay and channel sediments) = 0.288; n = 126
•	Shelf sediments; r = 0.541; n = 32

Figure 22. Scattergram of lead and mud. (Letters and numbers shown next to plotted points are sample station numbers for sediments that plot above the trend set by other sediments--see figure 16 for explanation; r = correlation coefficient; n = number of samples.)



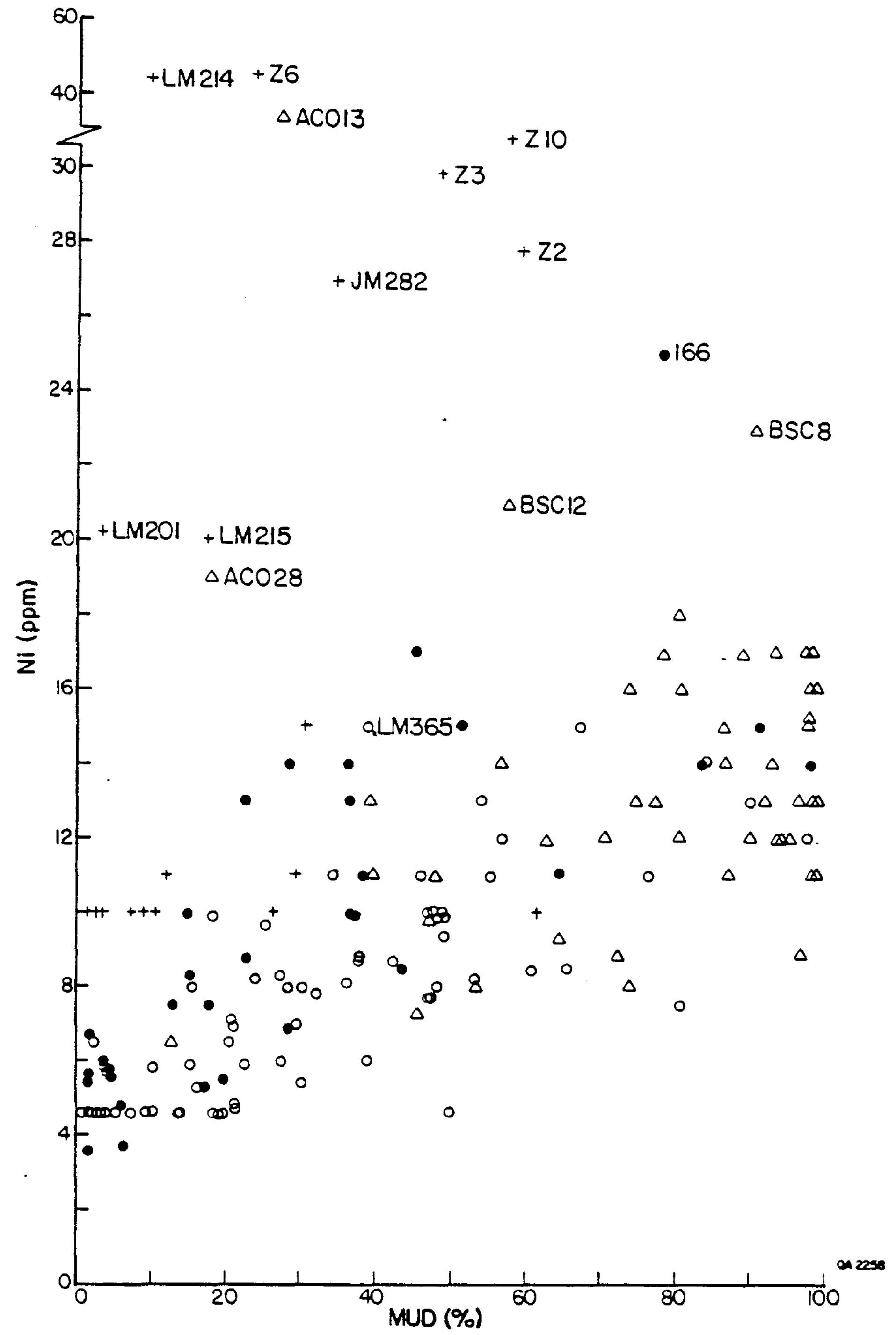
o Bay sediments; Mn analyses by USGS; r = 0.751; n = 71
+ Bay sediments; Mn analyses by Bureau of Economic Geology; r = 0.850; n = 19
Δ Channel sediments; Mn analyses by USGS
r (for USGS analyzed bay and channel sediments) = 0.807; n = 126
• Shelf sediments; Mn analyses by USGS; r = -0.132; n = 32

Figure 23. Scattergram of manganese and mud. (Letters and numbers shown next to plotted points are sample station numbers for sediments that plot above the trend set by other sediments--see figure 16 for explanation; r = correlation coefficient; n = number of samples.)

Shelf sediments.--Surface sediments on the inner shelf contain between 100 and 1100 ppm manganese; however, most samples contain between 400 and 600 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. The largest continuous areas delineate shelf segments where manganese concentrations are less than 400 ppm. In contrast, areas where manganese values exceed 600 ppm are generally small and discontinuous. Considering all the manganese values obtained from the Brownsville-Harlingen inner shelf, there is no statistical correlation between manganese abundance and sediment type or grain size (fig. 23).

Nickel

Bay sediments.--Concentrations of nickel (Ni) in bay sediments range from less than 5 to 79 ppm (pl. IVB), with a mean concentration of between 5 and 10 ppm. The highest concentration--79 ppm--occurs in sediment collected near Three Islands adjacent to the Intracoastal Waterway. Overall, channel sediments (Arroyo Colorado, Brownsville Ship Channel, Intracoastal Waterway) contain higher levels of nickel (mean value of about 14 ppm) because the channels have higher percentages of mud and there is a relatively good correlation between percent mud and ppm nickel (fig. 24). Four channel stations (ACO 13 and 28, and BSC 8 and 12), however, have higher than normal concentrations of nickel for the amount of mud they contain; it is possible that anthropogenic sources of nickel contributed to these anomalies. Other anomalous values of nickel shown on the scattergram in figure 24 are principally from South Bay, and from west of the Intracoastal Waterway between the Arroyo Colorado and Port Mansfield. The fact that these samples stand out may be more an artifact of the two methods of analyses used (see section on data acquisition and analysis). Areas with high sand concentrations, such as adjacent to the wind-tidal flats along Padre Island, contain less than 5 ppm nickel. Most of the sediments with more than 75 percent mud contain more than 12 ppm nickel.



o Bay sediments; Ni analyses by USGS; r = 0.759; n = 71
+ Bay sediments; Ni analyses by Bureau of Economic Geology; r = 0.410; n = 19
Δ Channel sediments; Ni analyses by USGS
r (for USGS analyzed bay and channel sediments) = 0.644; n = 126
• Shelf sediments; Ni analyses by USGS; r = 0.763; n = 32

Figure 24. Scattergram of nickel and mud. (Letters and numbers shown next to plotted points are sample station numbers for sediments that plot above the trend set by other sediments--see figure 16 for explanation; r = correlation coefficient; n = number of samples.)

Shelf sediments.--Concentrations of nickel in shelf sediments only range from less than 1.5 to 25 ppm; nevertheless, distinct patterns emerge within this limited range (pl. IVB). The clearest pattern is an increase in an offshore direction associated with decreases in sediment size. Abundance of nickel also increases towards the mouth of the Rio Grande. Lowest concentrations are found nearshore in irregularly shaped, discontinuous patches. These areas of low nickel are also characterized by high sand content. Conversely, highest nickel concentrations occur in association with fine-grained sediments. Examples of the latter associations are found between stations 165 and 254 and between stations 364 and 386. These maximum concentrations are comparable to those found in sediments of the adjacent bays. However, shelf sediments generally have higher concentrations of nickel than do bay sediments when the relationship with sediment texture is taken into consideration (fig. 24). The high nickel concentration measured at station 394 is probably anomalous because relict stiff mud was also sampled at that site (fig. 13).

Strontium

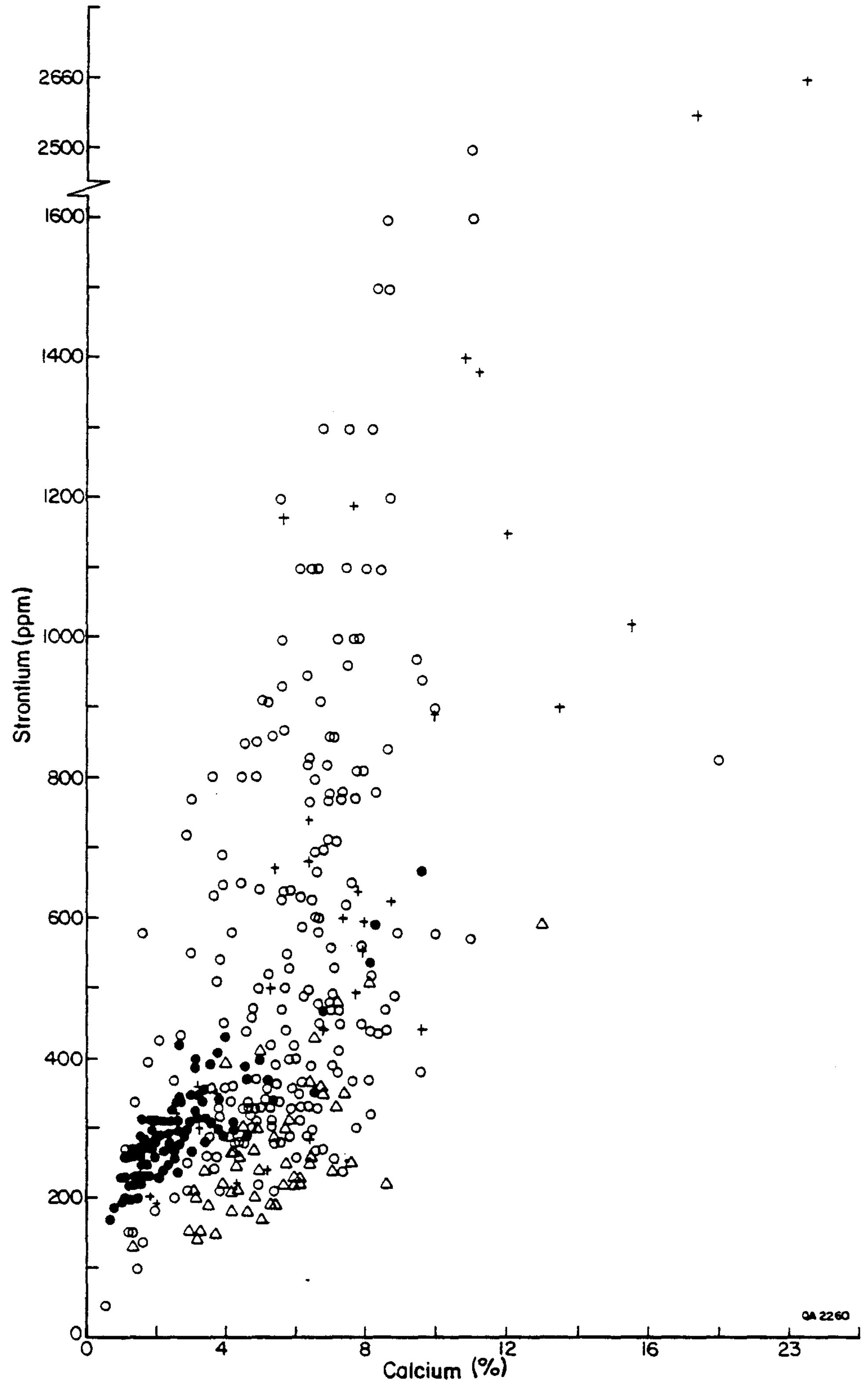
Bay sediments.--Strontium (Sr) concentrations in bay sediments range from less than 50 ppm to more than 2600 ppm (pl. IVC). High values are commonly less than 1300 ppm, with about ten exceptions. The exceptions occur in Laguna Madre sediments north of the mouth of the Arroyo Colorado Cutoff (pl. IVC). In the southern part of Laguna Madre and in South Bay strontium concentrations are mostly below 500 ppm. In the area of intensive sampling (fig. 4), distribution patterns are complex and systematic trends are not apparent although there is a tendency for strontium concentrations to be higher along the eastern half of Laguna Madre and lower on the western half. This general trend is reversed in the upper part of Laguna Madre north of Port Mansfield Channel (pl. IVC).

Comparisons of strontium (pl. IVC) and calcium (pl. IIC) show an obvious relationship in their distribution patterns. There is usually a high statistical correlation between these two elements (for example, Holmes, 1974, and White and others, 1983). However, the correlation coefficient between strontium and calcium in bay-lagoon sediments in the Brownsville-

Harlingen area is 0.537, which is substantially lower than that in bay sediments in the Corpus Christi (White and others, 1983) and Galveston-Houston (White and others, in preparation) areas where correlation coefficients are 0.903 and 0.971, respectively. A scattergram of strontium and calcium shows considerable scatter in Laguna Madre sediments (fig. 25). Increases in strontium concentrations are not met by a corresponding linear increase in calcium concentrations.

The lower correlation coefficient and associated broad scatter between strontium and calcium in bay sediments in the Brownsville-Harlingen area is probably caused in part by sample variability marked by differences in densities of marine grasses (figs. 11 and 12) and varying kinds and quantities of shell material. Laguna Madre in the Brownsville-Harlingen area is similar to north Laguna Madre and Redfish Bay in the Corpus Christi area (White and others, 1983), in that all are shallow, sandy lagoons where marine grasses are common. Strontium-to-calcium ratios in these lagoonal areas are also similar; the ratios are high compared to other bay sediments and plot above them in scattergrams. 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 others (particularly gastropods) are composed of aragonite, which has a higher strontium-to-calcium ratio than calcite (Odum, 1957; Galstoff, 1964). The higher strontium-to-calcium ratios in grassflat areas are perhaps related to the marine grasses, and associated mollusks, crustaceans, and algae. Brown algae, which have very high strontium-to-calcium ratios (Odum, 1957), may occur as epiphytes on marine grasses (Edwards, 1976). Another algae, Acetabularia crenulata, which contains aragonite, is abundant in some areas in south Laguna Madre (Herber, 1981). In addition, serpulid worm tubes in part composed of aragonite, commonly are encrusted on marine grasses.

Shelf sediments.--Strontium concentrations range from 170 to 540 ppm; however, most shelf sediments contain between 200 and 300 ppm (pl. IVC). The two extremes are anomalous and isolated samples; the highest concentrations come from shelly sediments along the former strandline. Lowest concentrations occur at isolated sample sites where sand is abundant.



o Bay sediments; analyses by USGS; r = 0.537; n = 68
+ Bay sediments; analyses by Bureau of Economic Geology; r = 0.697; n = 16
Δ Channel sediments; analyses by USGS
r (for USGS analyzed bay and channel sediments) = 0.535; n = 123
• Shelf sediments; analyses by USGS; r = 0.838; n = 32

Figure 25. Scattergram of strontium and calcium (r = correlation coefficient; n = number of samples).

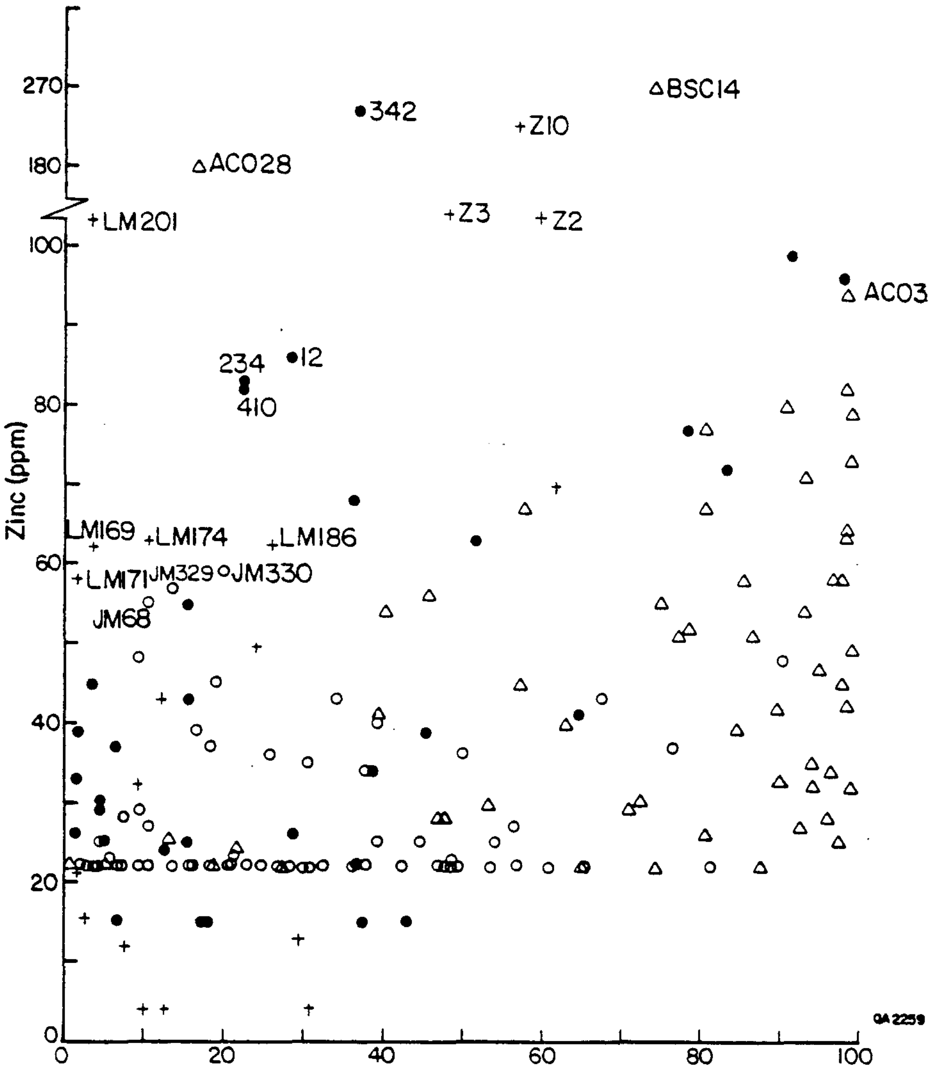
Strontium abundance is generally uniform over large areas and is substantially lower in sediments from the inner shelf than in sediments from adjacent bays. In fact the positive correlation between strontium and calcium (fig. 25) suggests two different populations with shelf sediments having a higher correlation coefficient than bay sediments.

Zinc

Bay sediments.--Concentrations of zinc (Zn) in bay sediments, excluding channels, range from less than 22 ppm to more than 100 ppm (pl. IVD). The average concentration including channel sediments (Brownsville Ship Channel, Arroyo Colorado, Intracoastal Waterway, and Port Mansfield Channel) is about 40 ppm. Channel sediments as a whole contain higher concentrations of zinc than bay-floor sediments. The highest concentration in the Brownsville-Harlingen area was measured in sediments collected from the Intracoastal Waterway near Three Islands (station SLMC 14, app. B). This concentration of zinc, 1300 ppm, is an extremely high value and is almost five times the next highest value of 270 ppm, also anomalously high, from the head of the Brownsville Ship Channel (pl. IVD).

A comparison of the distribution of zinc (pl. IVD) with the distribution of sediment texture (pl. I) suggests a relationship between the two. Broadly speaking, zinc levels are higher in finer-grained sediment and lower in coarser-grained sediment. Extensive areas mapped as sand and muddy sand in Laguna Madre (pl. IA) contain less than 22 ppm zinc. Slightly muddier sediments along the western or mainland half of Laguna Madre typically contain higher levels of zinc ranging between 25 ppm and 45 ppm. A belt of sediment with anomalous concentrations of zinc (>70 ppm) extends from near Rattlesnake Island westward across the lagoon toward Padre Island (pl. IVD).

Channel sediments as a whole contain more mud than bay sediments and the mean concentration of zinc is about 50 ppm. Sediments with anomalous concentrations of zinc with respect to the amount of mud they contain, for example ACO 28 and BSC 14, stand out on a scattergram relating zinc and mud (fig. 26). Many samples (for instance, those from South Bay--Z stations, fig. 26) analyzed by the Bureau of Economic Geology appear anomalous in the



o Bay sediments; Zn analyses by USGS; r = -0.055; n = 29

\+ Bay sediments; Zn analyses by Bureau of Economic Geology; r = 0.605; n = 16

Δ Channel sediments; Zn analyses by USGS

r (for USGS analyzed bay and channel sediments) = 0.164; n = 77

• Shelf sediments; Zn analyses by USGS; r = 0.391; n = 32

Figure 26. Scattergram of zinc and mud. (Letters and numbers shown next to plotted points are sample station numbers for sediments that plot above the trend set by other sediments--see figure 16 for explanation; r = correlation coefficient; n = number of samples.)

scattergram as well. While it is possible that these anomalies are "real" and are the result of anthropogenic contributions of zinc to the sediments, it is also possible that laboratory contamination produced the elevated levels of zinc (Clara Ho, chemist, personal communication, 1984).

Shelf sediments.--Zinc in surface sediments from the inner shelf ranges from less than 15 to 240 ppm (pl. IVD). Highest concentrations are usually limited in areal extent. The maximum values of zinc are comparable to those found in sediments of adjacent Laguna Madre (fig. 26). Zinc concentrations generally increase in an offshore direction. Lowest concentrations occur where sand is abundant and highest concentrations coincide with fine-grained sediments and the former strandline. Sediments containing more than 65 ppm zinc are limited to single sample stations or a larger trend that extends from stations 1 to 64 near the mouth of the Rio Grande. In relation to surrounding sediments, the area between stations 506 and 550 exhibits unusually high concentrations of zinc as well as manganese, iron, copper, and chromium. This area also coincides with the site of a Spanish shipwreck that has been excavated and preserved by the Texas Antiquities Committee.

Textural and Geochemical Relationships

The bay-estuary-lagoon and inner shelf systems are dynamic environments in which complex, physical, chemical, and biological interactions occur. Over the past two decades, since the classic study by Krauskopf (1956), numerous studies have been conducted regarding the concentration, speciation, migration pathways, physicochemical conditions, and diagenetic changes of major, minor, and trace elements occurring in both water and sediments of fresh, estuarine, and marine systems. Many of these studies have used selective extraction techniques to determine what proportion of a particular trace metal or element 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 surrounding trace element behavior in estuaries, particularly with respect to solid-solution exchange, has led to considerable disagreement (Aston, 1978; Förstner and Wittman, 1981).

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

The correlation between decreasing grain size and increasing trace metal concentrations in sediments of submerged lands--apparent in the maps and graphs discussed earlier in this section--is in agreement with numerous other studies (for example, Turekian, 1965; Shimp and others, 1970; and 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, comparisons 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 seasonal differences in trace metal concentrations.

Among several variables that apparently account for the higher concentrations of trace metals in fine-grained sediments are: (1) the mineralogic makeup of the sediment which generally affects grain size (de Groot and others, 1976); (2) the high 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 Brownsville-Harlingen area, two 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), and (2) conducting simple regression analyses and plotting trace metal concentrations against percent mud (<63μm) (figs. 16-26), percent clay (<3.9μm), percent TOC or parts-per-million oxides of manganese. In method 2, the most commonly used measure of grain-size is percent mud (<63μm). This is primarily because percent mud shows a good correlation with trace element concentrations and also because it was measured in more sediment samples than percent clay or mean phi.

The significance of trace metal concentrations in the Brownsville-Harlingen 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 4). These latter concentrations are thought to represent "base line" values that are derived from natural sources and that 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 the Brownsville-Harlingen area (Bowles, 1983). Also included in table 4 for comparison purposes are some high concentrations of trace metals measured in estuarine sediments (Warshaw, 1976).

Average trace-element concentrations in muds of the Brownsville-Harlingen area are comparable to or lower than "base line" levels for all elements (table 4). The highest concentrations for nine elements, barium, boron, chromium, copper, iron, lead, manganese, nickel, and zinc, however, are above "base line" values (table 4). Five of these elements (chromium, copper, lead, nickel, and zinc) locally exceed proposed screening levels for dredged sediment disposal established by the United States Environmental Protection Agency (table 5). (Screening levels have not been established for barium, boron, iron, and manganese.)

Abnormally high trace metal concentrations in sediments at many locations are probably the result of anthropogenic contributions. In the bays, most of the highest concentrations were found in channel sediments such as the Brownsville Ship Channel where ship dismantling, repairing and ore loading facilities are probable sources of high levels of trace metals (copper, lead, manganese, and zinc) that have been previously reported (Bowles, 1983). In many cases the concentrations of trace metals in a given sediment sample may not appear excessively high, or even above "background" levels. When normalized with percent mud in a scattergram, however, the sample may plot outside the trend set by the majority of samples. 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. For most sediments in the bay system, the relationship between the sandy bay floor stations in Laguna Madre and the muddy sediments from dredged channels is a linear one with channel stations completing the approximately linear trend at the muddy end (60 to 100%) of the scattergrams (fig. 15 through 24). Sediment samples that plot outside the "norm," such as certain stations from Brownsville Ship Channel and the Arroyo Colorado, can be seen in scattergrams for chromium, copper, iron, lead, manganese, nickel, and zinc. While 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, it is probable that many are abnormal because of anthropogenic contributions of trace elements to the system. In determining which samples are above normal for the amount of mud they contain, it is important to compare bay sediments with other bay

Table 4. Comparison of trace element concentrations in sediments (mud) of the Brownsville-Harlingen area with those in uncontaminated sediments (baseline levels) and contaminated estuarine sediments along the Texas coast. Values in parts per million.

	Brownsville-Harlingen Area[1]				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]	High estuarine sediment value, Texas coast[7]
Barium	272	1,100	355	570	580	750	800			910
Boron	82	220	89	130	100		100		90	
Chromium	25	94	33	160	90	100	100	63	66-72	134
Copper	20	84	26	63	45	48	57	21	37	1,510
Iron	15,000	43,000	30,000	62,000	47,200		33,300			
Lead	18	810*	19	24	20	20	20	31	21	340
Manganese	557	1,140	623	1,100	850	850	670			1,400
Nickel	14	79	17	25	68	55	95	33	40	160
Zinc	52	270*	86	240	95	95	80	93		4,900

[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)
*Channel sediments

Table 5. Heavy-metal screening levels proposed by the U. S. Environmental Protection Agency (1974) for dredged sediment disposal in EPA Region VI.

Metal	Sediment concentration in mg/kg dry weight (ppm air dried)
Arsenic	5.0
Cadmium	2.0
Chromium (total)	100
Copper	50
Lead	50
Mercury	1.0
Nickel	50
Zinc	75

sediments and shelf sediments with other shelf sediments; these two sets of data often follow different trends.

In many areas of the bay-estuary-lagoon system in the Brownsville-Harlingen area, trace metals have similar distribution patterns. For example, some of the highest concentrations outside of channels of boron (pl. IIC), chromium (pl. IIIA), copper (pl. IIIB), iron (pl. IIIC), lead (pl. IIID), nickel (pl. IVB), and zinc (pl. IVD) occur in the vicinity of Three Islands and the mouth of the Arroyo Colorado Cutoff. Although trace metal distribution patterns in these areas generally mimic the finer-grained sediments (muds), locally trace metal concentations are anomalous with respect to associated mud content. One possible source of some trace metals in lagoon sediments, is the Arroyo Colorado and North Floodway. Also, past military operations just south of Stover Cove (during World War II a tract of land now in the Laguna Atascosa National Wildlife Refuge was used as a gunnery range, Fleetwood, 1973) may have contributed to trace metal levels in lagoon sediments in this area. In 1984 numerous copper-oxide coated bullets were found scattered across the barren, dry flats south of Stover Cove.

In the Corpus Christi area (White and others, 1983), a comparison of trace element concentration in bay and shelf sediments showed some consistent trends for many of the trace elements. Scattergrams of percent mud and boron, copper, iron, nickel, lead, and to some degree chromium, showed that the scattering of shelf sediments reflected linear trends as did the scatter of bay sediments; however, shelf sediments consistently fell 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 ϕ, percent clay, and TOC, as demonstrated by scattergrams 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 input of zinc into bay sediments.

A comparison of trace element concentrations in bay and shelf sediments in the Galveston-Houston area (White and others, in preparation), showed that barium, iron, manganese, and nickel follow a trend that is similar to the majority of elements in the Corpus Christi area. That is, in scattergrams where these elements are plotted against percent mud, shelf sediments generally plot above the upper scatter boundary of bay sediments. Accordingly, the mean concentrations of these elements in shelf muds (sediments composed of 75% or more of silt and clay) were higher than in bay muds (excluding sediments from channels such as the Houston Ship Channel). The trace metals chromium, copper, lead, and zinc, however, do not follow this trend. The mean concentrations of these elements in bay muds (excluding channel sediments) were higher than in shelf muds. These higher trace metal concentrations in bay sediments relative to shelf sediments suggest that the difference may be related to anthropogenic enrichment of trace metals in sediments in the bays. This suggestion presupposes that under normal conditions, shelf and bay muds either contain similar concentrations of these trace metals, or, as in the Corpus Christi area, shelf muds should contain higher trace metal concentrations. This assumption may be incorrect. It has not been adequately demonstrated that marine muds normally contain higher trace metal concentrations than bay muds. Although some studies have indicated that average concentrations of several 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), trace metal concentrations found in brackish-water shales were not significantly different from those found in marine shales (Keith and Degans, 1959).

In the Brownsville-Harlingen area only iron has a trend similar to the majority of sediments in the Corpus Christi area where shelf sediments plot above the upper scatter boundary of bay sediments. However, regression lines representing shelf sediments, for several elements besides iron, including barium, chromium, nickel, and zinc, plot above regression lines for bay sediments. This indicates that for a given percentage of mud, trace metal concentrations in shelf muds are typically higher than in lagoon muds. However, in some sediment low in mud and high in sand, three trace metals--chromium, iron, and manganese (figs. 19, 21 and 23)--scatter considerably above bay sediments as well as other shelf sediments composed mostly of mud. These sand-rich stations apparently contain heavy minerals that are sources of the trace metals. A plot of percent heavy minerals in four sediment samples against the concentration of selected elements, indicates a positive relationship for manganese and iron; chromium shows a positive relationships for three sediment samples (fig. 27). Highs of chromium, iron, and manganese in association with sand on the shelf, are thought to be natural occurrences associated with heavy minerals deposited with sands along relict strandplains that are presently submerged (see section on late Quaternary geologic history).

Comparisons of trace-element levels in sediments from the Brownsville-Harlingen, Corpus Christi, and Galveston-Houston areas (fig. 1), show some interesting relationships (table 6). In bay muds chromium, copper, lead, and nickel have similar mean concentrations in the Brownsville-Harlingen and Corpus Christi areas compared to the Galveston-Houston area where mean concentrations are about 1.5 to 2 times higher for these elements. The mean concentrations of barium and zinc in bay muds are highest in the Corpus Christi area where barium is 2 and 3 times higher and zinc is 1.5 and 1.8 times higher than in the Galveston-Houston and Brownsville-Harlingen areas, respectively. Mean concentrations of iron in bay muds are similar in the Galveston-Houston and Corpus Christi areas, where levels are about 1.6 times higher than in the Brownsville-Harlingen area. Boron and manganese are the only two elements that have similar mean concentrations in bay muds in all three areas.

Mean concentrations of trace elements in muds from the inner shelf are not as variable as in the bays for the three areas. No trace element from any of the three areas has a mean of more than 1.8 times the mean of the given element in the other areas. Chromium in shelf muds in the Corpus Christi area is 1.8 and 1.3 times that in Brownsville-Harlingen and Galveston-Houston, respectively. It should be noted however, that chromium is higher in some sands than muds in the Brownsville-Harlingen area (fig. 19). Means for boron, iron, and lead are not substantially different in shelf muds for the three areas. None of these elements in a particular

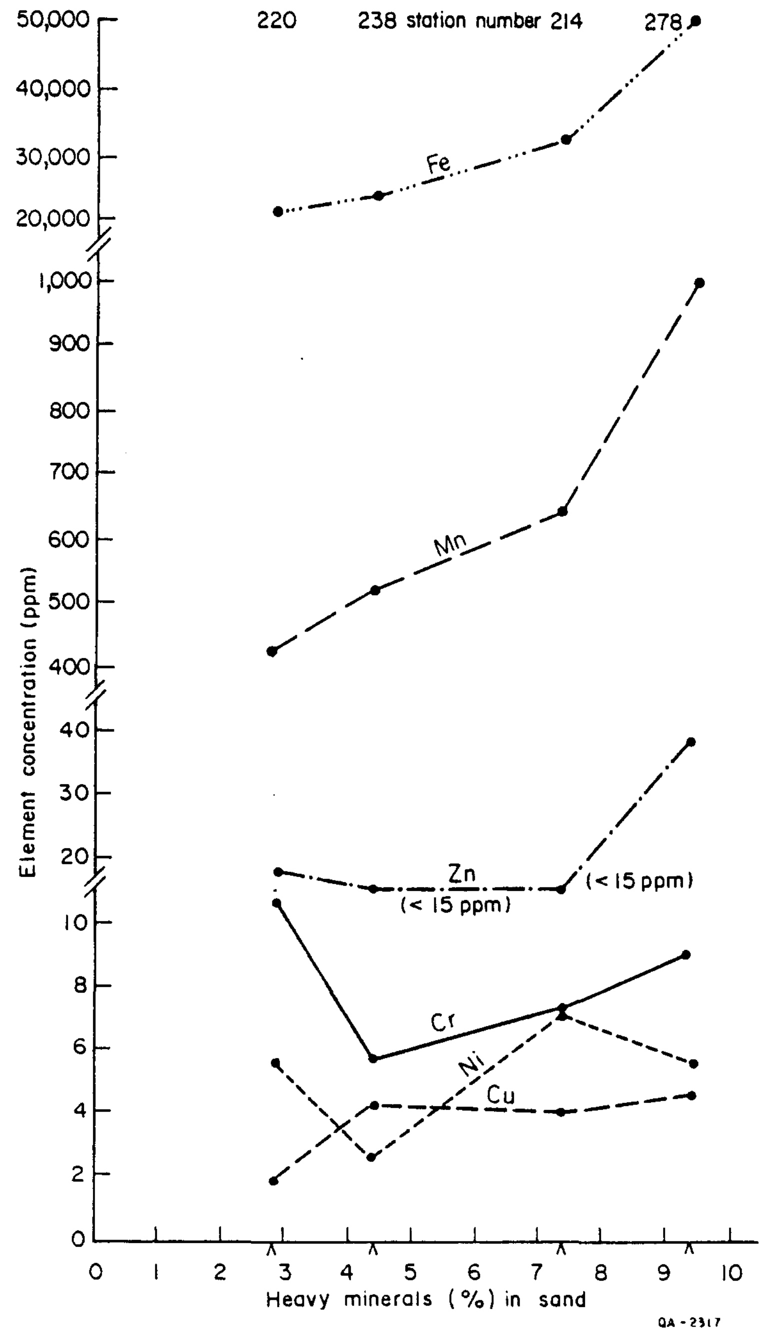


Figure 27. Relationships between trace element concentration in sediments and percentage of heavy minerals estimated in sands for four shelf stations (station number 214, 7.4% heavy minerals; 220, 2.8%; 238, 4.4%; 278, 9.4%).

Table 6. Comparison of mean concentrations of selected elements in bay and inner shelf muds (sediments composed of over 75% silt and clay) in the Brownsville-Harlingen, Galveston-Houston, and Corpus Christi submerged lands. Data from USGS chemical analysis. (Numbers in parentheses are "enrichment factors," where the lowest mean for each element serves 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.)

		Brownsville-Harlingen area	**Galveston-Houston area[v]**	**Corpus Christi area**
Barium (ppm)	Bay	272 (1.0)	410 (1.5)	800 (2.9)
	Shelf	355 (1.0)	538 (1.5)	478 (1.3)
Boron (ppm)	Bay	82 (1.1)	79 (1.1)	75 (1.0)
	Shelf	89 (1.3)	70 (1.0)	94 (1.3)
Chromium (ppm)	Bay	25 (1.0)	56 (2.2)	26 (1.0)
	Shelf	33 (1.0)	45 (1.4)	59 (1.8)
Copper (ppm)	Bay	20 (1.3)	27 (1.8)	15 (1.0)
	Shelf	26* (1.4)	18 (1.0)	24 (1.3)
Iron (ppm)	Bay	15,000 (1.0)	24,000 (1.6)	23,400 (1.6)
	Shelf	30,000 (1.0)	30,000 (1.0)	31,900 (1.1)
Lead (ppm)	Bay	18 (1.1)	34 (2.0)	17 (1.0)
	Shelf	19 (1.0)	19 (1.0)	25 (1.3)
Manganese (ppm)	Bay	557 (1.2)	475 (1.0)	535 (1.1)
	Shelf	623 (1.1)	783 (1.4)	560 (1.0)
Nickel (ppm)	Bay	14 (1.0)	22 (1.6)	15 (1.1)
	Shelf	17 (1.0)	28 (1.6)	22 (1.3)
Zinc (ppm)	Bay	52 (1.0)	62 (1.2)	93 (1.8)
	Shelf	86 (1.6)	53 (1.0)	60 (1.1)

[v] excludes sediments from Houston Ship Channel/Buffalo Bayou.
*based in part on estimates from line of regression with mud percent.

area has a mean concentration of more than 1.3 times the means found in the other areas. The mean concentration of barium in shelf muds is highest in the Galveston-Houston area where it is 1.5 times the lowest mean which occurs in the Brownsville-Harlingen area. Copper has similar concentrations in shelf muds in the Brownsville-Harlingen and Corpus Christi area, where the means are 1.3 and 1.4 times the mean in the Galveston-Houston area. Manganese is highest in shelf muds in the Galveston-Houston area where the mean concentration is about 1.3 and 1.4 times the values in the Brownsville-Harlingen and Corpus Christi areas, respectively.

Differences in trace metal concentrations in bay and shelf sediments in the Brownsville-Harlingen, Corpus Christi, and Galveston-Houston areas 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 Brownsville-Harlingen area, for example, are derived in part from the modern Rio Grande. Heavy minerals associated with Gulf sediments in the Corpus Christi area are derived in part from rivers along the northeastern part of the coast (Bullard, 1942). Among the rivers providing a source of heavy minerals, with which the trace metals may be associated, is the Colorado River, the drainage area of which includes igneous rocks and associated mineralization zones. In the Galveston-Houston area, sources of sediments include the Brazos, Mississippi, Trinity, Colorado, Neches, and Sabine Rivers. Other possibilities for differences in levels of trace metals in shelf sediments compared to bay sediments (and in the Brownsville-Harlingen, Corpus Christi, Galveston-Houston areas), are differences in clay mineralogy, total organic carbon, and physicochemical conditions which may affect precipitation of trace metals or the efficiency of adsorption of trace metals on surfaces of clay, organic carbon, and hydrous oxides of manganese and iron.

Of particular interest in analyzing bay- and shelf-sediment relationship in the Corpus Christi area (White and others, 1983), were reentrants of higher than normal concentrations of trace elements in shelf sediments in the vicinity of storm tidal passes. Most of the trace elements showed definite reentrant patterns (barium, boron, chromium, copper, iron, manganese, lead, strontium).

The association of the reentrants with what sometimes become temporary tidal passes, or storm washover areas, suggests that the reentrants are formed by sediments deposited by either storm flood or ebb tides or both. The possibility that the reentrants are related to ebb currents perhaps indicates that flocculation (of inorganic and organic particulates loaded with trace metals), adsorption, or precipitation of minerals or all these processes, occur as storm-related, brackish bay waters discharge through the passes/washovers and come into contact with the different physicochemical environment of marine water. For example, iron and manganese, both of which have the capability of sequestering trace metals as hydrous oxides (Jenne, 1968), behave nonconservatively (interactively) when crossing from the physiochemical conditions of fresher water to that of marine water. In fact, some studies suggest that dissolved iron and manganese decrease exponentially with increasing salinity indicating large scale removal of these two elements upon entering into 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 elements in the reentrants.

Maps of trace element distribution for the Port Lavaca and Bay City - Freeport map areas (fig. 1) also have trace-element reentrants associated with tidal passes. Lobes of sediments containing higher than normal trace element concentrations also extend gulfward from the mouths of the Colorado, Brazos, and Rio Grande Rivers. The higher concentrations at the river mouths are not unexpected because the rivers are a source of trace elements. In some areas, rivers contribute trace elements from both natural and anthropogenic sources.

Holmes (1982) has proposed that estuarine and bay systems along the northern Texas coast, including Matagorda Bay, are staging areas for the transportation of fine-grained sediments southward onto the Outer Continental shelf. This southward and southwestward expulsion of particulates loaded with trace metals, during and following the passage of polar air masses may account in part for the higher levels of trace metals in shelf sediments near the passes.

In the Brownsville-Harlingen area, the Rio Grande discharges only a short distance (approximately 7 mi or 11 km) south of the tidal inlet, Brazos Santiago Pass (fig. 4; pls. I-VI). Because the mouth of the Rio Grande and Brazos Santiago Pass are so near, it is difficult to determine the significance of each as outlets of the trace elements that occur in sediments on the inner shelf. It appears, however, that the silt and clay lobe and associated, slightly elevated, levels of boron, copper, manganese, nickel, lead, and zinc projecting gulfward from the mouth of the Rio Grande are related to discharges of the river. Sediments from the Rio Grande are known to contain a suite of heavy minerals (Bullard, 1942). Many are probable sources of the trace elements (fig. 27). In addition, municipal, industrial, and agricultural discharges into the Rio Grande are also possible sources of some trace metals.

The theory involving polar air masses for sediment movement on to the Continental Shelf proposed by Holmes (1982) for northern bay systems, is apparently not applicable to the Brownsville-Harlingen bay and inner shelf systems. The theory postulates that the high trace-metal content and fine-grained sediments (muds) in the vicinity of the tidal passes may be partly the result of discharging bay waters that are elevated by fresh-water inflows and wind tides in conjunction with storm passage. During these times, turbidity maxima (and associated trace metals including those from anthropogenic sources) forming in the bays may move through passes such as Brazos Santiago Pass and onto the inner shelf toward the southwest. Flocculation and precipitation begin and much of the suspended silts, clays, organics, and associated trace metals are deposited. The difficulty with the scenario in the South Texas area is that heavy rains do not necessarily accompany "northers" like they do on the upper coast so lagoon flushing would be less complete. If lagoon flushing does occur it would occur through Brazos Santiago Pass. Because longshore drift is southward during northers, the transport of sediments and associated trace elements would also be southward on the inner shelf, and out of the map area.

BENTHIC MACROINVERTEBRATES

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Introduction

This benthic macroinvertebrate study provides information on benthic populations in the State-owned submerged lands of the Brownsville-Harlingen area. The focus of this inventory has been: (1) identification and enumeration of the macrofauna; (2) identification and delineation of characteristic faunal assemblages; and (3) correlation of distributions and abundances to include investigation of sediment and faunal relationships.

Most of the relevant previous studies of the macrobenthos were based on samples from transects on the inner continental shelf and the outer continental shelf (OCS) in the Brownsville-Harlingen area and from samples taken from scattered stations in lower Laguna Madre. Lower Laguna Madre extends from the Brownsville Ship Channel north to approximately 8 mi (12.8 km) north of the northern edge of the map area where it grades into wind-tidal flats. The Intracoastal Waterway crosses these wind-tidal flats (or "the landcut") and connects lower and upper Laguna Madre. Many faunal surveys have dealt with specific groups of organisms rather than all macrofauna. Texas Parks and Wildlife (Breuer, 1962; Bryan 1971; Stokes, 1974) emphasized commercially important invertebrates, such as oysters, shrimp, and crabs, in their surveys. However, Breuer (1962) also presented a synoptic list of many other invertebrate species in his 1953 to 1959 survey of lower Laguna Madre and South Bay. Mollusks have probably been studied most. Nearly all characteristic species in Parkers' (1959) assemblages in lower Laguna Madre were mollusks. Polychaetes were not included in his species lists.

Few recent surveys of the macrobenthos have been conducted in lower Laguna Madre. Espey, Huston and Associates Inc. (1977) collected benthic samples from 15 stations near a proposed drainage canal in Willacy and Hidalgo Counties. Quantitative sampling was done to determine diversity and standing crop. They concluded that the distribution of benthic macroinvertebrates within the project area was a direct function of substrate composition; the more variable the substrate the greater the diversity.

Only three broad-based surveys have been conducted on the inner shelf of the Brownsville-Harlingen area. Hill and others (1982), Holland and others (1976), and Flint and Rabalais (1981) conducted benthic studies primarily on the South Texas OCS; only two stations in Holland and others (1976) and Flint and Rabalais (1981) surveys occurred within State submerged lands of the Brownsville-Harlingen area. Several of Hill and others (1982) nearshore stations occurred within State lands. This brief summary of previous work does not include all studies of the macrobenthos in the Brownsville-Harlingen area; only the more relevant studies have been mentioned.

Other studies have shown that species number and species content change seasonally (Holland and others, 1976; Flint and Rabalais, 1981). Although this study does not examine seasonal fluctuations in benthic populations, greater sample density than previous sampling programs gives more control on the areal distribution of organisms and assemblages and a better understanding of the diversity and spatial heterogeneity in the bays and on the inner shelf. Other differences include sampling techniques, sample analyses, and climatic conditions. These differences make it difficult to compare the results from this research with those of previous studies. However, some general comparisons can be made and these will be discussed in the sediment type and invertebrate distribution, total species diversity, and assemblage sections of this report.

Distribution in the Brownsville - Harlingen Area

Four hundred fourteen macroinvertebrate species (20,923 individuals) were found in the 216 samples examined in the Brownsville-Harlingen map area. Polychaetes were the most numerous species, followed by mollusks and crustaceans. Species counts for the three major groups (mollusks, polychaetes, and crustaceans) were higher on the inner shelf than in lower Laguna Madre or South Bay (table 7). Total species counts per station ranged from 3 to 83 on the inner shelf (pl. V). Highest counts generally occurred in the northern half of the map area at stations 3 to 8 mi (4.8 to 12.8 km) offshore. In lower Laguna Madre, total species counts per station were highest at grassflat stations near Brazos Santiago Pass. Generally, species counts were high from Brazos Santiago Pass north to the Three Islands area. Most grassflat stations south of Three Islands had more than 20 total species, whereas stations in the extensive grassflats north of Three Islands typically had less than 20 species per station. Stations bordering the wind-tidal flats near Padre Island had uniformly low species counts. Also, most stations in channels and the Intracoastal Waterway had low counts. Total species counts in South Bay ranged from 1 to 29, with stations 5, 6, and 7 having more than 20 species. Distributions of the polychaetes, mollusks, crustaceans, and other phyla are discussed individually, and the distributions are related to bathymetry and sediment type.

Mollusca

One hundred thirty-two species of live mollusks were collected from the Brownsville-Harlingen study area, including the polyplacophoran, Ischnochiton papillosus, 64 species each of gastropods and bivalves, and three species of scaphopods. Although 303 total species (live and dead species) were identified (appendix C), including the polyplacophoran, 183 gastropods, 117 bivalves, and three scaphopods, only those species collected live are considered in this report.

The number of gastropod and bivalve species collected were essentially equal on the shelf (48 gastropods, 44 bivalves) and in Laguna Madre (25 gastropods, 31 bivalves) but the bivalves accounted for 75.7% of the 2074 mollusk individuals collected on the shelf and 69.7% of the 3,191 individuals collected in Laguna Madre. In South Bay, the gastropod species (9) were about half as numerous as the bivalves (18) but the numbers of individuals were essentially the same (50 gastropods, 57 bivalves).

Table 7. Abundance of the major taxonomic groups, Brownsville-Harlingen area.

	Number of Stations Examined	All Species	All Individuals	Polychaete Species	Polychaete Individuals	Molluscan Species	Molluscan Individuals	Crustacean Species	Crustacean Individuals
Lower Laguna Madre*	93	173	9,146	80	3,780	57	3,191	36	2,175
South Bay	10	62	430	28	241	26	108	8	81
Inner Shelf	113	322	10,432	150	6,969	95	2,074	76	1,389
Total	216	391	20,008	168	10,990	132	5,373	91	3,645

*includes Arroyo Colorado River, Brownsville Ship Channel, Port Mansfield Channel, Laguna Madre Intracoastal Waterway

Many of the benthic species are restricted to a particular environment. For example, 36 of the 64 gastropod species and 29 of the 64 bivalve species were found only on the inner shelf, whereas 16 of the gastropods and 20 bivalves occurred only in the bays. The most abundant mollusks found in each system are listed in Table 8.

Bay-Estuary-Lagoon System

Lower Laguna Madre--Fifty-seven species of mollusks were collected in Laguna Madre. These included 25 gastropods, 31 bivalves, and the polyplacophoran, Ischnochiton papillosus. A total of 3,191 individuals were counted, of which 962 were gastropods, 2,224 bivalves, and five polyplacophorans.

Caecum pulchellum was the most abundant gastropod found. With 542 individuals, it was more numerous than any other mollusk species in the entire study area. It accounted for 56.3% of the gastropod individuals collected in Laguna Madre and 38.6% of the total gastropod individuals. It was found primarily in sediments of 80 to 100 percent sand. Bittium varium and Crepidula convexa were the next most abundant gastropods collected in Laguna Madre accounting for 11.9% and 10.8% of the gastropod individuals. They were found primarily in areas with medium to heavy stands of sea grasses.

Lyonsia hyalina floridana, Mulinia lateralis, and Nuculana acuta were the most abundant bivalves accounting for 15.3%, 14.4%, and 13.5% of the bivalve individuals respectively. Lyonsia was generally found associated with sea grasses in sediments of 60 to 80 percent sand. Mulinia and Nuculana were most often found in more open areas. Nuculana was collected from sediments of 60 to 80 percent sand, whereas Mulinia was found in sediments of 40 to 100 percent sand.

Tellina tampaensis, Abra aequalis, Mysella planulata, Tagelus plebeius and Ensis minor, while composing a smaller percentage of individuals than Lyonsia, Mulinia, and Nuculana were still rather abundant. Tellina, Abra, Mysella, and Tagelus were generally found in open bay areas in sediments of 60 to 80 percent sand. Ensis was found most often in areas of light stands of sea grasses and bay margins in 80 to 100 percent sand.

Table 8. Most abundant mollusk species of the Brownsville-Harlingen area.

Inner Shelf	Number of individuals	Percent of all (392) gastropod individuals
Gastropoda		
Natica pusilla	128	32.7
Terebra protexta	40	10.2
Vitrinella floridana	33	8.4
		Percent of all (1570) bivalve individuals
Bivalvia		
Linga amiantus	259	35.6
Abra aequalis	259	12.9
Diplodonta cf. soror	189	10.4
Tellina versicolor	135	9.9
		Percent of all (112) scaphopod individuals
Scaphopoda		
Cadulus carolinensis	51	45.6
Dentalium texasianum	35	31.2
Dentalium eboreum	26	23.2
Lower Laguna Madre		Percent of all (962) gastropod individuals
Gastropoda		
Caecum pulchellum	542	56.3
Bittium varium	114	11.9
Crepidula convexa	104	10.8
		Percent of all (2224) bivalve individuals
Bivalvia		
Lyonsia hyalina floridana	340	15.3
Mulinia lateralis	321	14.4
Nuculana acuta	300	13.5
Tellina tampaensis	205	9.2
Abra aequalis	169	7.6
Mysella planulata	141	6.3
Tagelus plebeius	106	4.8
Ensis minor	105	4.7
South Bay		Percent of all (50) gastropod individuals
Gastropoda		
Odostomia impressa	16	32.0
Bittium varium	9	18.0
Crepidula convexa	8	16.0
Crepidula plana	8	16.0
		Percent of all (57) bivalve individuals
Bivalvia		
Macoma tenta	20	35.1

South Bay--Twenty-six species of mollusks were collected in South Bay. These included nine gastropods, 16 bivalves, and Ischnochiton papillosus. A total of 108 individuals were counted including 50 gastropods, 57 bivalves, and 1 polyplacophoran.

Odostomia impressa was the most abundant gastropod found in South Bay accounting for 32% of the gastropod individuals. It was present on clumps of the oyster, Crassostrea virginica. Other species of gastropods which were relatively abundant were Bittium varium, Crepidula convexa and C. plana. Bittium occurred predominantly in areas of sea grass as did C. convexa. Crepidula plana was most abundant on shell fragments in grassy areas.

Macoma tenta was the most commonly found bivalve, comprising 35.1% of the 57 bivalve individuals found in South Bay. It occurred most often in sediments of 40 to 60 percent sand.

Arroyo Colorado River--No molluscan species were found in the one Arroyo Colorado River sample.

Inner Shelf

Ninety-five species of mollusks were collected on the inner shelf. Of these, 48 were gastropods, 44 bivalves, and three were scaphopods. A total of 2074 individuals were counted of which bivalves accounted for 75.7%.

Natica pusilla was the most abundant gastropod collected on the inner shelf with 128 or 32.7% of the 392 gastropod individuals counted. The next most abundant species were Terebra protexta and Vitrinella floridana with 40 (10.2%) and 33 (8.4%) individuals respectively. Natica was associated with sediments of 80 to 100 percent sand, whereas Terebra occurred in sediments of 60 to 100 percent sand. Vitrinella was found most often in sediments of 40 to 80 percent sand.

Linga amiantus and Abra aequalis were the most abundant of the bivalves found on the shelf with 259 individuals each. The next most abundant were Diplodonta cf. soror and Tellina versicolor with 189 (12%) and 135 (8.6%) individuals respectively. Linga and Diplodonta occurred primarily in sediments of 60 to 80 percent sand, whereas Abra and Tellina were found most often in sediments of 80 to 100 percent sand.

Of the 112 scaphopod individuals counted, Cadulus carolinensis accounted for 45.6%, Dentalium texasianum 31.2%, and D. eboreum 23.2%. Cadulus and D. texasianum were found in sediments of 60 to 100 percent sand and D. eboreum in sediments of 80 to 100 percent sand.

Polychaeta

One hundred sixty-eight polychaete species numbering 10,990 individuals were found in the 216 samples from the Brownsville-Harlingen area. Paraprionospio pinnata and Magelona cf. phyllisae were the most abundant and ubiquitous species on the inner shelf. In the bays, Prionospio heterobranchia was most abundant. A list of all polychaete species occurring in the Brownsville-Harlingen area is included in appendix C. Distribution of sediment, expressed as percent sand and referred to in this section, is shown on plate IC.

Bay-Estuary-Lagoon System

Lower Laguna Madre--Eighty species (3,780 individuals) were taken from the 93 stations examined in lower Laguna Madre. Highest species counts occurred at stations just north of the Brownsville Ship Channel in the southern part of lower Laguna Madre. Only four stations north of Three Islands had species counts above 10, whereas 19 stations south of Three Islands had counts greater than 10. The highest species count, 20, occurred at station 397, just north of the Brownsville Ship Channel. Most of the abundant species, such as Prionospio heterobranchia, Chone duneri, Melinna maculata, Streblospio benedicti, Exogone dispar, and Syllis cornuta, were species commonly found in marine grassflats in other bays of the Texas coast such as in upper Laguna Madre and Redfish Bay in the Corpus Christi area (White and others, 1983).

Prionospio heterobranchia was the dominant polychaete in both the grassflats of lower Laguna Madre (table 9) and in upper Laguna Madre and Redfish Bay (White and others, 1983). Melinna maculata was the most ubiquitous species in lower Laguna Madre, occurring in almost 50% of the samples.

Table 9. Most abundant polychaete species of the Brownsville-Harlingen area.

Inner Shelf	Number of individuals	Percent of all (6,969) individuals
Paraprionospio pinnata	732	10.5
Magelona cf. *phyllisae*	605	8.7
Lumbrineris verrilli	542	7.8
Nereis micromma	448	6.4
Armandia agilis	369	5.3
Isolda pulchella	262	3.8
Aglaophamus verrilli	257	3.7
Diopatra cuprea	242	3.5
Apoprionospio pygmaea	202	2.9
Onuphis eremita oculata	145	2.1

Lower Laguna Madre	Number of individuals	Percent of all (3,780) individuals
Prionospio heterobranchia	703	18.6
Chone duneri	400	10.6
Mediomastus californiensis	349	9.2
Capitella capitata	308	8.1
Melinna maculata	306	8.1
Streblospio benedicti	304	8.0
Exogone dispar	113	3.0
Syllis cornuta	110	2.9

South Bay	Number of individuals	Percent of all (241) individuals
Prionospio heterobranchia	54	22.4
Mediomastus californiensis	34	14.1
Euclymene sp.	23	9.5
Tharyx marioni	20	8.3
Capitella capitata	19	7.9
Streblospio benedicti	17	7.1

South Bay--Species counts in South Bay were generally low with four of the 10 samples containing mollusks. The highest count, 15 species, occurred at station 7, an oyster reef station. As in lower Laguna Madre, Prionospio heterobranchia was the most abundant species (table 9).

Arroyo Colorado River--Two polychaete species occurred at the only station examined from the Arroyo Colorado River. No other live macrobenthic species were found in the sample.

Inner Shelf

One hundred fifty polychaete species (6,969 individuals) were found in the 113 shelf samples. This diversity is substantially greater than the 89 species from the Corpus Christi inner shelf (White and others, 1983) and 73 species from the Galveston inner shelf (White and others, in preparation). Species counts were highest at stations in the middle and northern half of the map area away from the Rio Grande and Brazos Santiago Pass. Five stations in the mid to northern sections had over 40 species. Sediment at the five stations ranged from 60 to 100 percent sand. The highest species count, 57, occurred at station 435. Species counts at stations south of Brazos Santiago Pass were generally low. Only two stations had over 20 species.

Paraprionospio pinnata and Magelona cf. phyllisae were the two most abundant species. Both species were also abundant on the inner shelf in the Corpus Christi area (White and others, 1983) and in the Galveston area (White and others, in preparation).

Crustacea

Ninety-one crustacean species (3,645 individuals) were identified from the bays and inner shelf in the study area. The decapods represented by 36 species were the most abundant order. The amphipod Ampelisca abdita with almost 25% of the total number of individuals was the most abundant species. A complete listing of all crustacea and their distribution can be found in appendix C.

Bay-Estuary-Lagoon System

Lower Laguna Madre--Thirty-six species (2,175 individuals) were identified from lower Laguna Madre. Although the highest species count (14) occurred at station 202 in the northern part of the map area, high counts generally occurred at stations south of Three Islands. The amphipods were the most abundant of the crustacean groups. Ampelisca abdita, the most abundant crustacean, comprised over 39% of the crustacean fauna (table 10). Most species were strongly associated with marine grassflats.

South Bay--Eight species (81 individuals) were identified in South Bay. As in lower Laguna Madre, the amphipods were the most abundant of the crustacean groups and Ampelisca abdita was the most abundant species.

Arroyo Colorado River--No crustacean species were found in the one Arroyo Colorado River sample.

Inner Shelf

Seventy-six species (1,389 individuals) occurred on the inner shelf. Stations with the highest species counts (more than six species) generally occurred in the middle to northern part of the map area. Only one station south of Brazos Santiago Pass had more than six species. Twenty-three stations north of the pass had more than six species. The highest species count, 16, occurred at station 545.

The most abundant crustacean species were generally found in sandy substrates. Of the five most abundant species, Trichophoxus floridanus, Platyschnopus sp., and Protohaustorius cf. bousfieldi often occurred together at nearshore, sandy (80 to 100 percent sand) stations. The other two abundant species, Ampelisca agassizi and A. cristoides, were found at slightly muddier (60 to 80 percent sand) and deeper stations.

Other Phyla

Thirteen phyla besides the Annelida, Mollusca, and Arthropoda occurred in the Brownville-Harlingen area. They were Cnidaria, Platyhelminthes, Nemertinea, Aschelminthes, Chaetog-

Table 10. Most abundant crustacean species of the Brownsville-Harlingen area.

Inner Shelf	Number of individuals	Percent of all (1,389) individuals
Trichophoxus floridanus	276	19.9
Platyschnopus sp.	141	10.1
Ampelisca cristoides	134	9.6
Ampelisca agassizi	125	9.0
Protohaustorius cf. bousfieldi	95	6.8

Lower Laguna Madre	Number of individuals	Percent of all (2,175) individuals
Ampelisca abdita	856	39.4
Oxyurostylis salinoi	212	9.7
Balanus sp.	162	7.4
Cymadusa compta	150	6.9
Elasmopus levis	117	5.4

South Bay	Number of individuals	Percent of all (81) individuals
Ampelisca abdita	33	40.7
Cymadusa compta	21	25.9

natha, Bryozoa, Brachiopoda, Phoronida, Sipunculida, Echinodermata, Echiurida, Hemichordata, and Chordata (appendix C). Many phyla were so little known or difficult to identify that most identifications in these groups are not to species level.

The three most abundant phyla, Cnidaria, Nemertinea, Sipunculida, occur primarily on the inner shelf, although most phyla are found both in lower Laguna Madre and the inner shelf. The most abundant phylum on the inner shelf, the Nemertinea, occur at over 55 percent of the stations. The brittlestars (Ophiuroidea) are also well represented by at least five species on the inner shelf. In lower Laguna Madre, sea anemones (unidentified) and the phoronid, Phoronis architecta are the most abundant of the other phyla.

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 was generally greatest in a depth range of 48 to 72 ft (14.6 to 21.9 m) (fig. 28 and table 11). The only group with higher averages at depths other than 48 to 72 ft (14.6 to 21.9 m) was the Crustacea (table 11). Crustaceans were most abundant at shallower depths of 30 to 36 ft (9.1 to 11.0 m) (fig. 28).

The mollusks, crustacea, and polychaetes exhibited a decrease in the average number of species per station beyond a depth of 72 ft (21.9 m) (fig. 28). The other less abundant groups were almost uniformly distributed throughout their depth range. The average number of individuals for all groups generally followed the same pattern of depth distribution as that of the species, showing a sharp decrease at depths of 72 ft (21.9 m). Highest individual counts occurred in a depth range of 42 to 72 ft (12.8 to 21.9 m).

Some of the environmental parameters that are related to water depth and partially determine invertebrate distribution are: (1) sediment distribution and other environmental factors related to sediment type such as the distribution of total organic carbon (sediment-faunal relationships are discussed in the following section on sediment type and invertebrate distribution); (2) turbidity; Parker (1960) reported that the 1 to 12 fathom (1.8 to 21.9 m) zone

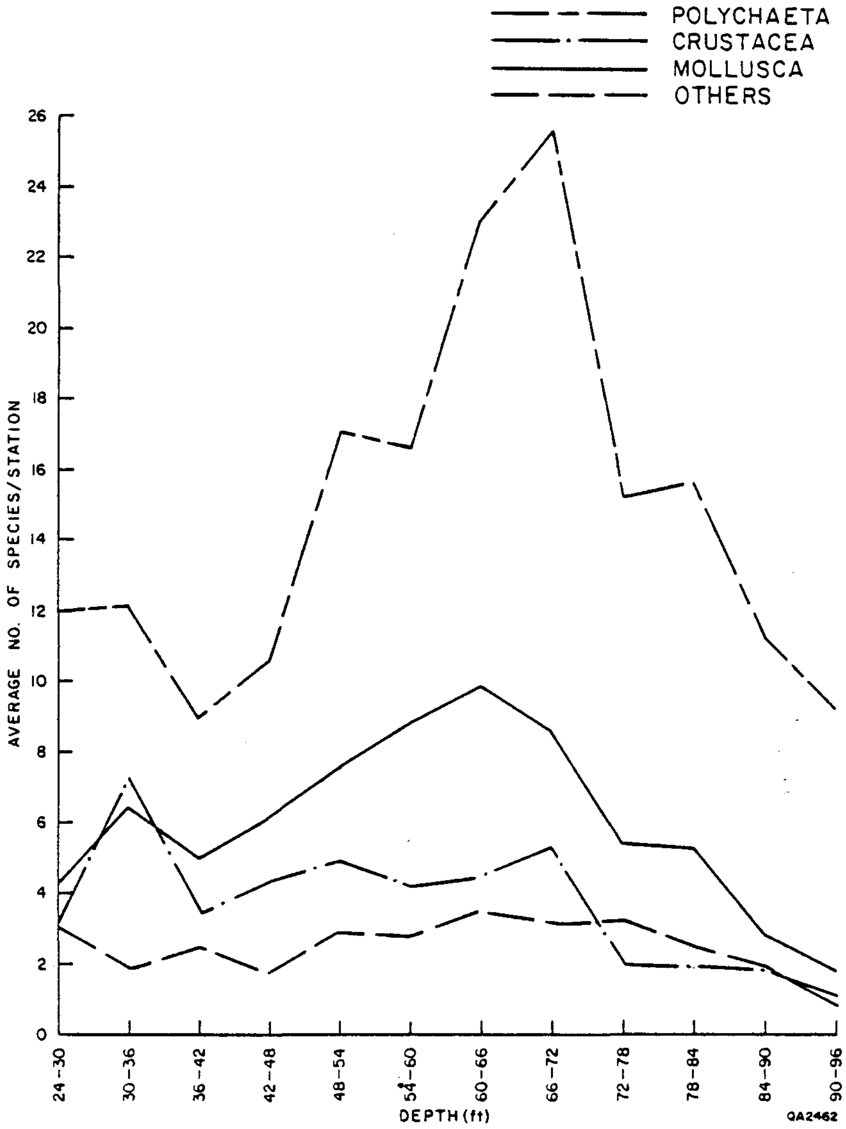


Figure 28. Distribution by depth of the average number of live species per station of the major groups.

Table 11. 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)	11.3	48-72 (14.6-21.9)	17.4	72-96 (21.9-29.3)	13.1
Mollusca	24-48 (7.3-14.6)	5.9	48-72 (14.6-21.9)	8.7	72-96 (21.9-29.3)	4.0
Crustacea	24-48 (7.3-14.6)	5.4	48-72 (14.6-21.9)	4.7	72-96 (21.9-29.3)	1.7
Other Groups	24-48 (7.3-14.6)	2.0	48-72 (14.6-21.9)	3.1	72-96 (21.9-29.3)	2.2
Total	24-48 (7.3-14.6)	24.6	48-72 (14.6-21.9)	36.9	72-96 (21.9-29.3)	21.5

in the northern Gulf of Mexico is constantly turbulent; (3) changes in bottom water temperature; Hill (1982) and Parker (1960) found that bottom-water temperature changes with increasing water depth; and (4) oxygen levels; oxygen levels could be more important than temperature on the density and distribution of organisms (Hill, 1982).

Because of overall shallowness of the bays, invertebrate distribution in the bays is not considered to be affected by depth. Other factors such as sediment type, although obviously related to bathymetry, and salinity are probably greater determinants of invertebrate distribution in the bays.

Sediment Type and Invertebrate Distribution

Sediment type is a primary influence on benthic macroinvertebrate distribution (Sanders, 1958, and Purdy, 1964). Many of the morphologic and physiologic adaptations of organisms are to different properties of sediment. These relations are important for a number of reasons including predicting man's impact on coastal environments. Probably one of the most drastic changes that occur in benthic communities is the alteration of substrate resulting in the replacement of one community by another (Johnson, 1971). Dredging and filling operations and the erection of structures may cause sediment changes along with changes in the erosional and depositional patterns. A knowledge of faunal-sediment relations is important in predicting the biological consequences of man's activities on the coast. Certainly on the inner shelf and especially in the shallow bays of the Brownsville-Harlingen area extreme fluctuations in temperature and salinity are common and may play a more significant role in invertebrate distribution than does substrate. However, the substrate and other environmental parameters related to sediment distribution are important in controlling invertebrate distribution.

The relationship between organic carbon content and sediment texture (fig. 16) influences the distribution of benthic macroinvertebrates. An ecologically important attribute of an invertebrate is its feeding type. Many of the benthic species are either deposit or suspension feeders. Deposit feeders feed on bottom deposits of nonliving organic detritus and associated microorganisms, and suspension feeders feed on microorganisms in surrounding waters. Since fine-grained sediments generally contain more organic matter than do coarse-grained deposits, the proportion of deposit feeders comprising the bottom fauna will increase as the organic content of the substrate increases (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 benthos studies of the Brownsville-Harlingen area. Parker (1959) listed the dominant sediment type for macroinvertebrate assemblages in lower Laguna Madre. On the inner shelf, Hill and others (1982) studied the correlation between sand-to-mud ratios and various biological parameters, and Holland and others (1976) described macroinfaunal distribution from the South Texas Outer Continental Shelf on the basis of sediment type and bathymetry.

Parker (1959) delineated two assemblages in lower Laguna Madre, an inlet influenced assemblage with sand substrates and an open, shallow hypersaline bay assemblage with sand and shelly sand substrates. Parker's discussion of the relationship between sediment and assemblage distribution was limited to a list of dominant substrates for each assemblage. According to Parker, extreme fluctuations of other physical factors, such as salinity and temperature, were the important factors which influenced the composition of biological assemblages in lower Laguna Madre.

All the biological factors that Hill and others (1982) studied on the South Texas Outer Continental Shelf correlated best with sand-to-mud ratios. A series of regression analyses showed that species number, number of individuals, and biomass increased with increasing sand-to-mud ratios. The most significant increase occurred where the sand-to-mud ratios exceeded 1.00. Water depth was the only other physical variable that made a significant increase in the proportion of variation. Hill and others emphasized that other factors 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 (10 to 27 m) in Holland and others (1976) study had substrates of muddy sand. Sediments at deep stations (65 to 134 m) were silty clay and mid-depth station sediments represented a transition zone that ranged 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.

On the inner shelf and in the bays, scattergrams and histograms show the relationship between species number and sediment type. Numbers of all species (figs. 29, 33, and 37) and number of species for each of the major taxonomic groups, polychaetes, mollusks, and crustacea are plotted against percent sand (figs. 30 to 32 and 34 to 37). Also, histograms depicting faunal distribution versus sediment type along two inner shelf transects show sediment-faunal relationships for all species (fig. 38) and for each of the major taxonomic groups (figs. 39 to 41).

On the inner shelf, correlation coefficients for all species and for mollusks, polychaetes, and crustacea are positive, although there is a wide spread in numbers of species in both muddy and sandy sediments. This positive correlation between percent sand and species number is greater for crustacea and mollusks (figs. 30 and 32) than for polychaetes and total species (figs. 29 and 31). Both histograms (fig. 37) and scattergrams (figs. 29 to 32) show that highest species counts generally occur in the 60 to 100 percent sand range. The optimum range for all species and for mollusks and polychaetes is 60 to 90 percent (figs. 29 to 32); the optimum range for the crustacea is 70 to near 100 percent (fig. 32).

Histograms of two inner shelf transects (figs. 38 to 41) show that highest species counts generally occur at stations from 3 to 7 mi (4.8 to 11.2 km) offshore and with sediments of greater than 50 percent sand. Crustacean species counts are highest from 1 to 5 mi (1.6 to 8.0 km) offshore (fig. 41). High individual counts are variable, occurring at stations from 1 to 11 mi (1.6 to 17.6 km) offshore.

Histograms of the two inner shelf transects also depict the dominance of sandy sediments on the Brownsville-Harlingen inner shelf. Sands (greater than 50 percent sand) are present to 10 mi (16 km) offshore on both transects. On the inner shelf in the Corpus Christi area (White and

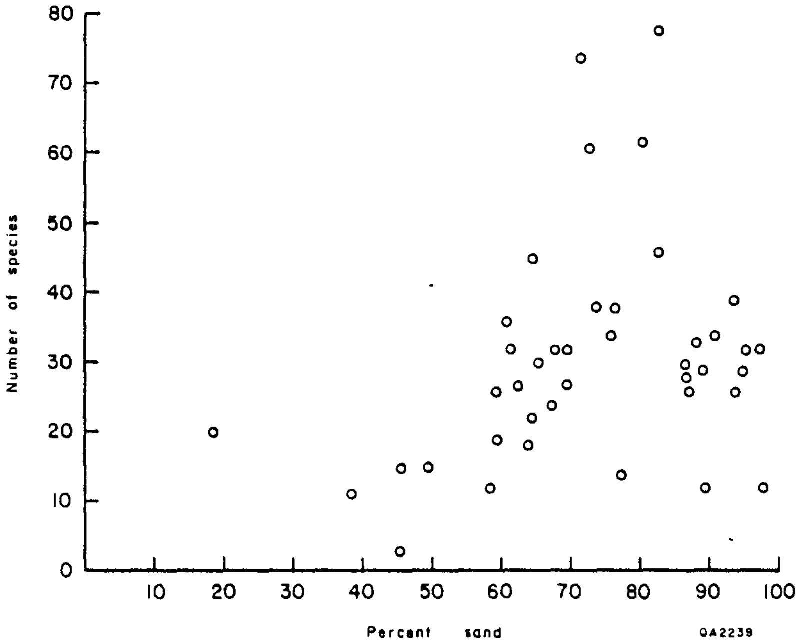


Figure 29. Scattergram of total species and sand on the inner shelf. correlation coefficient (r) = 0.291

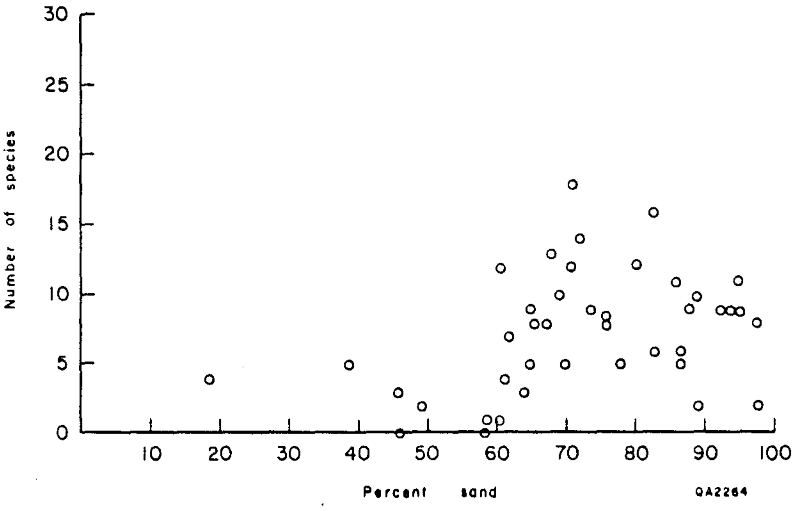


Figure 30. Scattergram of mollusks and sand on the inner shelf. r = 0.363

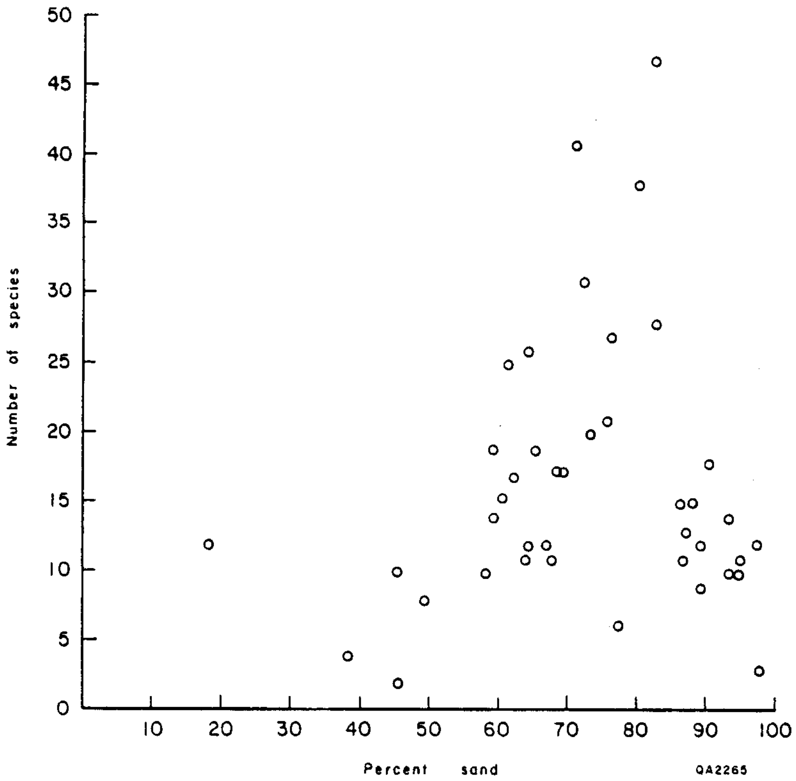


Figure 31. Scattergram of polychaetes and sand on the inner shelf.
r = 0.106

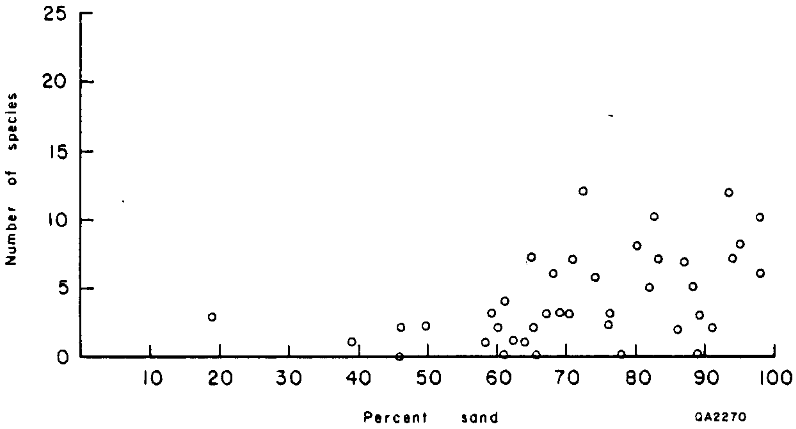


Figure 32. Scattergram of crustacea and sand on the inner shelf.
r = 0.492

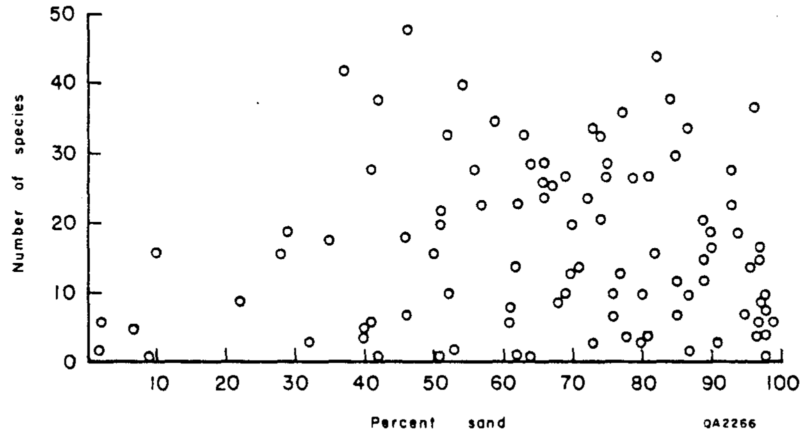


Figure 33. Scattergram of total species and sand in the bays. correlation coefficient (r) = 0.083

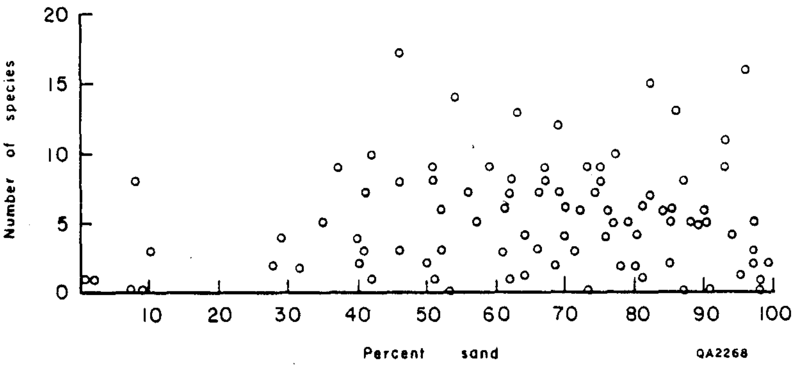


Figure 34. Scattergram of mollusks and sand in the bays. r = 0.116

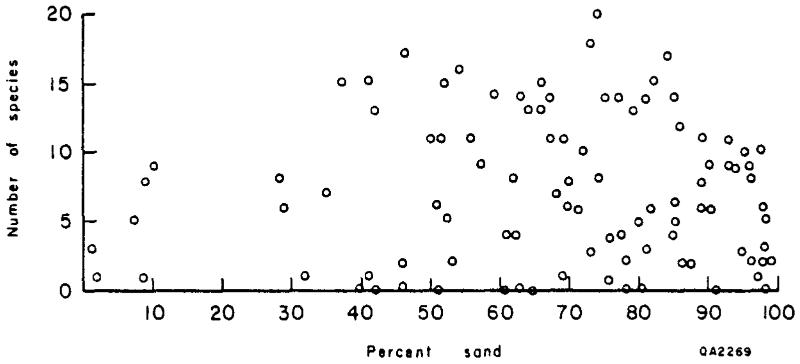


Figure 35. Scattergram of polychaetes and sand in the bays.
r = 0.076

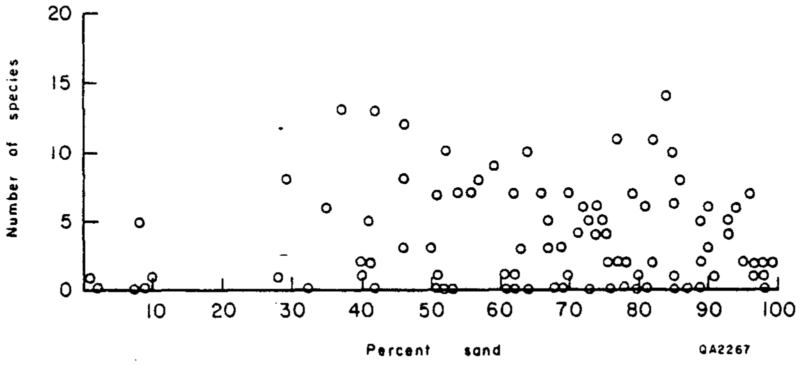


Figure 36. Scattergram of crustacea and sand in the bay.
r = -0.001

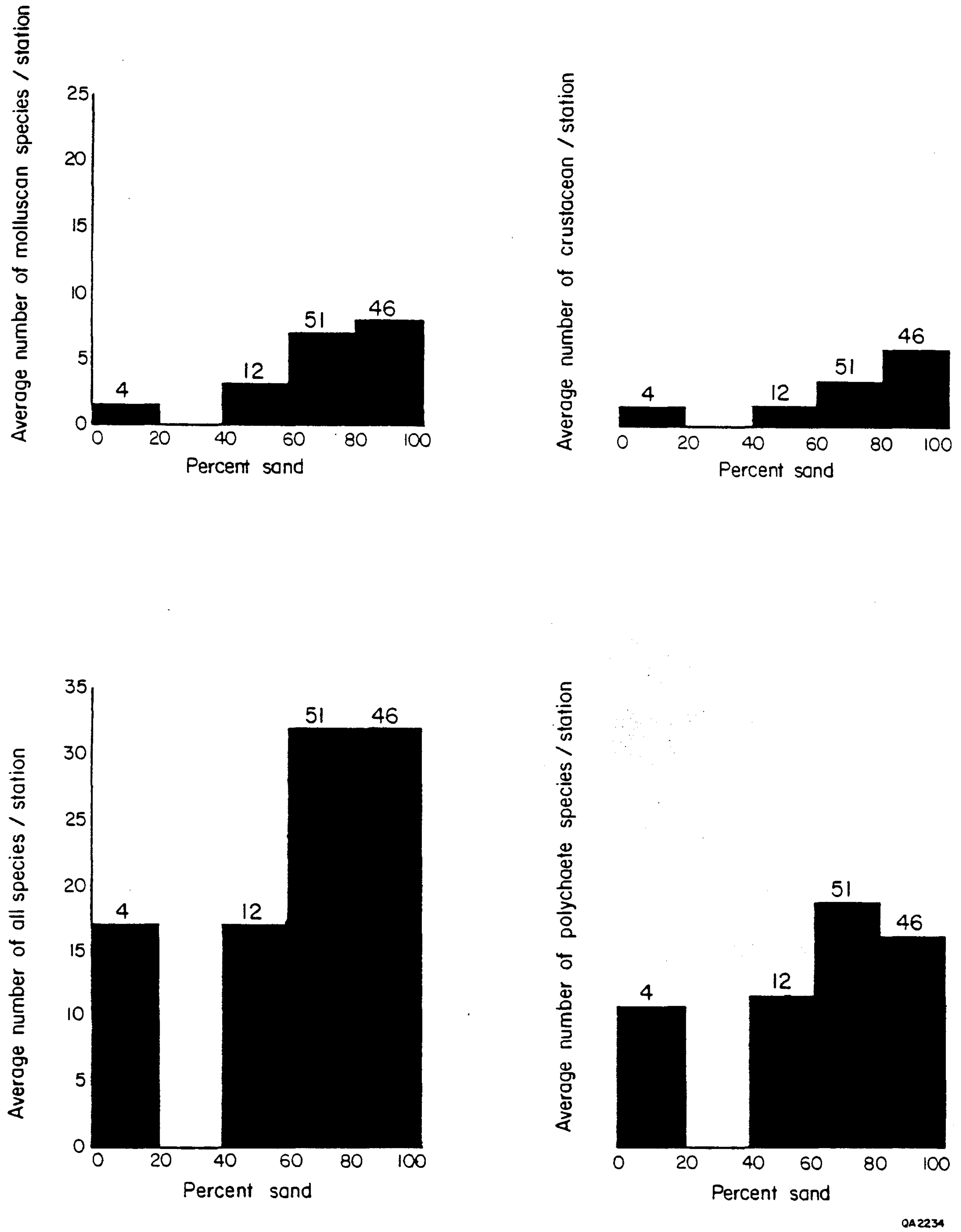


Figure 37. Molluscan, crustacean, polychaete, and all species and percent sand on the inner shelf. Numbers above bars equal number of stations within that sediment type.

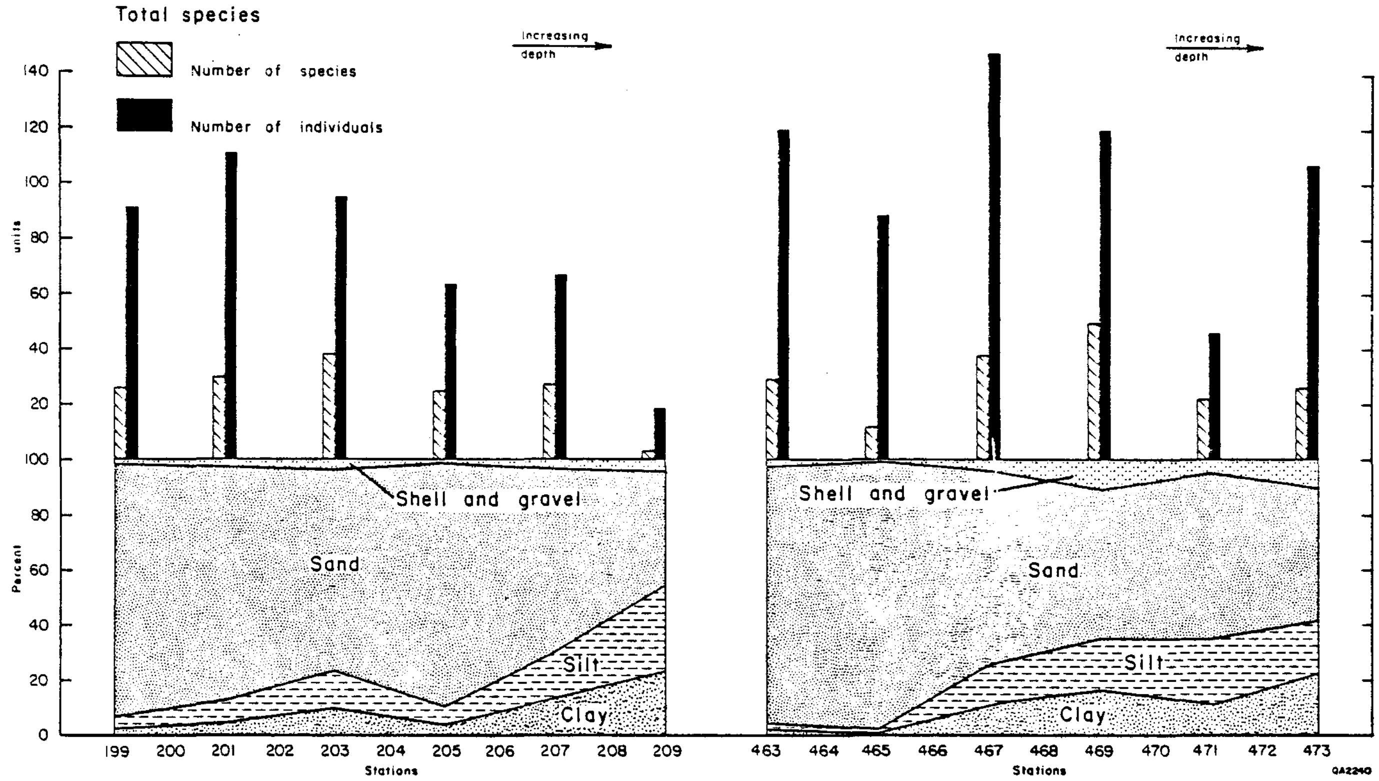


Figure 38. Total species distribution along two inner shelf transects.

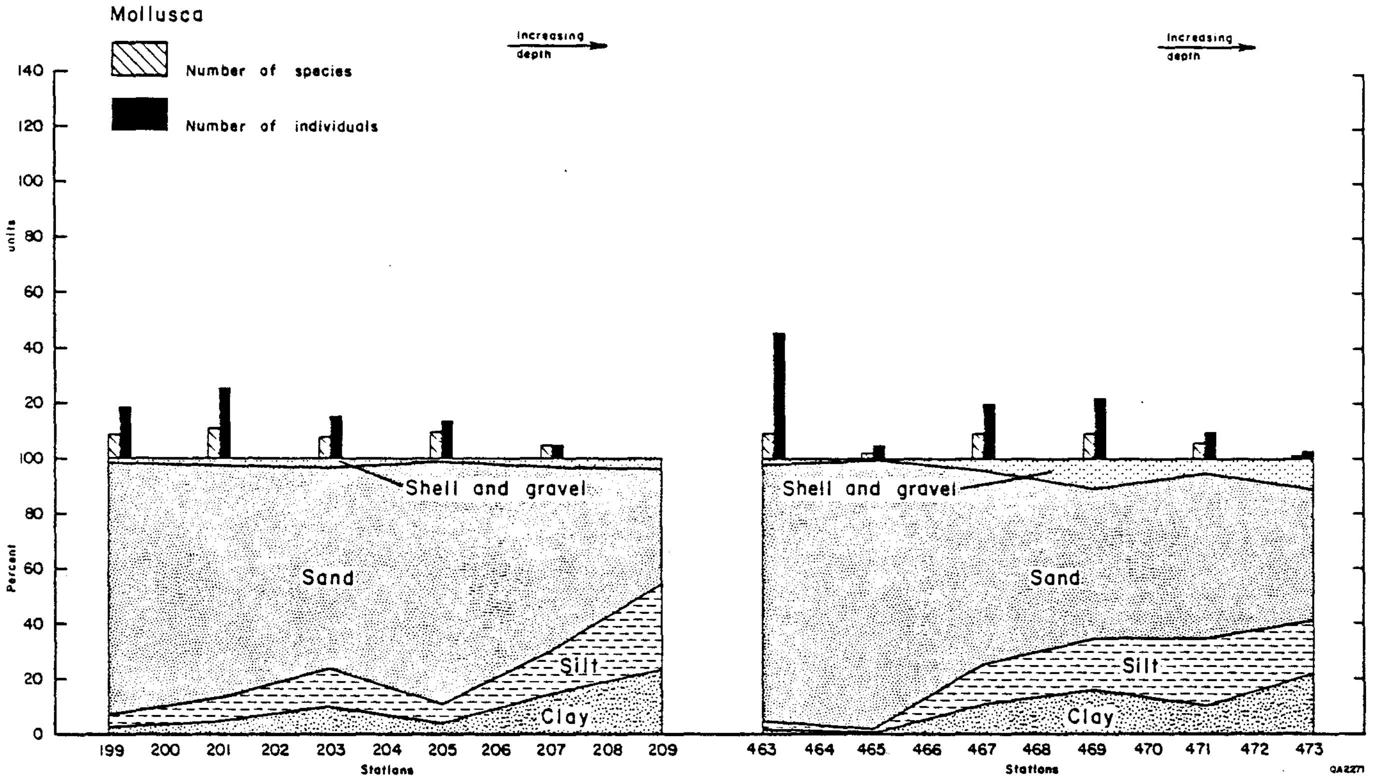


Figure 39. Molluscan distribution along two inner shelf transects. No mollusks were present at station 209.

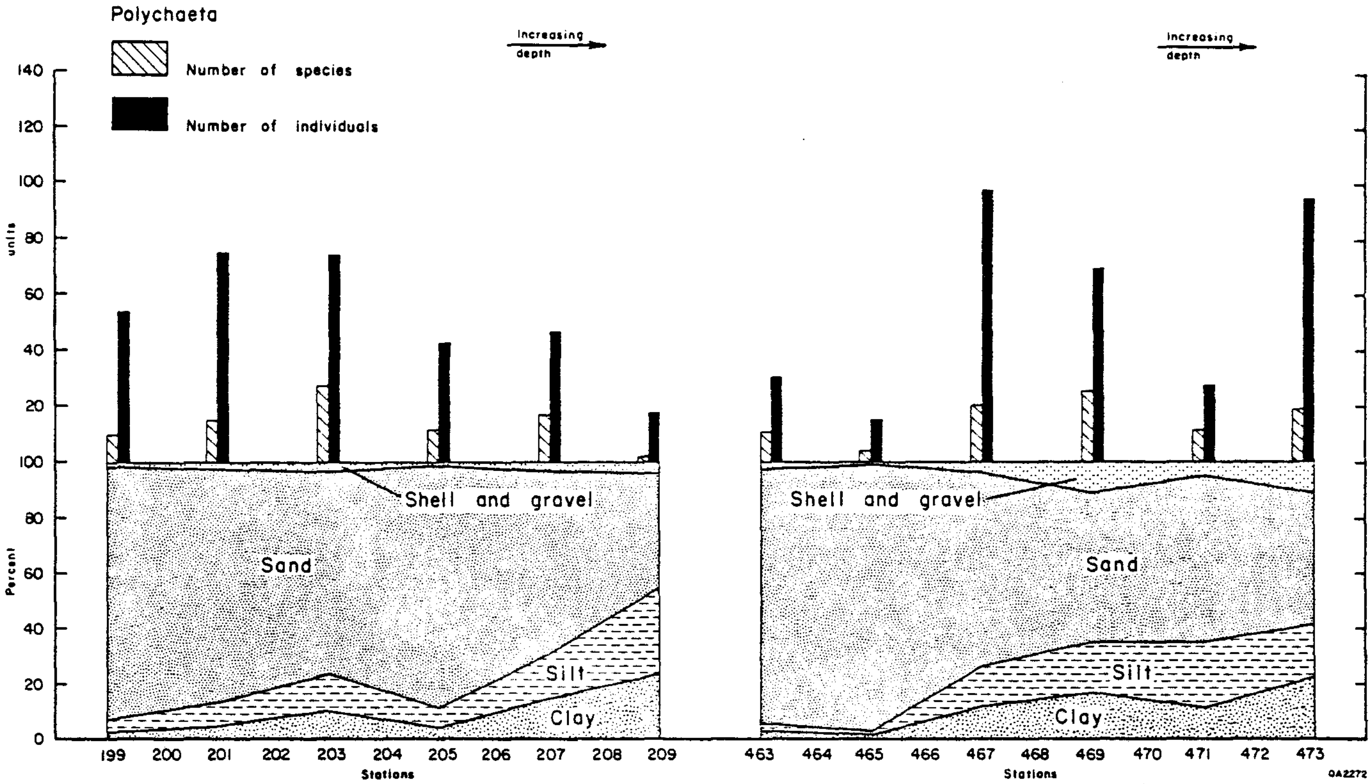


Figure 40. Polychaete distribution along two inner shelf transects.

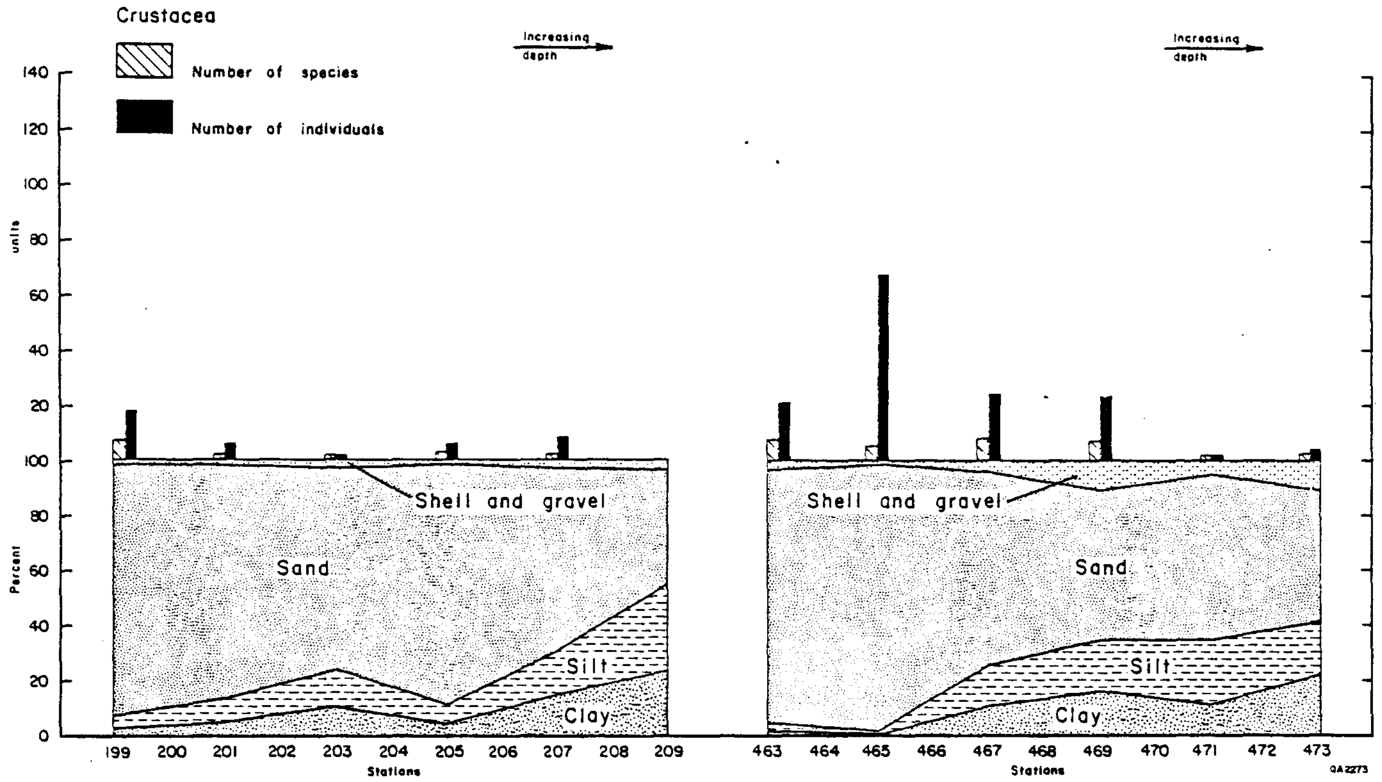


Figure 41. Crustacean distribution along two inner shelf transects. No crustaceans were found at station 209.

others, 1983) and in the Galveston-Houston area (White and others, in preparation), sand is not as abundant and muds are usually dominant at stations closer to shore than on the Brownsville-Harlingen inner shelf. Therefore, since high numbers of species on the inner shelf are generally associated with sandy and muddy sand substrates (60 to 90 percent sand), high counts may occur farther offshore in the Brownsville-Harlingen area (3 to 7 mi or 4.8 to 11.2 km) than in the Corpus Christi (1 to 3 mi or 1.6 to 4.8 km) or Galveston-Houston (1 to 2 mi or 1.6 to 3.2 km) areas.

Among several variables that may account for the higher number of species in substrates with 60 to 90 percent sand and an integral but smaller percentage of silt and clay are: (1) substrates with small amounts of silt and clay give a certain rigidity to sandy substrates, so that tunnels of burrowers would tend to stay open (Harry, 1976); (2) substrates with too much silt and clay may have reduced capillary circulation and thus increased chances of anaerobic conditions (Purdy, 1964); (3) substrates in nearshore areas, where sand content may range from 90 to 100 percent, are highly mobile and many benthic organisms cannot adapt to substrate mobility (Purdy, 1964); (4) substrates with moderate amounts of mud may contain a mixture of both suspension and deposit feeders. Johnson, 1971, concluded that most clean sand species cannot tolerate large amounts of silt and clay while mud species have special adaptations--probably related to feeding and respiration--to do so; and (5) substrates with greater than 90 percent sand have low total organic carbon values and thus fewer deposit feeders that feed on the organics in the sediment (Purdy, 1964). Since many mollusk and polychaete species are deposit feeders, the optimum percent sand range is slightly lower than for the crustacea which probably contain more filter feeding species than the mollusks or polychaetes.

Just as the inner shelf in the Brownsville-Harlingen area is dominated by sandy substrates, lower Laguna Madre is predominantly sand. Total species counts and diversity indices (pl. V) are uniformly low in the sands adjacent to the wind-tidal flats and in water less than 2 ft (0.6 m) deep. Muddy sand occurs lagoonward of the broad sand belt adjacent to the wind-tidal flats and in most of the northern and southern parts of the lagoon (pl. IA). Muddy sand accumulated in water whose depths range from less than 1 ft (0.3 m) to greater than 8 ft (2.4 m). Total species counts and diversities are higher in the muddy sands than in the sandy sediments adjacent to Padre Island.

In lower Laguna Madre and South Bay the correlation between percent sand and species number is much lower than on the inner shelf. Hydrographic factors such as salinity and temperature, and the presence or absence of marine grasses are probably more significant than sediment type in controlling invertebrate distribution. Scattergrams comparing species number with percent sand (figs. 33 to 36) show a very broad scatter in both muddy and sandy sediments. Total species counts are highest at grassflat stations near Brazos Santiago Pass, and, in general, counts are high from the Pass north to the Three Islands area. Sediment in this area is predominantly muddy sand.

Breuer (1962) reported that as the distance northward from Brazos Santiago Pass increases the number of invertebrate species decreases, but the number of individuals within the remaining species increases. Such variations are attributed to salinity changes from near normal marine salinity at Brazos Santiago Pass to hypersaline conditions near the landcut.

Total Species Diversity

An important biological aspect of an animal community is its diversity. There are two definitions of species diversity; usually it is 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, has to do with the numerical percentage composition of the various species present in the sample. The more the constituent species are represented by equal numbers of individuals, the more diverse the fauna. This 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 (Holland and others, 1973b; Boesch, 1972) 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, however (McIntosh, 1967), because it is very easy to "read" meanings into the numbers that are not there. This 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 by itself may be misleading. For example, the equation will give the same H' value to any sample with only one species, whether that sample is composed of one individual or 100 individuals. 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 have been subjectively grouped in this study into low (H' = 1.000 - 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, will be referring to that particular subjective classification.

Bay-Estuary-Lagoon System

Diversity values in lower Laguna Madre vary from north to south; values are lowest in the northern and middle parts of the lagoon and highest in the southern section. Highest values occur at grassflat stations in the southern section and at stations near Brazos Santiago Pass. A significant part of Laguna Madre contains grassflats which contribute to the high diversity of the system (median diversity = 2.269). Diversity values at grassflat stations in Redfish Bay and upper Laguna Madre in the Corpus Christi area are also high (White and others, 1983). Sandy stations bordering the wind-tidal flats in lower Laguna Madre have low diversity values.

Breuer (1962) reported that as the distance from Brazos Santiago Pass is increased and the salinity deviates from Gulf salinity (32 to 35 $^{o}/oo$), the number of species decreases, but the total number of individuals of the remaining species increases. Therefore, as species numbers decrease and numbers of individuals increase, diversity values (H') decrease because of the decrease in the equitability component (relative abundance of the species) in the formula.

Inner Shelf

Diversity values on the inner shelf are uniformly very high. Only 9 of the 113 examined stations (8%) have indices below 2.000; 50 stations (44% of the examined stations) have indices above 3.000. The median value of 2.933 is much higher than the median values for the inner shelves in the Corpus Christi area (1.708) (White and others, 1983) and the Galveston-Houston area (2.293) (White and others, in preparation).

There appears to be little correlation between diversity and sediment type. Very high diversity values occur at both sandy, nearshore stations and muddy stations that occur farther offshore or near the mouth of the Rio Grande where mud is being deposited. Five of the nine stations with indices below 2.000 occur in sandy (80 to 100 percent sand) sediment; the other four stations have substrates of muddy sand or sandy mud.

Hill and others (1982) used the Shannon 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 200 m isobath. The 20 m isobath was the general inshore boundary. Several stations were within the submerged State lands in the Brownsville-Harlingen area.

Hill and others (1982) found that the highest diversity values (> 2.750) were concentrated mainly within the southern one-third of their study area and were associated with coarse-grained substrates. Over the South Texas OCS, diversity generally decreased with increasing water depth. Hill and others 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 felt that greater sediment variability might explain higher diversities at shallow stations on the South Texas OCS than at deeper stations with 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 infaunal diversity on their southernmost transect averaged slightly higher than the other three transects. Numbers of individuals and species were highest at their nearshore, sandy stations. Infaunal equitability values showed a general increase with depth on all transects, reflecting the relatively even distribution of individuals among species at the deep 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 objective analysis and of simplification of complex data such as those generated in the State-owned submerged lands program. Also, the results are repeatable by any investigator studying the same data. An additional advantage is flexibility, which allows the researcher to apply different sorting methods, standardization methods, transformations, and correlation coefficients.

The basic procedure behind cluster analysis is 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 classified may be grouped either by station collections, with species content as the attribute (normal classification), or by species, with abundance at each station as the attribute (inverse classification). Dendrograms 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 are then 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 a comparison of the groups with other data such as textural, hydrographic, or bathymetric data.

Specific steps followed in the cluster analysis procedure include (1) reduction of data, (2) standardization of data, (3) calculation of the similarity matrix using the Canberra metric dissimilarity coefficient, (4) formation of dendrograms using the flexible sorting method on dissimilarity coefficients (Clifford and Stephenson, 1975), and (5) construction of two-way tables.

Large data sets require some reduction for easier handling by the computer and for interpreting data. Data reduction was often necessary because the capacity of the cluster program is 150 species and 150 stations. 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 uncommon species can be neglected in ecological classifications (Clifford and Stephenson, 1975). All rare species were included in diversity computations.

Another data manipulation was station and species standardization. Station standardization computes proportions of the total number of individuals at a site contributed by each species. This reduces the dominance of those species having a large number of individuals. Species standardization, on the other hand, is 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 then constructed for each pair of stations or species. The Canberra metric dissimilarity measure (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. 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 those animals living together in any given combination of environmental factors) in the Brownsville-Harlingen map area. Numerical analyses helped delineate three assemblages on the inner shelf and six in the bays and lagoons.

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 parameter. 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 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) recruitment or loss of species from an area; (3) patchiness in spatial and temporal distribution of many populations; (4) natural seasonal variations in distribution 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 map units in each bay is variable (see pl. V). Sample stations were carefully preselected according to a number of factors, including sediment type and proximity of other examined stations. The number and spacing of data points provided adequate control for the overall distribution of map units. Table 12 lists number of species and individuals and some physical characteristics for each assemblage. A listing of the characteristic species is given in table 13.

Bay-Estuary-Lagoon System

The six assemblages mapped in lower Laguna Madre, South Bay, and the Arroyo Colorado River are bay margin, bay center, grassflat, inlet-influenced, river-influenced, and oyster reef assemblages. A grassflat assemblage occurs in both South Bay and lower Laguna Madre, but the faunal content differs.

Cluster analysis of data from stations in the bay systems in the Brownsville-Harlingen area 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

Table 12. Characteristics of benthic faunal assemblages in the Brownsville-Harlingen 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')
Inner Shelf						
Nearshore	31	25	96	92	24-66 (7.3-20.1)	1.227- 3.250
Transitional	51	40	128	70	30-84 (9.1-25.6)	2.069- 3.929
Outer	31	19	54	53	24-96 (7.3-29.3)	0.943- 3.236
Lower Laguna Madre						
Bay margin	11	4	26	82	0.3-3 (0.1-0.9)	0.000- 1.413
Bay center	17	17	101	63	3-14 (0.9-4.3)	0.562- 3.056
Grassflat	55	22	133	69	0.3-15 (0.1-4.6)	0.000- 3.119
Inlet influenced	9	10	56	63	5-35 (1.5-10.7)	0.637- 2.348
South Bay						
Grassflat	9	10	37	43	0.5-3 (0.2-0.9)	0.000- 2.770
Oyster reef	1	28	113	41	0.5 (0.2)	2.634
Arroyo Colorado						
River influenced	1	2	4	53	1.0 (0.3)	0.693

Table 13. Characteristic species in macroinvertebrate assemblages of the Brownsville-Harlingen area.

Bay-Estuary-Lagoon
Lower Laguna Madre
  Bay Margin
  Mollusca
    Bivalvia
    Tellina tampaensis
    Anomalocardia auberiana
  Polychaeta
    Haploscoloplos foliosus
  Crustacea
    Hargeria rapax
  Grassflat
    Mollusca
    Bivalvia
    Laevicardium mortoni
    Tagelus plebeius
    Cumingia tellinoides
    Chione cancellata
    Amygdalum papyria
  Gastropoda
    Caecum pulchellum
    Bittium varium
  Polychaeta
    Capitella capitata
    Melinna maculata
    Chone duneri
    Prionospio heterobranchia
    Syllis cornuta
    Eteone heteropoda
    Polydora ligni
    Mediomastus californiensis
    Streblospio benedicti
    Exogone dispar
  Crustacea
    Ampelisca abdita
    Hargeria rapax
    Cymadusa compta
    Oxyurostylis salinoi
    Erichsonella filiformis isabelensis
    Cymodoce faxoni
  Bay Center
  Mollusca
    Bivalvia
    Lyonsia hyalina floridana
    Mulinia lateralis
    Nuculana acuta
    Ensis minor
  Polychaeta
    Mediomastus californiensis
  Inlet influenced
  Mollusca

  - Bivalvia
    - *Abra aequalis*

  - Polychaeta
    - *Armandia maculata*
    - *Cossura delta*
    - *Sigambra tentaculata*
    - *Mediomastus californiensis*
- South Bay
  - Grassflat
  - Mollusca
  - Bivalvia
    - *Macoma tenta*
  - Gastropoda
    - *Bittium varium*
  - Polychaeta
    - *Prionospio heterobranchia*
    - *Mediomastus californiensis*
  - Crustacea
    - *Ampelisca abdita*
    - *Cymadusa compta*
  - Oyster reef
  - Mollusca
  - Bivalvia
    - *Crassostrea virginica*
    - *Brachidontes exustus*
  - Gastropoda
    - *Odostomia impressa*
  - Polychaeta
    - *Tharyx marioni*
    - *Hydroides dianthus*
    - *Prionospio heterobranchia*
  - Arroyo Colorado
  - River influenced
  - Polychaeta
    - *Streblospio benedicti*
    - *Laeonereis culveri*
- Inner Shelf
  - Nearshore
  - Mollusca
  - Bivalvia
    - *Tellina versicolor*
    - *Parvilucina multilineata*
    - *Strigilla mirabilis*
  - Gastropoda
    - *Natica pusilla*
    - *Polinices duplicatus*
  - Scaphopoda
    - *Dentalium eboreum*
  - Polychaeta
    - *Spiophanes bombyx*
    - *Apoprionospio pygmaea*
    - *Magelona pettiboneae*

- *Onuphis eremita oculata*
- *Armandia agilis*
- *Haploscoloplos foliosus*
- *Haploscoloplos fragilis*
- Crustacea
  - *Trichophoxus floridanus*
  - *Platyschnopus* sp. "A"
  - *Protohaustorius* cf. *bousfieldi*
  - *Monoculodes* cf. *nyei*
  - *Tiron tropakis*
  - *Synchelidium americanum*
  - *Bowmaniella* cf. *dissimilis*
- Transitional
  - Mollusca
  - Bivalvia
    - *Abra aequalis*
    - *Linga amiantus*
    - *Diplodonta* cf. *soror*
    - *Tellina versicolor*
    - *Parvilucina multilineata*
  - Gastropoda
    - *Natica pusilla*
  - Scaphopoda
    - *Dentalium texasianum*
  - Polychaeta
    - *Isolda pulchella*
    - *Clymenella torquata*
    - *Sthenelais boa*
    - *Magelona* cf. *phyllisae*
    - *Aglaophamus verrilli*
    - *Lumbrineris tenuis*
    - *Diopatra cuprea*
    - *Laonice cirrata*
    - *Paraprionospio pinnata*
    - *Nereis micromma*
    - *Glycera americana*
    - *Lumbrineris ernesti*
    - *Lumbrineris verrilli*
    - *Spiophanes bombyx*
  - Crustacea
    - *Euceramus praelongus*
    - *Uniciola irrorata*
- Outer
  - Mollusca
  - Bivalvia
    - *Linga amiantus*
    - *Nucula proxima*
  - Polychaeta
    - *Magelona* cf. *phyllisae*
    - *Diopatra cuprea*
    - *Paraprionospio pinnata*
    - *Prionospio steenstrupi*
    - *Nereis micromma*

Lumbrineris ernesti
Lumbrineris verrilli

hydrographic variability in the bays. Many species occur in a majority of the assemblages as well as in both lower Laguna Madre and South Bay.

Lower Laguna Madre

Lower Laguna Madre has four of the six designated bay assemblages; only the oyster reef and river-influenced assemblages are not present. The grassflat assemblage covers the largest area, whereas the inlet-influenced assemblage is restricted to stations in and near Port Mansfield Channel and Brazos Santiago Pass. The bay center assemblage is composed of two areas, one in the southern part of the lagoon from Port Isabel to near Three Islands and an area along the Intracoastal Waterway from approximately 6 mi (10 km) south to 9 mi (14.4 km) north of Port Mansfield. The two areas are separated by grassflats that cover most of the central part of lower Laguna Madre. A bay margin assemblage occurs along the margins of the wind-tidal flats from just south of station 0.5 to near the northern edge of the map boundary. A bay margin assemblage also occurs on the mainland side of the lagoon at station 61.5.

Much of lower Laguna Madre contains a grassflat assemblage, characterized by a large number of invertebrate species (table 13). The average number of species and individuals per station is highest of any bay assemblage (table 12). This assemblage generally occurs where sand percentages average greater than 60 percent sand. Species diversities (H') in the grassflats of southern Laguna Madre are generally high to very high (2.000 to 2.500+). Diversity values are generally lower in the grassflats of the central and northern parts of the lagoon (pl. V).

Several studies have shown that macrofaunal densities at sites vegetated by seagrasses were higher than nearby, unvegetated sites (Santos and Simon, 1974; Stoner, 1980; Virnstein, 1983). It has also been shown that invertebrate species number within a seagrass habitat is not significantly related to numbers of plant species. However, plant biomass is significantly correlated with both species number and abundance of invertebrates at sample sites (Heck and Wetstone, 1977). Information on the distribution of marine grasses appears in the introduction.

The bay center assemblage is split into two areas by extensive grassflats in the central part of the lagoon. One area occurs in southern Laguna Madre and is generally restricted to deeper and slightly muddier stations of the lagoon where little or no marine grasses grow. The bay center assemblage in the northern part of the lagoon occurs along the Intracoastal Waterway, north and south of Port Mansfield Channel, at slightly deeper and muddier stations than the surrounding grassflats. Species characteristic of the bay center assemblage include bivalve mollusks and the polychaete, Mediomastus californiensis.

A bay margin assemblage occurs primarily in the sandy, very shallow portion of lower Laguna Madre bordering the wind-tidal flats near Padre Island. Characteristic invertebrate species are the bivalves, Tellina tampaensis and Anomalocardia auberiana, the polychaete, Haploscoloplos foliosus, and the crustacean, Hargeria rapax. Diversity values (H') are all low (0.000 - 1.413). Species and individual counts are the lowest of the bay assemblages.

An inlet-influenced assemblage occurs in Brazos Santiago Pass, Brownsville Ship Channel, and Port Mansfield Channel. Most species characteristic of this assemblage are also found in abundance on the inner shelf and at bay and channel stations near the inlets. Only the polychaete, Mediomastus californiensis, is widespread throughout the bay.

Parker (1959) recognized two assemblages in lower Laguna Madre, an inlet-influenced assemblage and an open shallow, hypersaline lagoon assemblage. The inlet-influenced assemblage was restricted to the southern part of lower Laguna Madre, from Brazos Santiago Pass to just south of the Three Islands area, and the open hypersaline lagoon assemblage included the rest of lower Laguna Madre.

The primary difference between Parker's assemblages and assemblages delineated in this study is that Parker did not recognize a grassflat assemblage, although he admitted that marine vegetation was one of the major factors influencing the composition of his assemblages. Since extensive grassflats occur within the areas covered by both of Parker's assemblages, many of the molluscan species that are included in the grassflat assemblage occur either in Parker's inlet-influenced or his open hypersaline lagoon assemblage.

South Bay

Two assemblages characterize South Bay. Except for an oyster reef assemblage at station 7, most of South Bay contains a grassflat assemblage. Most species occurring in the grassflat assemblage are also found in the grassflats of lower Laguna Madre (table 13). The oyster reef assemblage at station 7 includes the oyster Crassostrea virginica and its associated mollusks, Brachidontes exustus and Odostomia impressa.

Oysters are commercially harvested from South Bay (Breuer, 1962; Hamilton, 1982). Breuer reported that South Bay contained the only sizable concentration of oysters south of Corpus Christi. In spite of the seemingly adverse conditions of salinities in excess of 40 ᵒ/oo and very turbid waters, limited oyster production has occurred in South Bay for over 40 years (Breuer, 1962; Hamilton, 1982).

Arroyo Colorado River

The only station analyzed in the Arroyo Colorado River, station 29, contains a river-influenced assemblage of only two polychaetes, Streblospio benedicti and Laeonereis culveri.

Inner Shelf

Cluster analysis separated the inner-shelf fauna into three assemblages: a nearshore assemblage, characterized by relatively shallow bathymetry and high sand substrates; a transitional assemblage with species that are present in both the nearshore and outer assemblages; and an outer assemblage characterized by primarily polychaete species. Characteristic species for each of these assemblages are shown in table 13.

Nearshore Assemblage

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 1 to 9 mi (1.6 to 14.4 km) with greatest distances occurring southeast of the Port Mansfield Ship Channel and near the northern boundary of the map area. The nearshore assemblage extends 1 to 3 mi (1.6 to 4.8 km) offshore from approximately 2 mi (3.2 km) north of the mouth of the Rio Grande to 19 mi (30.4 km) north of Brazos Santiago Pass and 4 to 7 mi (6.4 to 11.2 km) offshore from 19 mi (30.4 km) north of Brazos Santiago Pass to the northern edge of the map area (pl. V). Between 19 and 27 mi (30.4 and 43.2 km) north of Brazos Santiago Pass, a transition assemblage replaces the nearshore assemblage at stations 1 to 3 mi (1.6 to 4.8 km) from the shoreline.

Characteristic species in the nearshore assemblage include a large number of polychaetes and crustaceans (table 13). Crustaceans are almost entirely restricted to this nearshore, sandy environment. Several of the characteristic molluscan species and the polychaete Spiophanes bombyx also occur in the transitional assemblage.

Fifteen of the 33 macroinfaunal species listed in the shallow water station groups of Holland and others (1976) are also characteristic of the nearshore and transitional assemblages in this study. Species typical of their shallow stations were present in all seasons. Polychaetes were dominant.

Transitional Assemblage

The transitional assemblage generally occurs between the nearshore and outer assemblages at stations 2 to 10 mi (3.2 to 16 km) offshore and at water depths of 30 to 84 ft (9.1 to 25.6 m). However, the transitional assemblage also occurs at stations 1 to 3 mi (1.6 to 4.8 km) from the shoreline near the middle of the study area. Sediment type at transitional assemblage stations is relatively sandy, averaging 70 percent sand.

Many of the transitional assemblage species also occur either in the outer or nearshore assemblages (table 13). Very few species are totally restricted to the transitional assemblage. Species and individual averages per station are the highest of the three inner shelf assemblages. Diversity values (H') are very high; only three values are below 2.500.

Outer Assemblage

From approximately 2 1/2 mi (4 km) north of the mouth of the Rio Grande to the northern edge of the map sheet, the outer assemblage extends from the transitional assemblage boundary, 6 to 10 mi (9.6 to 16 km) offshore, to the limit of the study area, approximately 11 mi (17.6 km) offshore. Near the mouth of the Rio Grande, the outer assemblage replaces the nearshore and transitional assemblage at stations 1 to 6 mi (1.6 to 9.6 km) offshore. The average percent sand for stations in the outer assemblage is 53 percent, with a range of 18 to 66 percent sand. Polychaetes, especially *Magelona* cf. *phyllisae* and *Paraprionospio pinnata*, are dominant in this assemblage.

Other workers have used cluster analysis to identify macrobenthic assemblages on the inner shelf. Hill and others (1982) delineated four assemblages, one of which was found in the southernmost part of the South Texas OCS, an area that included part of the submerged State lands seaward of the 20 m isobath. This assemblage occurred in a wide range of water depths extending from the inner to outer shelf. The inshore boundary was not determined because of the limits of the study area. This assemblage was the most densely populated and the most diverse (in numbers of species) of the four assemblages. Many of the characteristic species in this diverse assemblage also were characteristic of one or all of the assemblages from the State submerged lands.

Summary

The following significant findings resulted from this baseline study:

(1) Species distribution

- (a) Total species counts per station on the inner shelf ranged from 3 to 83. Highest counts generally occurred in the northern half of the map area at stations 3 to 8 mi (4.8 to 12.8 km) offshore.
- (b) In lower Laguna Madre, total species counts per station were highest at grassflat stations near Brazos Santiago Pass. Stations bordering the wind-tidal flats near Padre Island had uniformly low species counts.
- (c) Total species counts in South Bay ranged from 1 to 29 species.
- (d) On the inner shelf, the average number of species per station was generally greatest in a depth range of 48 to 72 ft (14.6 to 21.9 m).

(2) Substrate-species relationships

- (a) On the inner shelf, the highest species counts generally occurred in the 60 to 100 percent sand range.
- (b) In lower Laguna Madre and South Bay the correlation between percent sand and species number was much lower than on the inner shelf.
- (c) Total species counts and diversities in lower Laguna Madre were higher in the muddy sands than in the sandy sediments adjacent to Padre Island.

(3) Species diversity

- (a) Diversity values were lowest in the northern and middle parts of lower Laguna Madre and highest at grassflat stations in the southern section.
- (b) Diversity values on the inner shelf were uniformly very high.
- (c) There appeared to be little correlation between diversity and sediment type on the inner shelf.

(4) Macroinvertebrate assemblages

Cluster analysis permitted delineation of three assemblages on the inner shelf and six in the bays.

WETLANDS

William A. White and Katherine E. Schmedes

Classification of Wetlands

Preparation of the Environmental Geologic Atlas (Brown, 1972-1980) and participation in the U.S. Fish and Wildlife Service National Wetlands Inventory 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 features such as reefs, marshes and swamps, subaqueous grassflats, and plant-stabilized sediment where biologic activity is of principal importance" (Fisher and others, 1972). One of the special-use maps that evolved in the Environmental Geologic Atlas project and that is included in each of the atlases is a map of Environments and Biologic Assemblages, which illustrates coastal wetlands and their distribution. Maps from this earlier atlas series were major sources of wetland information for the submerged lands atlas series.

Maps prepared by the Biological Services Program, U.S. Fish and Wildlife Service, for the National Wetlands Inventory (NWI) were used as collateral data in delineating wetlands in many areas. NWI maps depict wetlands in accordance with the classification of wetlands and deep-water habitats by Cowardin and others, 1979.

The wetland units described and mapped in this report (table 14) on submerged lands 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.

Table 14. Wetlands and associated environments, Brownsville-Harlingen 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 navigation channels
- Beaches and berms along bay-estuary-lagoon margins

Map Units Characterized by Vegetation Assemblages:
- Grassflats
- Salt-water marshes
    - Proximal marsh
    - Distal marsh
    - Mangrove 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 and vegetated saline flats
- Woodlands in fluvial areas and in poorly drained depressions

A major departure in this classification from that of the earlier atlases is the subdivision of fresh-, brackish- and salt-water marshes into predominantly wet or dry areas. Thus, each of the marsh types has two 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 subdivided, also, 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. In this regard, 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 with 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 much broader and more generalized than the water regimes established in the U.S. Fish and Wildlife 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 15. One change involves depicting wetlands that have developed on dredged spoil, rather than designating these areas as simply 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 supporting marsh vegetation were mapped as marshes.

Table 15. Comparison of wetlands classified in this report with those classified in the Environmental Geologic Atlas of the Texas Coastal Zone, Brownsville-Harlingen area (Brown and others, 1980). The X's indicate those units that are similar in characteristics or that encompass similar map areas.

	CLASSIFICATION OF WETLANDS FROM ENVIRONMENTAL GEOLOGIC ATLAS ENVIRONMENTS AND BIOLOGIC ASSEMBLAGES MAP (From Brown and others, 1980)															
CLASSIFICATION OF WETLANDS AND ASSOCIATED MAP UNITS DEFINED AND MAPPED IN THIS REPORT	Beach	Washover channel, fan, and wind-deflation trough and storm runnel	Sand flats, wind-tidal	Fresh- to brackish-water bodies, landlocked ponds and lakes	Berms along and near bay-lagoon margin, storm deposits	Barren land, abandoned tidal creeks, small bayside beaches, sand flats, active point bars	Grassflats	Salt-water marsh	Brackish- to fresh-water marsh	Inland fresh-water marsh	Frequently flooded fluvial areas	Fluvial woodlands	Poorly drained depressions	Saline grasslands	Intense wind-deflation and wind-tidal activity, erosion of sand sheet	Subaqueous and subaerial spoil
Beaches	X															
Washover areas		X	X													
Sand flats, wind-tidal		X	X												X	X
Sand 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 navigation channels			X	X												
Beaches and berms					X	X										
Grassflats							X									X
Salt-water marshes																
Proximal marsh								X								X
Distal marsh								X						X		X
Mangrove marsh					X			X								
Brackish-water marshes																
Low marsh				X				X	X	X	X		X			
High marsh				X				X	X	X	X		X	X		
Fresh-water marshes																
Low marsh				X						X	X		X			
High marsh				X						X	X		X			
Sand or mud flats/marshes, undifferentiated			X					X							X	X
Wetland/upland areas, undifferentiated															X	
Transitional areas and vegetated saline flats			X		X						X		X	X		
Woodlands in fluvial areas and in poorly drained depressions												X	X			

Interpretation and Delineation of Wetlands

Wetlands in most of the map area were interpreted and delineated using stereoscopic, color-infrared (CIR) 1:66,000-scale positive transparencies, taken in 1979 by NASA. In the southern part of the map area (primarily in an area along the Rio Grande River near Brownsville and Brownsville Ship Channel), CIR-stereoscopic photographs with a scale of 1:58,000, taken in 1983 by the National High Altitude Photography Program were used. The 1979 photographs were taken in November, and the 1983 photographs in January and February. The main differences recorded by the photographs are that ground conditions were substantially wetter and tides were higher at the time the 1979 photographs were taken compared to the 1983 photographs. The contrast in moisture depicted in the two different photographic sequences helps to emphasize the intermittent nature of many "wetlands" in this dry region where evapotranspiration significantly exceeds precipitation.

In this report 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 units were determined primarily through photographic analysis supported by a limited number of field checks in which the kinds of vegetation and the soil moisture or degree of inundation were recorded. Although the use of color-infrared photographs and additional field checks (more than 150 field site surveys, including reoccupation of some sites, were conducted in the Brownsville-Harlingen area) have allowed better resolution of salt-, brackish- and fresh-water assemblages than was possible previously in the geologic atlas series, many of the map unit boundaries are based solely on photographic interpretation, without field verification.

Although map boundaries are shown as distinct lines, in many cases the lines are approximations because the boundaries are gradational. Many species overlap within the various map units. In nature, there is often an inexact line where one vegetation type or moisture regime stops and another begins; this is particularly evident in the study area because of the general lack of sharp changes in elevation. Often there is a gradation involving a mixture of species or a gradation in the 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 provides additional useful information about the coastal wetlands.

Several factors enhanced our ability to interpret moisture levels or inundation frequency: (1) photographs were high quality, and represent a uniform period of time (November 7-13, 1979) for almost the entire coast, and (2) records of precipitation indicate 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. Also, 1979 was characterized by higher annual precipitation than normal, and September (two months before the photographs were taken) was a month in which above normal precipitation occurred (figs. 7 and 8). Both of these factors, high tides and above normal precipitation, would tend to produce wetter conditions than normal. Still, in a given region, wetland environments can be compared and classified relative to each other. Salt- and brackish-water marshes and flats can be delineated according to their moisture or water content (high and low marshes), although there will be a tendency toward an upland shift in the map units. Accordingly, some areas that under normal conditions might more appropriately be included within the drier, high marsh map unit, will be included in the wetter, or more frequently inundated, low marsh map unit, and some flats that might be more appropriately designated wind-tidal flats might be classified as shallow subaqueous flats (water).

High and low marshes and flats are relative terms that are best applied in a designated geographic area. These terms are less accurately comparable and cannot be assumed equivalent in terms of the permanence of moisture or water for the northern and southern coastal areas. In the lower Rio Grande Valley where evapotranspiration greatly exceeds precipitation, many low marshes are intermittently wet and could best be designated as 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 (on which they are interpreted) were taken. Lower marshes are typically lower topographically or deeper geomorphically and, thus, retain moisture longer than higher marshes. In addition, in dryer areas or during dryer periods when surface water is not present, the water table should be nearer the surface in the low marsh compared to the high marsh. The dry south Texas climate also presents a dilemma as to what constitutes a wetland. More about this problem is presented in the section entitled "Mapped Wetland Environments."

Wetlands and Related Environments along the Texas Coast

Depositional Setting

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

The pattern of interconnected facies and geomorphic features that characterize the numerous types of coastal wetlands are the result of Modern-Holocene and Pleistocene depositional and erosional processes. Physical processes acting on the wetlands include rainfall, runoff and streams, evapotranspiration, waves and longshore currents, astronomical and wind tides, hurricanes and tropical storms, 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-estuarine-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 fluvial related environments, including active and abandoned stream channels, natural levees, point bars, crevasse splays, and floodbasins, are flooded at varying frequencies, depending on climatic and topographic conditions and locations of streams and drainage systems. Discharge of the rivers into the bay-estuarine system or into the Gulf has produced a suite of deltaic-related environments, including distributary and tidal channels, levees, marshes, interdistributary basins, and bay-margin environments (Environmental Geologic Atlas project, Brown, 1972-1980). Within many of these depositional environments, flood-prone lands extending inland from the bay margins, and flood-prone depressions scattered across the 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 some areas, and deflation flats or depressions in others. 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 man-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 in the area of 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 nature of 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. As a result, 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 extensive 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-estuarine-lagoon system, which in turn are reflected in the wetland environments. The extensive areas of salt- and brackish-water marshes that occupy inter-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 area).

Wetlands in the Brownsville-Harlingen Area

Mapped Wetland Environments

Eighteen wetland environments are delineated within the Brownsville-Harlingen area (pl. V, table 14). These wetland units are defined principally on the basis of (1) vegetation communities, which reflect salinities and substrate moisture among other conditions,

(2) frequency of flooding or elevation, as determined by surface water or soil moisture, and (3) hydrodynamic processes/conditions (for example, fluvial or tidal processes) that have formed and maintain the wetland environments.

A dilemma in this dry subhumid south Texas area is defining the boundary between salt- or brackish-water marshes and dryer vegetated saline flats or transitional areas into which many of the marshes grade. Broad "barren" wind-tidal flats in the Brownsville-Harlingen area such as in Bahia Grande (pl. IV), are not only sources of clay and silt that accumulate in clay dunes along the leeward side of the flats (Price, 1958; Brown and others, 1980), but also these areas are sources of saline dust that is transported miles inland (Johnson, 1955) by prevailing southeasterly winds. In addition, shallow ground water in many areas is slightly to moderately saline. Thus, saline soils are not limited to intertidal areas along the bay and lagoon margins but extend inland several miles (km) 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 soil salinity stress.

Data are not available to provide a good record of inundation frequencies of many topographically low flats with extensive Borrichia frutescens, but 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 causes root rot (Park Nobel, UCLA, 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. Using this definition, topographically low flats with Opuntia would be excluded from the wetland or marsh category. Other site specific data that provide some evidence that a site has a shallow water table or periodic standing water, are mud shrimp and crab burrows, algal mats, and dessication cracks. In the absence of specific field data for all sites, which is impractical to collect on such an extensive mapping project, it is a matter of interpretation and extrapolation from aerial photographic signatures that have been verified in the field as to which areas constitute wetlands. Effort was made to be as consistent as possible, but for many purposes, interpretation and delineation of upper marsh boundaries on regional photographs cannot be a 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 Brownsville-Harlingen area. Typical plants found in various wetland environments are listed in table 16.

Beaches

Gulf beaches lie between the Gulf shoreline and the edge of fore-island dunes in the Brownville-Harlingen area. 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 (fig. 42), which include storm channels and portions of the washover fans that lie bayward of the channels, occur as barren sand flats subject to high velocity inundation 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 and, in higher fringing areas, *Spartina*

Table 16. Typical plants found in wetland environments mapped in the Brownsville-Harlingen area. List compiled from field work and with reference to Correll and Correll (1975), Fleetwood (1973), Johnson (1955), Jones (1975), Gould and Box (1965), and U.S. Army Corps of Engineers (1982).

ENVIRONMENT	SCIENTIFIC NAME	COMMON NAME
GRASSFLAT (subaqueous marine grasses)	Halodule beaudettei	shoalgrass
	Cymodocea filiformis	manatee grass
	Ruppia maritima	wigeongrass
	Halophila engelmannii	clovergrass
	Thalassia testudinum	turtlegrass
SALT-WATER MARSH	Batis maritima	saltwort
	Salicornia virginica	glasswort
	Salicornia bigelovii	glasswort
	Distichlis spicata	seashore saltgrass
	Borrichia frutescens	sea ox-eye
	Monanthochloe littoralis	shoregrass
	Suaeda spp.	seablite
	Lycium carolinianum	Carolina wolfberry
	Sesuvium portulacastrum	sea purslane
	Heliotropium curassavicum	seaside heliotrope
	Spartina spartinae	gulf cordgrass, sacahuista
	Spartina patens	marshhay cordgrass
	Avicennia germinans	black mangrove
	Iva spp.	sumpweed
	Limonium nashii	sea lavender
	Scirpus maritimus	salt-marsh bulrush
	Sporobolus spp.	dropseed

Table 16. (cont.)

ENVIRONMENT	SCIENTIFIC NAME	COMMON NAME
BRACKISH-WATER MARSH	*Spartina spartinae*	gulf cordgrass, sacahuista
	Spartina patens	marshhay cordgrass
	Borrichia frutescens	sea ox-eye
	Distichlis spicata	seashore saltgrass
	Monanthochloe littoralis	shoregrass
	Scirpus maritimus	salt marsh bulrush
	Scirpus americanus	three-square bulrush
	Scirpus californicus	California bulrush
	Typha domingensis	cattail, tule
	Phragmites australis	common reed
	Eleocharis parvula	dwarf spikerush
	Eleocharis spp.	spikerush
	Cyperus spp.	flatsedge
	Bacopa monnieri	waterhyssop
	Aster subulatus	saltmarsh aster
	Paspalum vaginatum	seashore paspalum
	Iva spp.	sumpweed
	Batis maritima	saltwort
	Heliotropium curassavicum	seaside heliotrope
	Sesuvium portulacastrum	sea purslane
	Salicornia spp.	glasswort
	Suaeda spp.	seablite
	Limonium nashii	sea lavender
	Lycium carolinianum	Carolina wolfberry
	Sporobolus spp.	dropseed
	Hydrocotyle spp.	marsh pennywort

Table 16. (cont.)

ENVIRONMENT	SCIENTIFIC NAME	COMMON NAME
FRESH-WATER MARSH	*Spartina spartinae*	gulf cordgrass, sacahuista
	Typha domingensis	cattail, tule
	Scirpus americanus	three-square bulrush
	Scirpus californicus	California bulrush
	Paspalum lividum	longtom
	Eleocharis spp.	spikesedge
	Cyperus spp.	flatsedge
	Ludwigia spp.	seedbox
	Sagittaria spp.	arrowhead
	Polygonum spp.	smartweed
	Phragmites australis	common reed
	Bacopa monnieri	waterhyssop
	Echinodorus spp.	burrhead
	Eichhornia crassipes	water hyacinth
	Echinochloa sp.	water grass
	Leptochloa spp.	sprangletop
	Lemna spp.	duckweed
	Hydrocotyle spp.	marsh pennywort
	Sesbania drummondii	rattlebush
	Salix nigra	black willow

Table 16. (cont.)

ENVIRONMENT	SCIENTIFIC NAME	COMMON NAME
TRANSITIONAL AREAS AND VEGETATED SALINE FLATS	Spartina spartinae	gulf cordgrass, sacahuista
	Cynodon dactylon	bermuda grass
	Borrichia frutescens	sea ox-eye
	Monanthochloe littoralis	shoregrass
	Salicornia spp.	glasswort
	Batis maritima	saltwort
	Suaeda spp.	seablite
	Lycium carolinianum	Carolina wolfberry
	Heliotropium curassavicum	seaside heliotrope
	Paspalum spp.	paspalum
	Paspalum lividum	longtom
	Panicum spp.	panicum
	Andropogon glomeratus	bushy bluestem
	Iva spp.	sumpweed
	Aristida spp.	threeawn
	Setaria spp.	bristlegrass
	Helianthus spp.	sunflower
	Sorghum halepense	johnsongrass
	Cassia fasciculata	partridge pea
	Cyperus spp.	flatsedge
	Eleocharis	spikerush
	Scirpus spp.	bulrush
	Croton spp.	doveweed
	Spartina patens	marshhay cordgrass
	Baccharis halimifolia	groundsel bush
	Sesbania drummondii	rattlebush
	Spartina cynosuroides	big cordgrass

Table 16. (cont.)

ENVIRONMENT	SCIENTIFIC NAME	COMMON NAME
FLUVIAL AND FLOOD-PRONE WOODLANDS	Acacia farnesiana	huisache
	Parkinsonia aculeata	retama
	Tamarix gallica	salt cedar
	Salix nigra	black willow
	Celtis laevigata	hackberry/sugarberry
	Celtis pallida	spiny hackberry
	Sapium sebiferum	chinese tallow
	Sabal texana	Texas palmetto
	Fraxinus spp.	ash
	Ulmus crassifolia	cedar elm
	Washingtonia sp.	palm
	Phoenix sp.	date palm

patens, Spartina spartinae, Ipomoea spp. and Croton punctatus occur. Active (barren) washover areas have a very broad distribution in the Brownsville-Harlingen map area. Relict washover channels that have gained some amount of 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.

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

Shallow subaqueous flats were delineated (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 and navigation channels were included in this map unit (pl. V). The tidal pools locally support submerged grasses such as Ruppia maritima.

Sand and Mud Flats, Low and High Wind-Tidal Flats 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 for lack of field data, but generally these flats are characterized by moist or wet surfaces and/or blue-green algal mats (fig. 43). Commonly, on the mainland side of Laguna Madre, flats 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 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, 1980) which are flooded by storm tides, and (2) fluvial channel deposits that

Figure 42. Washover area on South Padre Island. Photograph taken a few days after Hurricane Allen made landfall in this area in 1980.

Figure 43. Dark algal mats on a wind-tidal flat between Brownsville Ship Channel and the Rio Grande. Eroding clay dune is in foreground.

include barren channel margins and bars along the Rio Grande, Arroyo Colorado, and other drainage networks. On the mainland, barren flats also occur in areas adjacent to vegetated saline flats substantially removed from lagoon waters. These flats, while perhaps inundated by surging bay waters accompanying tropical cyclones, are unaffected by wind tides but are mapped with the wind-tidal flat units for cartographic simplicity.

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 area of Corpus Christi and southward down the coast including the Brownsville-Harlingen area (an area coincident with 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-marsh vegetation, particularly along tidal channels that fill and drain the flats. Common species are Salicornia virginica, Salicornia bigelovii, Batis maritima, Suaeda spp., Monanthochloe littoralis, and Heliotropium curassavicum.

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 that occur along bay margins. Although shell berms and sand beaches are mapped as a single unit, the shell berms are topograpically higher features constructed by storm waves that pile up shell material at levels out of reach of the daily tides and waves. Included locally in this map unit are ridges of muddy sand occurring along the margins of tidal flats. Only barren areas are included in this map unit. Where beaches and berms are low enough and are extensively vegetated with marsh plants, they are mapped as marshland.

Grassflats

The distribution of marine grasses (grassflats) was determined from aerial photographs, and also with reference to sample description and live benthic macroinvertebrates identified in sediments taken from submerged lands. Although this map unit consists primarily of areas relatively densely vegetated with marine grasses, it also includes areas with moderate to sparse vegetation. Grassflats are widely distributed in the Brownsville-Harlingen area (pl. V and figs. 11 and 12). Species occurring in grassflats include the following spermatophytes: *Halodule beaudettei*, *Ruppia maritima*, *Cymodocea filiformis*, *Halophila engelmannii*, and *Thalassia testudinum*. More information on grassflats appears in the sections on distribution of marine grasses and macroinvertebrate assemblages.

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 that exists along the Gulf coast prevents the establishment along much of the coast 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), from those areas less frequently flooded because of higher elevations and distal locations with respect to bay-estuarine water (distal salt-water marshes) (fig. 44). Proximal salt-water marshes commonly contain one or more of the following species: *Batis maritima*, *Salicornia virginica*, *Salicornia bigelovii*, *Distichlis spicata*, *Borrichia frutescens*, *Suaeda* spp., *Monanthochloe littoralis*, *Avicennia germinans*, *Lycium carolinianum*, *Sesuvium portulacastrum*, *Iva frutescens*, and *Heliotropium curassavicum*. Many species grow in a range of elevations and therefore occur in both distal and proximal assemblages. *Spartina alterniflora*, which is abundant in the proximal community along the upper Texas coast, is rare in the Brownsville-Harlingen area. It occurs in limited stands in intertidal areas on South Padre Island near the Queen Isabella Causeway.

Species typically present in the distal community include those listed for proximal areas, but the order and dominant type vary. Borrichia frutescens, Monanthochloe littoralis, Distichlis spicata, Suaeda spp., and Heliotropium curassavicum are more common. Species such as Spartina spartinae and Spartina patens, which are more characteristic of brackish-water marshes, are scattered overall but locally abundant. Distal marshes locally grade into vegetated saline flats.

The mangrove salt-marsh community (Avicennia germinans) is scattered throughout the southern region of the Texas coast (fig. 45). Avicennia, the black mangrove, is an evergreen shrub, commonly no taller than 3 to 6 ft (1 to 2 m) (Sherrod and McMillan, 1981). An exception to this general height, which characterizes the Texas Coast, occurs near the mouth of the Rio Grande. Mangroves in a small isolated grove at this location were more than 10 ft (3 m) tall in 1983. Mangroves tend to grow along the margins of bays, lagoons, and tidal channels, and locally become relatively densely concentrated on low marshy islands near tidal inlets. In areas where mangroves occur extensively in homogeneous stands or are the predominant species in a community, such as along margins of San Martin Lake in the Brownsville-Harlingen area, they are distinguished as a subunit within the salt-water marsh system (pl. V). In areas where mangroves are scattered among other salt-water marsh plants, they are included with the other marsh plants in either the proximal community (commonly) or the distal community (less commonly), depending on frequency of inundation as interpreted from aerial photographs.

Mangroves are affected by continuous low temperatures, which can kill them, and by storms, which can uproot them (Steven Frishman, personal communication, 1982). Most of the larger mangrove shrubs along the Texas Coast were apparently killed by freezing temperatures in December of 1983. A low temperature of 20°F (-6.7°C) and a high of 30°F (-1.1°C) was recorded at Brownsville on December 25, 1983. Minimum temperatures were below freezing six out of eight days between December 24 and 31. Field reconnaissance in the Lower Rio Grande Valley in May 1984, indicated that with the exception of a few scattered small shrubs that had

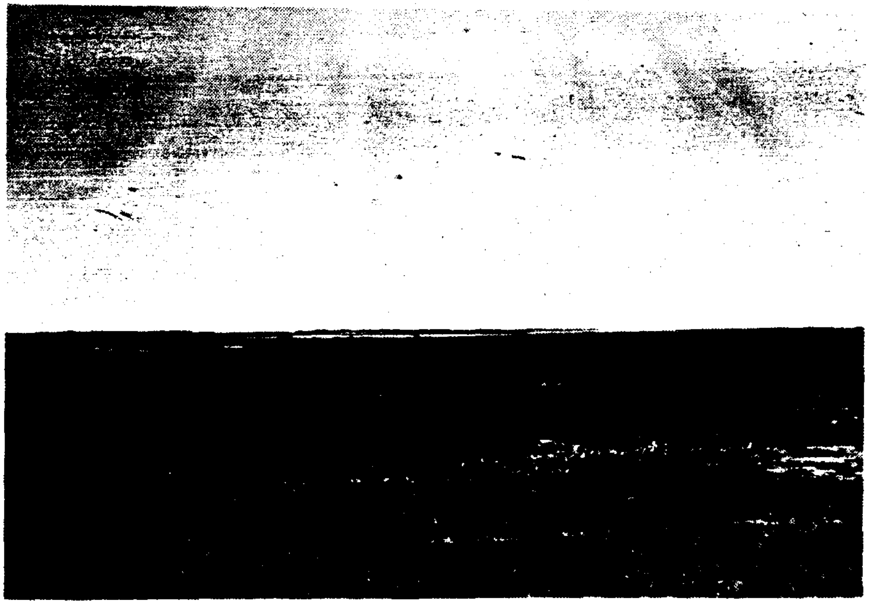


Figure 44. Distal salt-water marsh grading into small mangrove marsh. Location of marsh is between Los Montes and the Rio Grande (pl. V).

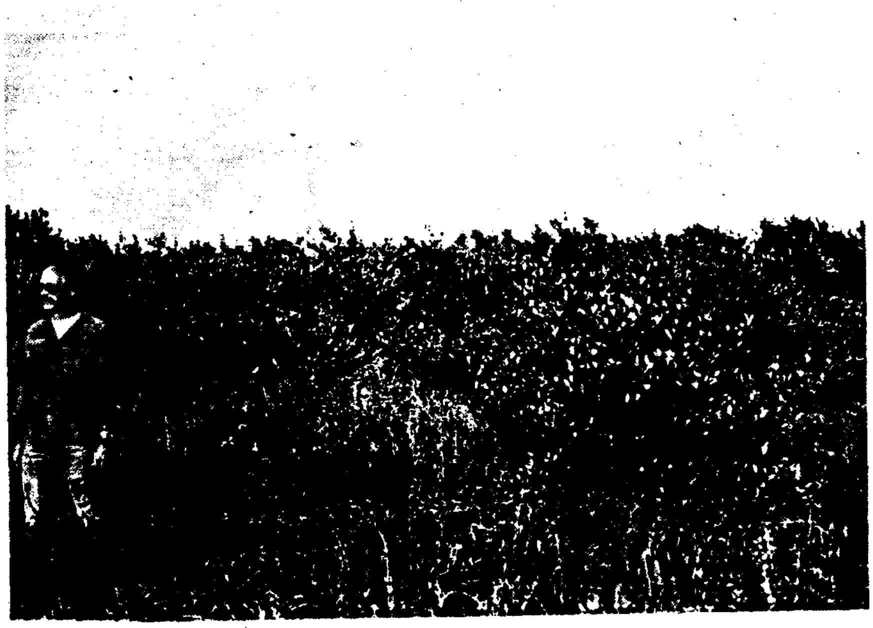


Figure 45. Black mangroves (Avicennia germinans) in a marsh near Los Montes and the Rio Grande.

basal green leaves, the mangroves were dead. Mangroves on Harbor Island in the Corpus Christi area suffered a similar fate (Calvin McMillan, personal communication, 1984). Resprouting should reestablish the mangroves, which apparently are more tolerant to chilling temperatures than the mangroves of more tropical origin (Sherrod and McMillan, 1981).

Brackish-Water Marshes

Brackish-water marsh environments usually occur inland from salt marshes. These areas, influenced both by storm-tidal flooding from bay-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 marshes and some of fresh marshes (fig. 46). The brackish marsh is transitional between the salt-water- and fresh-water-influenced environments. Although the break between the salt, brackish, and fresh marsh is shown along distinct lines on the map, the boundary is actually gradational and its width 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 standing surface water ("low" marshes), and (2) areas that appear to be less frequently flooded, having a drier wetland-plant assemblage and lower soil and surface moisture ("high" marshes). Among those plants occurring in wetter locations are *Scirpus maritimus*, *Scirpus californicus*, *Scirpus americanus*, *Eleocharis* spp., *Paspalum vaginatum*, and *Typha* sp., grading into saline to brackish flats of *Monanthochloe littoralis*, *Salicornia* spp., and *Distichlis spicata*, and into higher assemblages of *Spartina spartinae*, *Spartina patens*, *Borrichia frutescens*, *Phragmites australis*, *Baccharis halimifolia*, *Iva* sp., *Sporobolus* sp., *Heliotropium curassavicum*, *Limonium nashii*, and others (table 16).

In many places, the distinction between brackish- and salt-water marshes occurs where *Spartina spartinae*, *Spartina patens*, and *Borrichia frutescens* become significant components of the brackish marsh; fresher water species such as *Scirpus maritimus*, *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 basins and depressions (fig. 47). Environments in which the fresh marshes occur are generally beyond the limits of salt-water flooding except perhaps during hurricanes. Nevertheless, the fresh-water influence from rivers, precipitation, runoff, and/or ground water is sufficient to maintain a fresher water vegetation assemblage consisting of species such as Typha spp., Scirpus americanus, Scirpus californicus, Eleocharis sp., Cyperus sp., Bacopa monnieri, Ludwigia sp., Phragmites australis, Sagittaria spp., and Paspalum lividum in wetter areas ("low" marshes); the drier areas ("high" marshes) are typified by such species as Spartina spartinae, Paspalum sp., Polygonum spp., Panicum sp., Borrichia frutescens, Aster sp., Spartina patens, and 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.

Many vegetation species characterizing the brackish-marsh assemblage overlap with, or occur in, areas mapped as fresh-water marsh. Some species, such as Spartina spartinae (which in addition to occurring near the Gulf, occurs along the Nueces River more than 100 mi (160 km) inland), occur in salt-, brackish- and fresh-water marshes. Drier fresh-water marshes grade (often very subtly) into transitional areas, which also may be vegetated by Spartina spartinae (fig. 48). 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 not known, the assemblage apparently requires periodic inundation (McAtee, 1976). McAtee (1976) places Spartina spartinae at an elevation between lowland marshes and higher upland vegetation. Johnson (1955) noted that Spartina spartinae occurred above communities of Borrichia, Batis, and Monanthochloe. Fleetwood (1973) reported that Spartina spartinae in Laguna Atascosa National Wildlife Refuge 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

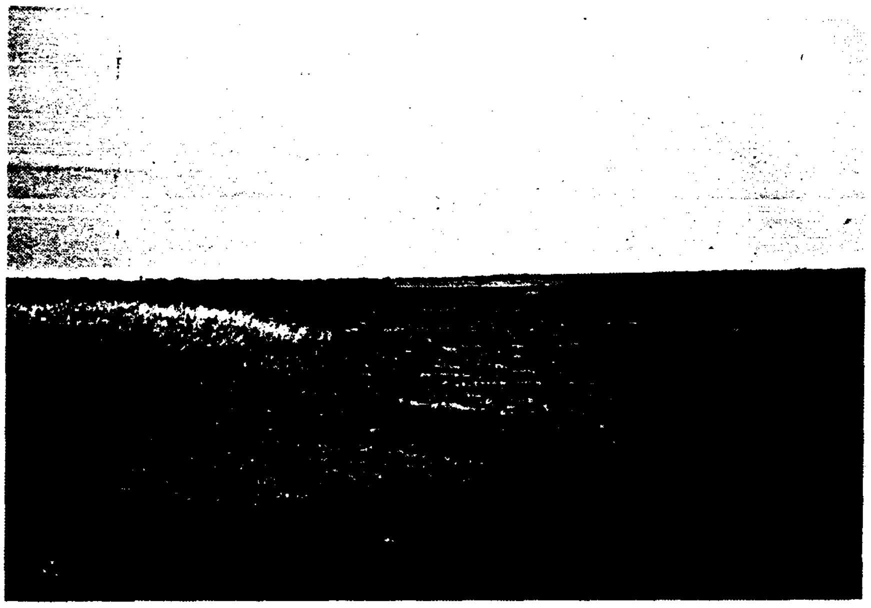


Figure 46. Brackish-water marsh in Laguna Atascosa National Wildlife Refuge. Taller vegetation is *Typha* sp.; shorter vegetation is predominantly *Heliotropium curassavicum*.

Figure 47. Fresh-water marsh and pond inland from Port Mansfield.

homogeneous nature of these assemblages and their relationship to the water table produces a definite mappable "signature" (color, hue, and texture) on color-infrared photographs. Expanses of Spartina spartinae were mapped in many areas as transitional areas. Spartina spartinae occurs 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 with marsh vegetation covering about 30 to 60 percent of their area. The unit is termed "undifferentiated" because no attempt was made to separately map marsh vegetation and barren sandflats. This would have been too difficult (at the mapping scale) as the configuration of these areas is too complex.

Comprising a relatively large area overall, this unit occurs principally in the area of the mouth of the Arroyo Colorado, inland from Laguna Atascosa, and in the vicinity of Bahia Grande and the Brownsville Ship Channel. 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.

Wetland/Upland Areas, Undifferentiated

These mapped environments are complex mixtures of wetland-upland areas typically characterized on the mainland by numerous, small depressions (generally less than 130 ft or 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 wind-tidal flats and/or salt-to brackish-water marshes. The complexities 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 when taken as a whole is significant.

Vegetation in the depressions on the mainland consists of a wide variation in species from depression to depression; 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 areas that, in terms of flooding and plant communities, lie between wetland and upland areas. 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 relatively wet or dry conditions. The "signature" as 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). Other representative species are listed in table 16. Scattered shrubs include Parkinsonia aculeata, Acacia farnesiana, Prosopis glandulosa, and Baccharis halimifolia.

The dilemma of separating vegetated saline flats (fig. 49) from marshes was discussed in the introductory comments in this section on wetlands in the Brownsville-Harlingen area. The difficulty is that vegetation species such as Batis maritima, Salicornia spp., Suaeda spp., Monanthochloe littoralis, and Borrichia frutescens and others that are typical of salt marshes also occur on the saline flats. Johnson (1955) recognized varying communities with respect to elevation. At the strandline or lowest elevation, a community of Batis-Salicornia-Suaeda grades almost imperceptibly into slightly higher elevations characterized by Borrichia-Batis-Monanthochloe, which in turn grades upward into a community of Spartina spartinae. Differen-

Figure 48. Spartina spartinae inland from Port Mansfield.

Figure 49. Saline vegetated flat between Brownsville Ship Channel and the Rio Grande. Vegetation includes Borrichia, Monanthochloe, Spartina spartinae and scattered Opuntia.

tiation of marshes and saline flats is based principally on interpretation of photographic signatures 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 undergo flooding frequently enough to support assemblages of water-tolerant trees and shrubs were delineated as fluvial woodlands (fig. 50). These fluvial woodlands areas are distinguishable on aerial photographs by slight color variations, which indicate wetter conditions in the fluvial woodlands than in adjacent topographically higher woodlands. The woodlands at the higher elevations may occasionally be flooded but usually less often than their mapped counterparts.

Fluvial woodlands include such trees and shrubs as *Parkinsonia aculeata*, *Acacia farnesiana*, *Salix nigra*, *Celtis* spp., *Tamarix* sp., *Ulmus crassifolia*, *Sepium sebiferum*, *Sabal* sp., *Washingtonia* sp., *Phoenix* sp., *Baccharis halimifolia*, *Sesbania* spp., *Prosopis glandulosa*, and *Fraxinus* sp.

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. Although similar to swamps, these depressions are generally small and are drier than swamps. Water-tolerant trees associated with the depressions include those listed above for 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 and meander scars that spot the coastal plains to deflation troughs or flats that are common on the eolian plain in the northern part of the Brownsville-Harlingen map area. Woodlands associated with man-made ponds, reservoirs, and stock tanks also are shown on the map.

Descriptions of Major Wetland Areas

Wetlands Associated with Modern-Holocene Fluvial-Deltaic Systems

The Rio Grande, unlike the Trinity and Nueces Rivers, which lie within entrenched valleys, is similar to the Brazos River in that it has essentially filled, with Modern-Holocene fluvial sediments, a broad valley that was incised when sea level was lowered during the Pleistocene (fig. 51). A surface transect across the fluvial-deltaic system reveals, in addition to the current course of the Rio Grande, numerous abandoned water filled channels or courses, locally called resacas, as well as oxbow lakes, mud-filled channels, interdistributary flood basins, broad wind-tidal flats, deflation flats and associated clay dunes.

The heart of the Holocene-Modern deltaic system as shown in figure 9, extends from Brazos Island inland to near the city of Los Fresnos, and includes South Bay, Laguna Larga, Bahia Grande, San Martin Lake, Loma Alta Lake, and Brownsville Ship Channel (pl. V). The most extensive map units are the barren wind-tidal flats that cover broad areas on each side of Brownsville Ship Channel. Many of the wind-tidal flats were flooded when the November 1979 aerial photographs, on which much of the area was mapped, were taken. Most of the flats were dry, however, on 1983 supplementary photographs taken in February. The topographically lower wind-tidal flat map unit may include some areas that are more frequently submerged than subaerially exposed, which would normally place them in the shallow subaqueous flat map category. Because of the dynamics of these areas and the difficulty of determining which flats are normally submerged, the low wind-tidal flat map unit was assigned to these areas. Higher, barren flats fringe many of the lower ones, particularly around the numerous clay dunes such as at Los Montes (pl. V), and on the fringes of dredged spoil placed along the Brownsville Ship Channel. Where the wind-tidal flats contact South Bay, they are outlined by a narrow band of black mangrove (pl. V).

Inland from Los Montes the flats grade into an area mapped as distal salt-water marshes, flats with scattered salt marsh vegetation, and into slightly higher transitional areas or

Figure 50. Woodlands along a water-filled abandoned channel (Resaca de los Cuates) of the Rio Grande.

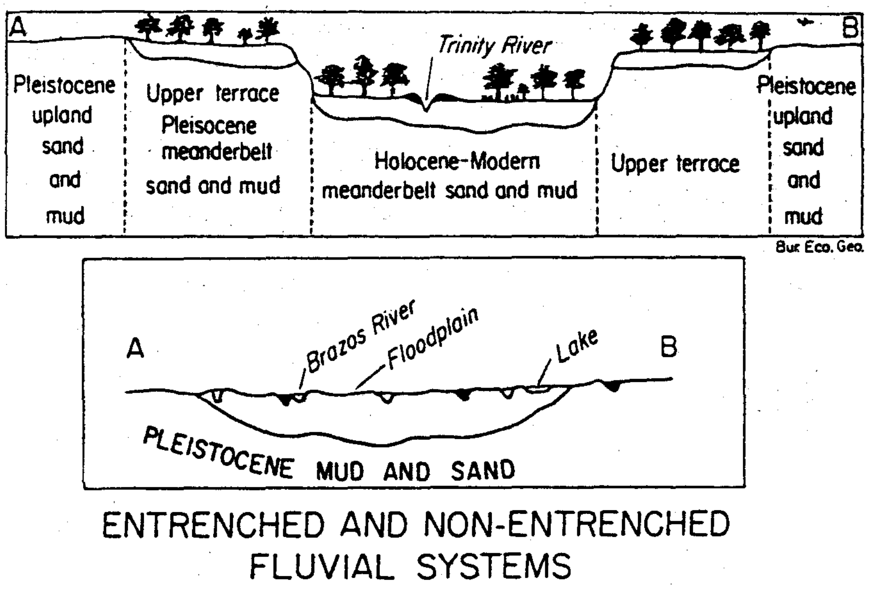


Figure 51. Cross sections of the Trinity and Brazos Rivers showing entrenched and non-entrenched fluvial systems (after Fisher and others, 1972).

vegetated saline flats. Salt-water marsh vegetation includes *Batis maritima*, *Salicornia* sp., *Monanthochloe littoralis*, *Suaeda* spp., *Borrichia frutescens* and others (table 16). The transitional areas or vegetated saline flats in this area are higher in elevation and have developed on distributary channel levee and crevasse splay deposits (Brown and others, 1981). *Cactii*, *Opuntia* sp., occur scattered over these higher predominantly *Borrichia* flats indicating infrequent flooding and a lower water table.

The isolated, small, circular, high brackish-water marsh just south of the Brownsville Ship Channel near its connection with Bahia Grande, is surrounded by clay dunes. The dominant vegetation in this unique area is *Borrichia frutescens* ringed along its upland margin by a narrow belt of *Monanthochloe littoralis*, which grades into an upland band of *Spartina cynosuroides*, and then brush that covers the clay dunes.

North of the Port Brownsville Channel, the most extensive salt-water marshes occur along the gulfward lobe of San Martin Lake. One of the best developed stands (prior to a freeze in December 1983) of black mangroves (*Avicennia germinans*) occurs along the inland margin of San Martin Lake near its connection with the Ship Channel. Along the margin of the lake farther away from the Ship Channel, proximal salt-water marshes become dominant. In higher areas the proximal marsh grades into distal marshes and flats with scattered marsh vegetation.

Around the upper lobe of San Martin Lake, which receives fresh- and brackish-water inflows, brackish-water marshes occur. The use of the brackish-water marsh map unit here is based on the growth of *Typha* sp. in some depressions plus the occurrence of extensive stands of *Scirpus maritimus* along Highway 48. However, on the surrounding flats a more saline vegetation assemblage occurs, much of which was mapped as transitional areas or vegetated saline flats.

Brackish-water marshes in more inland areas north of Loma Alta Lake include extensive *Spartina spartinae*, as well as *Paspalum vaginatum*, *Typha* sp., and *Borrichia frutescens*, and more saline species such as *Batis maritima*.

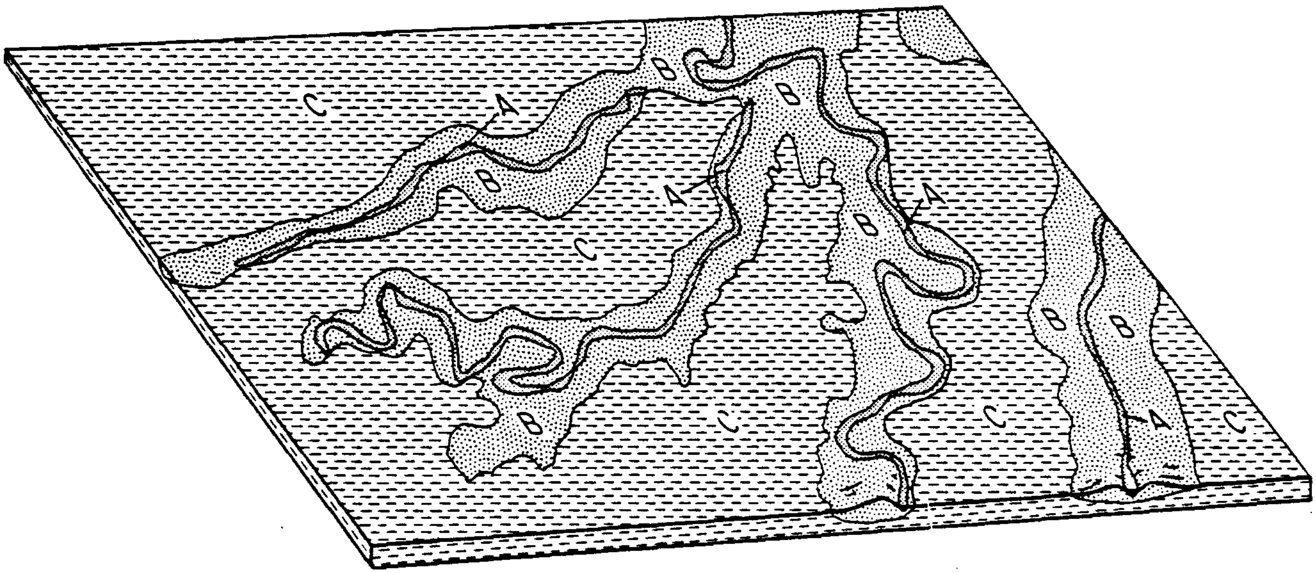
An interesting, repeating pattern occurs in map units between Laguna Vista Cove and Loma Alta Lake. The pattern is caused by a series of relict distributary channels and flanking levees that prograded toward the southeast forming divides that separate the interdistributary lows mapped as vegetated saline flats (or transitional areas) and barren flats (in upper Bahia Grande) (fig. 52). Where vegetated, these areas contain a saline vegetational community that is similar to distal salt-water marshes. For example, the vegetation on the flat that extends inland across Highway 100 from Laguna Larga includes mixtures of *Batis maritima*, *Salicornia* sp., and *Monanthochloe littoralis*, among others. The transitional areas or vegetated saline flats in more inland areas north of Loma Alta Lake contain similar assemblages as well as extensive *Spartina spartinae* in slightly higher areas.

The relict distributary channels that mark the centers of the upland depositional features that divide the flats, are vegetated with brackish-water species including *Spartina spartinae*. Along many of the channels, depressions pond water and provide a setting for low brackish-water marshes. Along other segments of the channels high brackish-water marshes, transitional areas and woodlands occur.

Inland from the Modern-Holocene deltaic system is the fluvial system (fig. 9). The majority of the wetlands occur in relict sinuous abandoned channels and courses, and associated meander scars and oxbow lakes. Wetlands in most of these relict Rio Grande channels are characterized by open water lined with narrow bands of fluvial woodlands, and locally fresh-water marshes. Marsh vegetation includes *Typha* sp., *Eleocharis* sp., *Scirpus* sp., and many others. Woodlands that line the channels include *Salix nigra*, *Acacia farnesiana*, *Parkinsonia aculeata*, *Celtis* spp., *Tamarix* sp., *Baccharis halimifolia* and others (table 16).

Wetlands in and Near Laguna Atascosa National Wildlife Refuge

In the vicinity of Laguna Atascosa National Wildlife Refuge between the Arroyo Colorado Cutoff, Laguna Vista Cove and Resaca de los Fresnos a wide variety of wetlands occur. Broad low wind-tidal flats extend inland from the margins of Laguna Madre between the Arroyo



Depositional Unit	Typical Map Unit
A. Abandoned distributary channel	Brackish-water marshes Transitional areas Woodlands
B. Levee and crevasse splay deposit	Uplands Transitional areas
C. Interdistributary basins	Salt-water and brackish-water marshes Vegetated saline flats and transitional areas Sand or mud flats

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Figure 52. Typical units mapped in the Modern-Holocene deltaic system. Note the repetitive pattern of units across the figure. (Depositional units modified from Brown and others, 1980.)

Colorado Cutoff and Gabrielson Island. Bordering the lagoon margin of the flats, particularly along southward facing shorelines of shallow landward projecting embayments or inlets such as those just north of Rincon de Guajardo, salt-water marshes, mangrove marshes, and flats with scattered marsh vegetation occur in narrow peripheral belts. The broad wind-tidal flats are interrupted in many areas by large brush covered upland clay dunes (fig. 53). Examples of the dunes are Rincon de Guajardo, Red Head Bluff, and Horse Island. Almost continuous bands of high barren flats outline most of the upland margins of the lower more frequently flooded wind-tidal flats. Many of the broad low mud flats were flooded at the time the November 1979, mapping photographs were taken.

Along Cayo Atascosa near the Arroyo Colorado Cutoff, salt-water marshes occur. Species include Distichlis spicata, Batis maritima, Sesuvium portulacastrum, Monanthochloe littoralis, scattered Borrichia frutescens, and others.

Inland from Cayo Atascosa and Laguna Atascosa a complex network of wetlands composed of water-bodies, brackish-water marshes, transitional areas or vegetated saline flats, and barren flats occur (pl. V). Adding to this spatially complicated network of wetlands are numerous clay dunes, the larger of which fringe the northern margin of Laguna Atascosa. Much of this complex wetland-upland system owes its existence to the relict Rio Grande channel--Resaca de los Cuates--which, when active, prograded northward across this area depositing broad flanking levees that constitute an upland divide separating Laguna Atascosa and Laguna Madre. An older, smaller fluvial-deltaic channel to the east constructed a similar upland divide separating the shallow embayment between Stover Cove and Port Isabel Municipal Airport from Laguna Madre (pl. V). The sinuous abandoned channels are the sites of brackish-water marshes vegetated along much of their lengths by Borrichia frutescens, Spartina spartinae, locally Typha sp., Scirpus sp., and other fresh- to brackish-water species. In some areas, species characterizing more saline conditions occur. Along more inland reaches of Resaca de los Cuates, woodlands characterized by many of the species listed in table 16 fringe the channels (fig. 50).

Figure 53. Brush-covered clay dune in Laguna Atascosa National Wildlife Refuge. Laguna Madre is in distance to right above clay dune; ponded water and brackish-water marsh is to left of dune.

The extensive belt of wetlands along the landward margins of Cayo Atascosa and Laguna Atascosa typify the setting that occurs in many areas of this semi-arid region. The water in the impounded Laguna Atascosa and associated water bodies seems to fit a fresh to brackish designation. Salinities in the spring of 1984, a drier period, typically ranged between 8 and 12 parts per thousand (Randall Moss, Oklahoma State University, personal communication, 1984). The water bodies are fresh enough for wildlife to drink (Gary Burke, Refuge Manager, personal communication, 1984). The salinities, however, fluctuate in accordance with climatic variations. Salinities in flats that extend outward from the water bodies are expectably much higher. The gradation from fresh to more saline species over a short distance at many locations in the Brownsville-Harlingen area is a common occurrence and presents somewhat of a mapping dilemma. Although these areas are typically designated as brackish, they encompass a broad spectrum of salinities ranging from almost fresh to saline from the ponded water to the adjacent vegetated flats.

Marshes that occur in areas of the National Wildlife Refuge, locally contain fresher species such as *Typha* sp., *Scirpus californicus*, and *Scirpus maritimus* near water bodies, but the vegetation typically grades into areas characterized by more saline species including *Distichlis spicata*, *Borrichia frutescens*, *Monanthochloe littoralis*, *Batis maritima*, *Salicornia* spp., *Suaeda* spp., *Lycium carolinianum*, *Heliotropium curassavicum*, and into higher areas of *Spartina spartinae*, among others. The more saline species grade out onto the extensive flats mapped along the inland border of the refuge. Broad areas of the flats are barren of vegetation and were mapped as high flats. In the past these flats were apparently occasionally flooded during extremely high tides by saline waters from Laguna Madre. A dam on Cayo Atascosa currently restricts waters from Laguna Madre from entering Laguna Atascosa and the adjacent inland flats. A similar vegetation setting characterizes the shallow impounded lake between Stover Cove and Port Isabel Municipal Airport.

In more inland areas outside of the Refuge, brackish and saline conditions extend into the vicinity of Cross and Sweeney Lakes. Vegetation along the margins of the lakes has a brackish to saline assemblage including Batis maritima, Borrichia frutescens, Spartina spartinae and others (fig. 54). Locally, Typha sp., is present; extensive (based on photographic analysis) stands of Typha sp. appear to be present in Sweeney Lake. In terms of the geologic setting, Sweeney and Cross Lakes occur just north of the edge of the Holocene-Modern Rio Grande fluvial-deltaic system, on Pleistocene substrates (Brown and others, 1980).

Wetlands in the Vicinity of the Arroyo Colorado Delta

The Arroyo Colorado is an entrenched headward eroding stream that has been dredged along much of its gulfward length. Most of the water flows through the Arroyo Colorado Cutoff. The "inactive" Arroyo Colorado delta plain that lies north of the Cutoff (pl. V), is a complex area where the interactions of fluvial, deltaic, and eolian processes have produced a spatially complex morphology with juxtaposed environments that range, topographically, from near sea level to more than 30 ft (9 m) above sea level. Abandoned natural levees along distributary channels have continued to aggrade, perhaps occasionally through reactivation of distributaries during floods, but more importantly through the accumulation of silt and clay blown from adjacent wind-tidal flats. The result is a complex maze of clay-dune uplands around which occur a variety of topographically lower environments including barren wind-tidal flats, sparsely and densely vegetated salt-water marshes, brackish-water marshes, transitional areas, and saline flats.

Most of this inactive delta grades into broad wind-tidal flats that slope gently toward the submerged areas of shallow Laguna Madre where marine grasses are common. Just northwest of the intersection of the Arroyo Colorado Cutoff and the Intracoastal Waterway along a small embayment partially enclosed by dredged spoil, proximal salt-water marsh fringes lagoon waters. Vegetation includes Batis maritima, Sesuvium portulacastrum, Salicornia spp., Distichlis spicata, Monanthochloe littoralis, Borrichia frutescens, Limonium nashii, Suaeda spp., and *Avicennia germinans*. Aerial photographic analysis indicates that black mangroves (*Avicennia germinans*) are dominant in some areas; these areas were mapped as mangrove salt-marshes.

In more inland areas between the Arroyo Colorado Cutoff and the Arroyo Colorado, distal salt-water marshes occur, characterized by *Borrichia frutescens*, *Monanthochloe littoralis*, *Batis maritima*, *Salicornia* spp., *Distichlis spicata*, and others listed in table 16. Higher areas, more removed from these saline marshes, become brackish and *Spartina spartinae* and *Borrichia frutescens* are more likely to predominate, although grading into flats vegetated with more saline species.

Most of the inactive distributary channels are characterized by barren, high flats and sparsely to moderately vegetated flats. These latter areas were mapped as sand or mud flats/marshes, undifferentiated.

Near the mouth of the Arroyo Colorado, fresh-water inflows, both from the Arroyo and the North Floodway (fig. 4), meet waters of saline Laguna Madre. The presence of *Phragmites australis* along the main channel of the Arroyo indicates brackish-water conditions occur. Generally, where stands of *Phragmites* could be distinguished on photographs, the brackish-water marsh unit was mapped. Salt-water and brackish-water marshes intergrade. Species composition in this area is a combination of those species listed in table 16 under salt-water and brackish-water marshes, with more brackish species fringing the water and grading onto adjacent flats into more salt-tolerant species.

Inland toward the mouth of the North Floodway high brackish marshes occur; lower brackish marshes fringe water bodies. The high marshes locally grade into transitional areas. The dominant species in this area appears to be *Spartina spartinae* in both brackish high marshes and slightly higher transitional areas.

Wetlands Extending Inland from the Arroyo Colorado - Fourmile Slough Area

Some of the most extensive wetlands in the Brownsville-Harlingen area extend from the margin of Laguna Madre inland north of the North Floodway (pl. V). An interesting southeast-northwest linear belt of wetlands marks the northeast boundary of this wetland zone, where it contacts the Holocene-Modern eolian system, characterized predominantly by upland vegetation-stabilized sand dunes (Brown and others, 1980).

From the margins of Laguna Madre, broad wind-tidal flats are cut by water-filled channels in the vicinity of Mullet Island and Fourmile Slough (pl. V). Proximal salt-water marshes fringe the channels and grade into flats with scattered vegetation (mapped as sand or mud flats/marshes, undifferentiated). The low broad wind-tidal flats wind through a maze of upland clay dunes that were mapped by Brown and others (1980), and that can be distinguished on plate V by closely-spaced contour lines. Most of these upland dunes are outlined with narrow belts of higher barren flats.

Inland, west of Hawk and Mullet Islands, transitional areas and sparsely vegetated saline flats cover broad areas, and grade, locally, into barren high flats. Depressed areas that are normally wetter than the surrounding saline flats were mapped as high brackish-water marshes; vegetation includes *Spartina spartinae* grading into more saline flats where vegetation includes *Monanthochloe littoralis*, *Batis maritima*, *Borrichia frutescens*, *Suaeda* spp. and others listed in table 16. These areas are at the saline end of the brackish-water marsh salinity spectrum and perhaps could have been mapped as distal salt-water marshes. Central areas are often low enough to contain standing water or saturated soils and were mapped as low brackish-water marshes. Low brackish-water marshes may contain dense stands of *Typha* sp. (fig. 55), as well as *Paspalum vaginatum*, and *Eleocharis* spp. These fresher areas grade outward into slightly higher more saline areas where vegetation includes *Borrichia frutescens*, *Distichlis spicata*, *Monanthochloe littoralis*, and scattered *Batis maritima*, *Limonium nashii*, *Salicornia* sp., and *Lycium carolinianum*. The *Distichlis* and *Borrichia* may intergrade along the margins with the

Figure 54. Brackish-water marsh in abandoned channel (Resaca de los Fresnos) just south of Cross Lake. Vegetation includes Batis and Borrichia.

Figure 55. Typha and Paspalum vaginatum in a brackish-water marsh inland from Port Mansfield.

Typha sp. (fig. 56). A salinity measurement in ponded water in such an area along Highway 186 about 1.5 mi (2.4 km) from Port Mansfield registered about 5 parts per thousand. Spartina spartinae (fig. 48) is another species that occurs extensively in this area, both in high brackish-water marshes and transitional areas.

The numerous, circular and elliptical shaped wetlands in the area between the North Floodway to just north of Highway 186 occupy Pleistocene fluvial mud-filled channels and entrenched meanderbelt sands (Brown and others, 1980). The linear and sinuous alignment of many of these wetlands mark the courses of these relict fluvial channels. Wetlands include water, high and low fresh-water marshes, brackish-water marshes, woodlands and transitional areas. Estacas Lake and the adjacent arcuate channel extending toward the town of Willamar (pl. V) are examples of large abandoned Pleistocene channels. Wetlands in this particular channel include high brackish-water marshes, water, and transitional areas. Vegetation includes Monanthochloe littoralis, Borrichia frutescens, Suaeda spp., Distichlis spicata, and Batis maritima. The large circular wetland just gulfward of Estacas Lake is an example of a wetland in a Pleistocene entrenched meanderbelt sand with the relict grain of the once active, migrating channel preserved (Brown and others, 1980). The relict accretionary ridges are tree covered and were mapped as woodlands in fluvial areas and poorly drained depressions. Although most of this large circular feature was mapped as low fresh-water marsh because of the extensively wet conditions shown on the 1979 aerial photographs, there appear to be many scattered trees in the depression.

Wetlands in the southeast-northwest oriented linear belt near the gulfward margin of the large El Jardin depression north of Highway 186, occupy a wind deflation area (Brown and others, 1980). This topographically low corridor apparently serves as a floodway during extensive aftermath rains that accompany tropical cyclones. Wetland types range from open water, to low and high fresh-water marshes to transitional areas. Although wetlands mapped in El Jardin include a central area of low fresh-water marsh grading outward into higher marshes, it should be reemphasized that conditions are relatively wet on the 1979 photographs used in mapping the wetlands. This depression, as with others in this semiarid region, could be mapped as a high marsh and transitional area during drier climatic cycles. Clay dunes that border the leeward side of El Jardin indicate a past history (perhaps ancient past) of occasional drying to the extent that the floor of this circular basin became a barren dry flat and the source of the windblown silt and clay that accumulated along its downwind (with respect to prevailing southeasterlies) margin.

Farther to the northwest of El Jardin, the corridor or belt of small circular wetlands broadens in an inland direction. These wetland depressions, most of which have probably originated through wind deflation, are surrounded by rolling dune topography vegetated with thick brush, or prairie grasslands in cleared areas. The wetlands follow a broad belt that extends off the northwest corner of the map sheet just north of La Sal Vieja (pl. V).

La Sal Vieja is a saline lake surrounded along much of its margin by barren flats. Salinity measurements by Texas Department of Water Resources (1971) of water in La Sal Vieja in the late 1960's indicate very saline conditions. Brackish high marshes mapped along the western extension of this lake are vegetated principally by Monanthochloe littoralis. Other species included Suaeda sp., Heliotropium curassavicum, Salicornia sp. and Borrichia frutescens. Many dead tree stumps occur in the western projecting arm of this lake (fig. 57). The brackish marshes are at the saline end of the salinity spectrum encompassing mapped brackish areas and could have been mapped as salt marshes. La Sal Vieja is flanked on its northern margin by large clay dunes defined by contour lines on plate V.

Modern-Holocene Eolian System

The eolian system extends northwestward from the Port Mansfield area and corresponds approximately to the area shown as Pleistocene deltaic and younger fluvial system beneath eolian deposit shown in figure 9. From the margins of Laguna Madre near Port Mansfield is an area of concentrated clay dunes (mapped as uplands) and deflation flats (mapped as wind-tidal

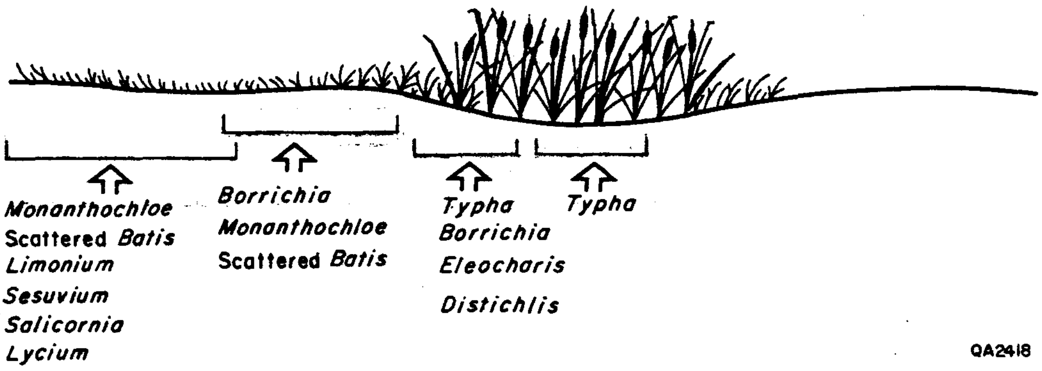

Figure 56. Zonation of vegetation in a brackish-water marsh inland from Port Mansfield.

Figure 57. Marsh composed predominantly of Monanthochloe littoralis along the inland margins of La Sal Vieja.

flats). Locally, spatially complex networks of barren flats and upland gullied clay dunes were mapped together as wetland/upland areas, undifferentiated.

This area between the southeast-northwest oriented channel that is located between Port Mansfield and Estacas Lake is the point of origin of the Modern-Holocene eolian system, that broadens to the northwest in alignment with the prevailing southeasterly winds that are the primary driving force of this complex dune system (fig. 58). The numerous small fresh-water marshes that occur in this area owe their existence to the deflation depressions left behind as active sand dunes migrate downwind to the northwest (fig. 58). These wetlands abruptly end along a southwest-northeast oriented front (pl. V). Northwest of this front, shrub and live-oak motte stabilized sand dunes provide a rolling topography of uplands whose highly permeable substrates are virtually barren of wetlands. The linear belt of wetlands that extend along the edge of El Jardin are not a part of, but mark the inland edge of this modern dune system.

Modern Barrier System

The modern barrier system is made up of South Padre and Brazos Islands (fig. 4; pl. V). Mapped wetlands are dominated by broad wind-tidal flats, particularly north of La Punta Larga on the back side of Padre Island, that slope gently toward Laguna Madre. The flats are connected to the Gulf beach through numerous storm washover channels. In most areas the channels grade imperceptibly into the wind-tidal flats, which are also washed over during storms. The division between these map units 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 (1980) and Weise and White (1980).

Large back island active dune complexes occur on the flats in the vicinity of Deer Island and northward. The dune complexes are generally made up of long narrow east-west oriented oblique dunes and interdune flats. Because of the cartographic complexity of showing the

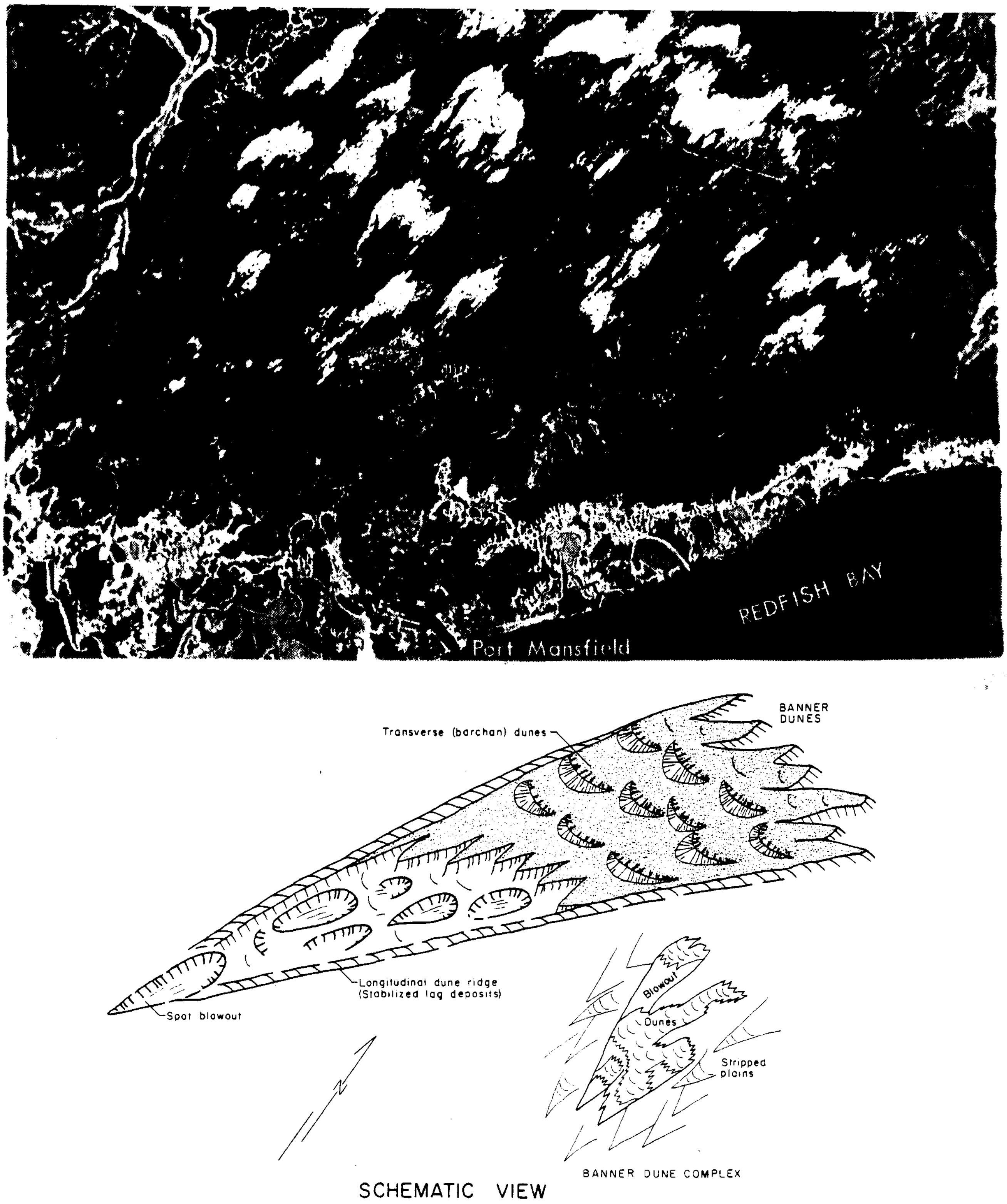

Figure 58. Active banner dune field, eolian system, Brownsville-Harlingen map area. Banner dunes within the South Texas eolian system are composed of a unique kind of large parabolic dune complex with smaller barchan dunes within the sand field. Strong relict grain of earlier base-leveled dunes indicates long history of dune activity. Aerial photograph is of the Modern-Holocene eolian system west of Port Mansfield. Schematic view illustrates the various features that compose an individual banner dune (from Brown and others, 1980; after Price, 1958; and Scott and others, 1964).

interlying flats and upland dunes separately, they were mostly mapped together as uplands. An exception is the dune field gulfward of Deer Island (pl. V). In this dune field the interlying flats were mapped to exemplify the complexity of these areas.

Locally, in mid-island areas brackish-water marshes occur in interlying swales between vegetated dunes and barrier flats. *Spartina spartinae* is common in some of these areas but other species include *Scirpus* sp. and *Eleocharis* sp. In some instances, conditions are fresh enough to support *Typha* sp. It should be reemphasized that transitional areas, which probably correspond to vegetated barrier flats in many areas, were not mapped on the barrier islands for cartographic simplicity.

A unique small brackish-water marsh occurs along the lagoon margin of Padre Island about 5 mi (8 km) north of Brazos Santiago Pass. Apparently fresh water discharges in this area from a small water-sewage treatment facility has produced a marsh where *Typha* sp., *Scirpus maritimus*, and *Scirpus americanus* grade lagoonward into *Batis maritima* and a narrow belt of *Spartina alterniflora* along the intertidal margin of Laguna Madre (fig. 59). This area and the small salt-water and mangrove marshes near the Queen Isabella Causeway are among the very few areas where *Spartina alterniflora* occurs in this semiarid region.

On the bayward side of Brazos Island, black mangroves occur in narrow bands along the margin of South Bay and along washover channels containing open water. Relict accretionary features in bayward areas of Brazos Island are composed of parallel ridges and swales. The swales are occasionally flooded and are the sites of barren sand flats, and flats with scattered salt-water marsh vegetation. Mesa del Gavilan is another accretionary feature, but the swales are typified by vegetated saline flats, which are mapped together with the upland ridges on plate V.

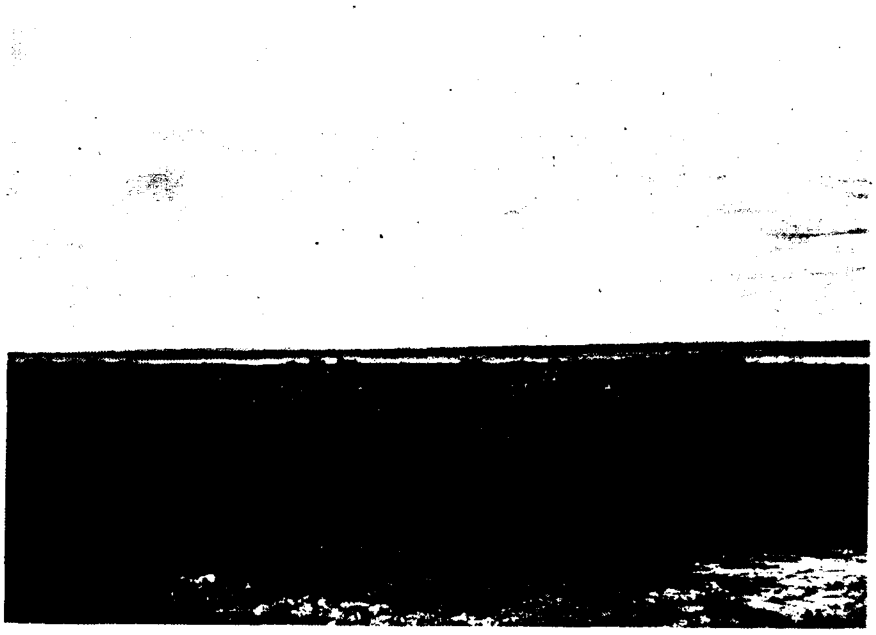

Figure 59. Brackish-water marsh on South Padre Island. Vegetation includes Scirpus maritimus, Scirpus americanus, Typha sp., Spartina patens, Distichlis spicata and Borrichia frutescens. Along the margins of Laguna Madre in distance, is a fringe of salt-water marsh composed of Spartina alterniflora and Batis maritima.

Changes in Wetland Distribution, 1960 to 1979-83

General changes in the distribution of wetlands can be determined by comparing plate V and the Environments and Biologic Assemblages Map of the Environmental Geologic Atlas--Brownsville-Harlingen Sheet (Brown and others, 1980). Most of the aerial photographs used in the coastal atlas project were taken in 1960, and for the submerged lands project (pl. V), in 1979 (and a few in 1983). Changes in natural environments, then, reflect this approximately 20-year period. Caution must be used in making comparisons, however, because the 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 15). Thus, direct, specific comparisons of changes in the distribution of all map units cannot accurately be made; general comparisons in selected areas can be made and are presented below. Some changes reflect the interpreter's ability to make more refined judgments using the more recent color-infrared photographs.

Modern Barrier Island System

The predominant wetland unit mapped on the modern barriers--Padre and Brazos Islands were the extensive wind-tidal flats and washover areas. A visual comparison of these units indicates no major changes that cannot be explained by differences in mapping criteria and assigned map units. Scattered small brackish- and salt-water marshes shown on plate V and not shown on the Environmental Geologic Atlas are due more to mapping conventions and quality of the more recent photographs than to an expansion of these marshes. The narrow band of black mangrove marshes fringing the bayward side of Brazos Island were apparently included with the tidal flat unit on the environmental atlas. A spread of marine grasses onto previously mapped wind-tidal flats due to submergence of the flats as described by White and others (1978) for Mustang Island, has apparently not occurred to the extent that it can be determined by a qualitative visual comparison. In some areas such as between La Punta Larga and Brazos Santiago Pass, marine grasses may have actually retreated lagoonward due to the deposition of storm washover fan deposits along the edge of the flats. In developed areas near the south end of Padre Island, dredged navigation channels adjacent to the shoreline have displaced some marine grasses. More quantitative methods are required to determine the extent of these changes that have occurred along the modern barrier-island shorelines.

Bay-Estuary-Lagoon Margins

A comparison of the general changes along the bay-estuary-lagoon margins (excluding the barrier islands) indicates an increase in the distribution of salt-water and mangrove marshes. The true extent of these increases is not possible to determine because they occur primarily along narrow belts and, where present, were apparently mapped with the wind-tidal flats on the environmental atlas map. However, a comparison of the 1960 photographs with those taken in 1979 does indicate a definite increase in marsh vegetation along the lagoon margins.

Among the more extensive increases are those that occurred in the vicinity of Mullet Island and Fourmile Slough between the Arroyo Colorado and Port Mansfield. A relatively broad belt of proximal salt-water marshes occurs along the landward projecting water filled inlets. In this area marshes were not mapped on the environmental atlas. The expansion and growth of marshes may reflect a slight rise in water levels and more frequent inundation in this area where salinities are moderated by fresh- to brackish-water inflow from the Arroyo Colorado and North Floodway.

A comparison of 1960 photographs with 1979 photographs indicates a slight increase in the distribution of marine grasses in some areas such as in the vicinity of Rattlesnake Island. This spread of marine grasses (also reported by Chin, unpublished manuscript) may indicate a relative rise in sea level due to compactional subsidence (Swanson and Thurlow, 1973), similar to that noted on the bayward side of Mustang Island reported by White and others (1978).

Scattered salt-water marsh vegetation occurs on flats surrounding spoil islands lining the intracoastal waterway south of Port Mansfield channel. Although the environmental atlas designates these areas as spoil deposits, a comparison of the 1960 photographs with those taken in 1979 indicates slight to moderate increases in marsh vegetation including mangroves, on the spoil island flats.

Except for the marginal belts of salt and mangrove marshes that locally line the lagoonward margins of the broad wind-tidal flats between Port Mansfield and Gabrielson Island, the tidal flats on plate V and the earlier atlases appear to cover similar areas. The exceptions are in more inland reaches which are discussed in the following section.

Inland Areas of the Coastal Plain

In the vicinity of Laguna Atascosa National Wildlife Refuge including that part north of the Arroyo Colorado Cutoff, salt-water and brackish-water marshes are much more abundant on plate V than on the maps in the earlier atlas. Part of the increase is due to differences in mapping criteria (and perhaps moisture conditions) used in the two projects. For example, many of the areas adjacent to Laguna Atascosa and Cayo Atascosa mapped in this project as brackish-water marshes were included within saline grasslands on the earlier atlas. Thus, it is difficult to make an accurate comparison of the marsh changes. However, boundaries of the saline grasslands inland from Laguna Atascosa, shown on the earlier Environments and Biologic Assemblages Map, are almost identical to the areas mapped as transitional or vegetated saline flats and barren flats on plate V.

In the vicinity of the Arroyo Colorado delta plain, and inland from Hawk Island, extensive wind-tidal flats mapped on the earlier atlas include broad sparsely vegetated saline flats (or transitional areas), but also distal salt-water marshes, and in more inland areas brackish water marshes shown on plate V. Much of the increase in marshes and vegetation on saline flats may be due to the interpreters ability to distinguish vegetation from dark algal mats on the 1979 color infrared photographs. Nevertheless, much of the increase in vegetation is real, and may be related to wetter conditions in the late 1970's prior to the period the 1979 aerial photographs were taken.

The extensive brackish-water and fresh-water marshes and transitional areas on the coastal plain north of the North Floodway shown on plate V, lie within areas mapped on the earlier atlas as (1) poorly drained depressions, which occasionally pond water, and (2) fresh to saline water bodies, which include landlocked ponds and playas. Accordingly, the apparent increase in wetlands shown on plate V is more a result of differences in mapping conventions and map unit designations, which favored geological units on the earlier Environmental Geologic Atlas.

Modern-Holocene Fluvial-Deltaic System

Comparisons of the Environmental Geologic Atlas map with plate V reveal obvious differences in the distribution of salt- and brackish-water marshes in the vicinity of the Brownsville Ship Channel on the Modern-Holocene deltaic system (fig. 9). Most of the marshes occur in areas mapped as saline grasslands on the earlier atlas, and perhaps reflect, in part, wetter conditions in the late 1970's. However, along the margins of San Martin Lake, mangroves and salt- and brackish-water marshes appear to have spread into areas previously mapped as barren wind-tidal flats. Changes in municipal and agricultural discharges into San Martin Lake, particularly along the more inland lobe, may have contributed to the spread of marshes. Extensive transitional and vegetated saline flats, shown on plate V, generally fall within the broad region of saline grasslands shown on the earlier atlas. In the more inland fluvial deltaic system, there is relatively close correspondence between wetlands in the resacas shown on plate V, and on the earlier atlas where the resacas generally were mapped as fresh and saline water bodies and frequently flooded fluvial areas.

Summary of Changes

In summary, a general visual comparison of wetlands shown on maps from the Environmental Geologic Atlas (Brown and others, 1980) with wetlands depicted on plate V of this report, reveals that among the changes that have occurred, at least locally, in the Brownsville-Harlingen area are:

(1) the spread, locally, of marshes including mangroves along the margins of wind-tidal flats,

(2) the erosion of subaerial spoil and encroachment of marsh vegetation along spoil island margins and flats,

(3) the spread, locally, of marine grassflats near the mainland shore of Laguna Madre,

(4) the displacement of marine grassflats along the back of Padre Island by dredged channels and local storm washover deposits.

For the most part, changes in wetlands are difficult to determine when comparing plate V and the earlier Environmental Geologic Atlas because of differences in map units and mapping criteria, which are in part reflective of the differences in quality of the 1979 color infrared stereopair used in this project, and the 1960, black and white, monoscopic photomosaics used in the earlier project. Still, some changes such as the spread of marsh vegetation along lagoon margins, and the spread of marine grasses in some areas near the mainland shore of Laguna Madre, can be verified by comparing photographs taken in 1960 and 1979. These changes may reflect compactional subsidence and relative sea-level rise postulated by Swanson and Thurlow (1973). In addition some changes can be attributed to contrasting climatic conditions manifested by droughts in the 1950's and above normal precipitation in 1979. In addition tidal levels reflected on the 1979 photographs were above normal.

Human activities have caused some changes, (Finley, 1978). It is a common practice to drain fresh-water wetlands in this agricultural region to increase the area over which crops can be grown. A more detailed analysis of wetlands, such as through historical monitoring, which would include quantitative areal determinations and comparisons of past and present wetlands, would provide data for a more critical appraisal of the extent, causes and significance of wetland changes in the Brownsville-Harlingen area. The U.S. Fish and Wildlife Service's Biological Services Program is in the process of digitizing and planimetering national wetlands inventory maps prepared from 1950's and 1979 vintage photographs. The results of this project for the entire Brownsville-Harlingen area are not yet available, but should provide additional information on wetland changes.

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A field and laboratory investigation of this magnitude requires the support of many people, some performing specific tasks and others providing the principal technical support throughout the duration of the project. The following list of major tasks and primary participants applies to the seven-atlas study as a whole, and not necessarily specifically to the Galveston-Houston atlas.

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 provided some assistance with shelf sampling.

Textural analyses of sediment were done by the Sedimentology Laboratory of the Bureau of Economic Geology by H. Seay Nance, Research Associate-in-Charge, Rick Dauzat, and Tom C. Freund. Geochemical analyses of sediment were performed by the U.S. Geological Survey. 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. 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, and Jeffrey Paine, 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 Katherine E. Schmedes.

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Appendix A
transferred
to Boys City/Project

APPENDIX B: TEXTURAL AND GEOCHEMICAL DATA, BROWNSVILLE-HARLINGEN AREA

ARROYO COLORADO

Sample No.[*]	Textural Analysis Gravel %	Sand %	Silt %	Clay %	Mud %	mean ϕ	Geochemistry TOC %	B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
1	0.00	14.32			85.68		0.9	42	320	6.0	24	20	1.7	530	15	26	230	58
2	0.00	1.16			98.84		1.5	50	210	6.1	24	29	1.4	660	13	30	220	64
3	0.00	1.38			98.62		1.5	78	260	7.0	34	30	2.0	910	17	42	240	94
4	0.00	1.93			98.07		1.0	65	240	6.0	29	29	1.8	560	15	37	220	82
5	0.00	24.93			75.07		0.6	47	260	5.6	22	23	1.5	770	13	18	230	55
6	0.00	19.08			80.92		0.7	65	350	7.6	34	25	1.8	730	16	22	250	77
7	0.00	22.39			77.61		1.1	48	270	5.4	28	20	1.6	570	13	19	190	51
8	0.00	2.00			98.00		1.0	71	240	5.4	23	18	1.5	130	15	16	290	58
9	0.00	60.41			39.59		0.4	40	390	6.4	21	18	1.5	440	13	15	260	41
10	0.00	6.81			93.19		1.0	58	290	6.4	23	24	1.5	490	14	18	250	54
11	0.00	51.86			48.14		0.5	48	430	5.7	26	11	1.3	430	11	14	250	28
12	0.00	0.79			99.21		1.2	58	190	4.6	21	18	1.4	360	13	16	180	49
13	0.00	72.44			27.56		0.4	21	440	6.1	14	9.3	1.0	290	37	13	230	<22
14	0.00	0.95			99.05		1.1	63	180	5.0	25	20	1.3	520	13	17	170	73
15	0.00	0.96			99.04		1.5	62	250	6.0	35	19	2.0	640	16	22	230	79
16	0.00	1.23			98.77		1.7	71	190	3.7	23	20	1.2	530	11	16	150	42
17	0.00	1.52			98.48		1.8	60	330	5.8	32	19	1.6	890	16	18	310	63
18	0.00	37.01			62.99		1.0	58	250	5.0	23	17	1.2	440	12	15	240	40
19	0.00	86.95			13.05		0.3	31	300	3.2	29	5.5	0.60	260	6.5	<10	140	25
20	0.00	5.25			94.75		1.6	69	230	4.4	22	19	1.3	450	12	11	210	47
21	0.00	2.32			97.68		1.3	72	260	4.8	24	17	1.2	460	17	15	200	45
22	0.00	3.11			96.89		1.4	63	180	3.3	19	17	1.0	440	8.9	<10	150	58
23	0.00	19.29			80.71		1.1	83	340	5.3	23	17	1.2	530	12	14	180	26
24	0.00	9.87			90.13		1.4	88	270	3.5	21	18	1.2	580	12	13	190	33
25	0.00	0.78			99.22		1.7	110	150	3.9	20	18	1.2	540	11	11	220	32
26	0.00	4.41			95.59		2.3	120	230	4.1	21	16	1.2	600	12	14	290	28
27	0.00	54.09			45.91		0.8	33	340	4.9	14	14	0.96	440	7.3	15	300	56
28	0.00	82.01			17.99		0.6	66	350	2.9	94	55	1.9	260	19	79	150	180
29	0.00	52.65			47.35		0.8	43	350'	6.7	19	9.4	1.1	560	9.8	11	350	28
30	0.00	29.01			70.99		0.9	63	370	4.2	23	15	1.2	550	12	14	180	29

BROWNSVILLE SHIP CHANNEL

Sample No.[*]	Textural Analysis Gravel %	Sand %	Silt %	Clay %	Mud %	mean ϕ	Geochemistry TOC %	B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
1	0.11	27.49	47.65	24.75	72.40	6.00	1.4	36	570	4.8	11	7.5	0.92	360	8.9	19	270	30
2	0.00	10.10	65.72	24.18	89.90	6.29	1.5	100	400	4.9	28	21	1.8	560	17	20	240	42
3							1.4											

[*] 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.)

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

			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
BROWNSVILLE SHIP CHANNEL, cont.																		
4	0.02	6.13	60.46	33.39	93.85	7.13	0.3											
5	0.00	7.07	65.86	27.07	92.93	6.55	0.7											
6	0.00	21.35	54.44	24.21	78.65	6.10	0.6	63	540	7.4	34	19	2.0	640	17	22	350	52
7							1.0											
8	0.19	8.93	57.86	33.02	90.88	6.88	0.6	120	420	7.2	35	28	2.6	700	23	26	330	80
9							0.5	58	540	5.7	22	13	1.4	490	13	17	300	24
10	0.00	6.44	57.36	36.20	93.56	7.01	0.6	87	370	6.7	33	27	1.9	850	17	23	260	71
11							1.1											
12	0.16	42.05	36.59	21.19	57.78	5.48	0.3	74	520	5.7	29	20	2.1	510	21	26	250	67
13							0.6											
14	0.00	25.90	39.72	34.38	74.10	6.49	1.3	65	570	5.7	62	35	1.8	770	16	100	220	270
FOURMILE SLOUGH																		
1																		
2[a]									495	8.67	76.5	15.9	2.64	1140	<25.0	<40.0	626	148
3[a]									487	5.28	44.2	25.1	1.62	572	27.5	<40.0	499	189
LAGUNA MADRE INTENSIVE SAMPLING AREA																		
0.5	0.54	98.10	0.77	0.59	1.36	2.67	0.6	26	270	1.7	1.6	4.1	0.24	110	<4.6	<10	270	<22
1	1.63	80.78	10.70	6.88	17.58	3.34	1.3											
2	2.56	76.89	11.51	9.05	20.56	3.67	1.2	81	360	6.5	15	8.5	0.92	300	6.5	11	390	<22
3	6.88	76.19	9.94	7.00	16.93	3.39	1.0											
4	0.55	67.23	18.17	14.06	32.22	4.34	1.0	93	310	5.4	18	12	0.95	270	7.8	12	360	<22
5	0.84	66.60	20.92	11.64	32.56	4.16	0.7											
6	1.27	59.29	25.86	13.58	39.44	4.29	1.1	61	290	6.5	13	9.2	0.70	340	6.0	11	340	40
7	4.14	73.84	19.31	2.71	22.02	3.31	1.0											
8	1.11	62.39	26.34	10.16	36.50	3.95	1.3	68	380	6.1	17	11	0.95	270	8.1	11	310	<22
9	2.20	71.19	19.72	6.88	26.60	3.55	0.9											
10	1.66	61.17	24.91	12.27	37.18	4.02	1.1											
10.5	0.48	50.30	41.54	7.68	49.22	4.39	0.5	68	420	6.2	20	19	1.2	320	9.4	13	330	22
11	0.62	51.49	36.89	11.00	47.89	4.54	0.5	110	300	4.2	16	13	0.95	330	7.7	<10	290	<22
12	0.06	34.77	44.89	20.28	65.17	5.53	0.6											
12.5	1.63	39.37	37.35	21.66	59.00	5.47	1.0											
13	2.10	44.02	37.44	16.44	53.88	5.17	0.7	130	290	3.5	14	12	0.90	380	8.2	<10	260	<22
14	1.78	73.96	18.09	6.18	24.27	3.35	0.8											
15							1.5											
16	1.17	56.67	30.46	11.69	42.15	4.29	1.0											
17	0.87	71.45	19.87	7.82	27.69	3.69	0.7	57	370	7.2	12	8.7	0.78	230	6.0	14	380	<22
18	2.26	73.71	16.90	7.13	24.03	3.61	0.8											
19	1.71	77.13	13.01	8.15	21.16	3.49	0.6	92	320	4.8	9.2	7.1	0.66	190	4.8	<10	370	<22
20							0.5											
21	0.31	18.24	63.02	18.42	81.45	5.75	2.8	100	220	3.5	17	17	1.0	280	7.9	11	290	<22
22							2.4											

	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 INTENSIVE SAMPLING AREA, 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
23	4.45	86.22	5.02	4.31	9.33	2.75	1.1	64	310	4.1	6.7	5.3	0.59	290	<4.6	<10	340	<22
24	0.31	96.47	1.96	1.26	3.22	2.67	0.2											
25							0.1											
26							0.6	53	290	5.6	5.5	4.8	0.48	140	<4.6	<10	470	<22
27							2.3											
28							1.0	79	310	5.3	15	9.5	0.81	250	7.3	10	330	<22
29							0.8											
30							0.6	89	350	7.9	15	10	0.77	270	5.5	13	450	<22
31							0.8											
32							0.5	57	370	7.2	32	8.3	0.70	160	5.9	<10	470	46
33							0.8											
34							0.8	54	370	5.3	15	10	0.82	260	7.1	<10	290	<22
35							1.7	120	270	5.2	17	15	1.1	370	8.4	<10	360	<22
36							1.7	110	380	8.6	27	17	1.2	400	10	14	440	45
37							1.3											
37.5							1.0	100	380	8.1	30	14	1.0	550	8.6	<10	440	30
38							0.7	49	220	8.3	6.5	5.3	0.45	220	<4.6	<10	780	<22
39							1.0	97	360	7.0	20	16	1.2	410	11	14	390	33
40							0.8											
41							0.9	71	320	5.0	18	14	0.96	380	8.5	<10	330	<22
42							0.6											
43							0.4	28	300	4.9	5.4	4.3	0.44	160	<4.6	<10	310	25
44							0.9											
45							0.7	60	260	8.8	8.6	5.4	0.46	210	<4.6	<10	490	44
46							0.5											
47							0.2	24	280	3.6	2.8	3.3	0.31	130	<4.6	<10	365	<22
48							0.2											
49							0.1											
50							0.3	21	290	3.7	2.9	3.5	0.32	130	<4.6	<10	510	<22
51							0.2											
52							1.6	140	220	6.2	6.2	5.4	0.62	240	<4.6	<10	490	32
53							1.3											
54							0.7	51	250	4.0	6.9	5.5	0.49	170	<4.6	<10	360	25
55							0.5											
56							0.7	50	250	8.1	10	6.7	0.58	260	<4.6	<10	540	43
57							1.0											
58							0.9	69	380	5.6	84	24	1.2	370	79	19	280	<22
59							1.0											
60							0.9	74	330	7.9	12	8.7	0.72	460	6.6	<10	560	<22
61							0.9	75	270	7.4	20	19	1.3	460	12	<10	240	55
61.5	1.03	8.75	56.51	33.70	90.21	6.88	1.2	150	250	6.1	20	17	1.4	540	13	12	350	48
62							1.2											
63	1.27	37.55	44.32	16.87	61.19	5.16	0.8	110	280	5.3	18	14	0.96	470	8.4	<10	330	<22
64							1.1											
64.5							0.5	110	360	4.4	18	10	1.1	350	8.9	<10	280	<22
65							0.5											
66	2.35	74.83	15.82	7.00	22.82	3.38	0.6	66	330	4.5	13	11	0.69	250	5.9	<10	330	<22
67							0.5											
68	4.59	84.68	6.26	4.47	10.73	2.12	0.6	61	250	8.9	12	8.0	0.74	320	5.8	<10	580	55
69							0.9											

	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 INTENSIVE SAMPLING AREA, 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
70	0.58	90.11	5.51	3.80	9.31	2.70	0.8	68	380	7.3	9.9	5.8	0.57	230	<4.6	<10	450	29
71							0.7											
72	1.24	95.24	2.05	1.47	3.52	2.59	0.4	45	270	7.1	4.0	4.2	0.37	160	<4.6	<10	860	<22
73							0.3											
74	0.00	97.37	1.98	0.65	2.63	2.56	0.2	17	360	2.0	3.2	3.7	0.32	98	<4.6	<10	190	<22
75							0.2											
76							0.4	27	310	2.7	5.0	3.0	0.31	74	<4.6	11	430	<22
77							0.4											
78							0.5	42	300	6.4	4.9	3.7	0.45	250	<4.6	13	770	30
79							0.5											
80							0.9	100	290	6.8	10	11	0.72	210	7.6	13	640	<22
81							0.7	56	350	5.9	8.9	5.6	0.68	220	5.3	10	530	29
82							0.6											
83							0.6	55	450	8.6	20	10	1.0	190	9.6	14	470	43
84							0.7											
85							1.0	63	330	5.6	21	16	1.4	370	11	15	280	33
86							0.7	58	340	10	13	11	0.83	300	8.3	14	580	33
87							1.3	95	320	6.5	32	18	1.7	500	15	18	270	46
88							0.5											
89							0.5	45	330	6.4	5.4	6.4	0.41	110	<4.6	<10	500	33
90							0.6	110	300	7.0	19	16	1.0	280	9.9	13	560	29
91							1.8											
92							0.5	30	260	5.6	2.8	3.3	0.29	88	<4.6	<10	640	23
93							0.4	30	180	3.9	3.3	3.6	0.29	140	<4.6	<10	690	<22
94							0.2											
101							0.3	75	350	5.1	4.4	3.5	0.33	130	<4.6	<10	910	26
102							0.5											
103							1.2	99	330	6.1	17	11	0.89	220	7.1	11	630	<22
104							0.8											
105							0.8	36	360	5.7	5.1	4.6	0.41	230	<4.6	10	500	26
106							0.9											
107							0.7	100	470	18	40	22	1.1	240	11	27	830	70
108							0.6											
109							0.6	56	350	5.9	13	11	0.44	230	4.8	11	760	<22
110	0.88	49.30	37.53	12.29	49.83	4.61	0.7	120	320	3.9	19	13	1.0	430	9.9	<10	310	<22
111							0.7											
112	0.30	50.61	36.41	12.68	49.09	4.52	0.6	110	370	5.8	17	14	1.1	370	10	11	400	<22
113							0.8											
114	4.90	76.66	12.32	6.12	18.44	2.99	0.5	39	330	10	19	5.3	0.58	200	9.9	<10	710	37
115							0.9											
116	2.85	81.04	12.39	3.72	16.11	2.90	1.0	77	330	8.2	13	6.5	0.61	300	5.3	<10	790	<22
117	0.93	93.40	3.85	1.83	5.68	2.66	0.6	33	270	6.4	6.7	3.4	0.29	170	<4.6	<10	830	25
118							0.4											
119	0.42	97.05	1.67	0.86	2.53	2.60	0.4	54	330	3.8	12	3.7	0.38	260	6.5	10	540	<22
120							0.4											
121	0.14	97.81	1.33	0.72	2.05	2.55	0.3	41	310	2.5	5.7	3.7	0.28	83	<4.6	10	370	<22
122							0.3											
123							0.4	41	400	5.3	7.5	17	0.37	240	9.2	14	860	76
124							0.4											

LAGUNA MADRE INTENSIVE SAMPLING AREA, cont.

	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
125							0.7	46	360	7.8	17	29	0.35	190	8.5	17	1000	73
126							0.9											
127							1.0	61	230	7.7	15	9.0	0.71	290	8.3	<10	810	50
128							0.7	44	220	6.8	22	57	0.56	250	17	18	700	91
129							1.5	92	320	4.6	25	18	1.3	500	13	12	340	35
130							0.6											
131							0.8	72	350	6.5	20	8.6	0.86	340	10	12	800	22
132							0.7											
133							0.8	220	400	3.8	27	19	1.7	630	17	15	330	35
134							0.7											
135							0.5	85	430	4.6	19	84	0.99	330	10	21	440	78
136							1.3	100	410	6.0	33	23	1.7	620	15	17	400	39
137							0.8	64	350	7.9	18	18	0.74	340	11	12	810	42
138							1.7											
139							0.6	73	350	7.4	10	7.4	0.61	290	7.0	14	1100	<22
140							0.5	53	360	8.4	8.0	4.2	0.45	280	7.7	12	1100	42
141							0.4	41	360	7.5	6.2	5.1	0.37	210	<4.6	12	960	<22
142							0.4											
142.5							1.0	130	350	6.1	20	6.5	1.0	320	8.6	17	1100	<22
143							0.2	24	320	3.0	6.8	3.2	0.29	220	6.3	<10	770	<22
144							0.3											
145							0.6	44	360	6.4	5.5	3.8	0.38	220	<4.6	<10	1100	25
146							0.6											
147							0.8	70	440	8.6	13	6.4	0.73	330	7.4	14	840	<22
148							0.8											
149							0.9	72	440	5.4	23	10	1.3	440	11	15	390	<22
150							1.1											
151							0.9	92	370	7.3	22	12	1.2	510	13	16	780	29
152	0.74	61.28	32.87	5.11	37.98	3.58	1.0	58	470	7.1	33	7.8	0.98	390	8.7	14	490	<22
153	1.01	29.37	64.40	5.22	69.62	4.90	0.9											
154	1.92	48.02	34.91	15.15	50.07	4.83	1.1	27	230	7.4	2.5	3.2	0.27	130	<4.6	<10	1300	36
155	3.11	70.38	17.17	9.33	26.50	3.66	1.1											
156	4.31	79.78	12.13	3.77	15.90	2.96	0.7	65	270	4.7	22	12	0.85	320	8.0	<10	320	<22
157	2.77	92.71	3.19	1.33	4.52	2.36	0.6											
158	1.67	94.56	2.97	0.79	3.76	2.50	0.4	57	300	9.9	6.1	4.5	0.42	240	5.8	11	900	<22
159	0.28	96.79	1.88	1.05	2.92	2.50	0.5											
160	0.08	61.89	17.46	20.56	38.02	4.60	1.5	110	300	9.4	18	9.3	0.96	320	8.8	15	970	34
161							0.6	58	310	6.3	5.2	3.5	0.39	110	<4.6	11	820	26
162							0.5											
163							0.6	27	270	5.5	1.4	3.3	0.18	51	<4.6	<10	1200	26
164							0.7	47	230	4.2	5.0	3.9	0.42	130	<4.6	<10	580	22
165							0.7											
166							1.0	53	260	7.4	6.1	4.6	0.49	210	6.8	<10	620	37
167							1.1	79	300	6.9	20	11	1.2	410	10	<10	350	35
168							1.1											
169							1.1	53	270	8.1	3.9	3.1	0.3	170	6.3	<10	1300	38
170							0.7	34	420	4.4	20	6.5	0.86	270	9.3	10	270	<22
171							1.1											
172							0.8	93	210	6.9	8.9	6.1	0.49	210	7.1	<10	710	35
173							0.7											

Sample	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 INTENSIVE SAMPLING AREA, cont.																		
174							0.9	56	390	7.7	23	14	1.3	530	12	15	300	41
175							0.5	32	330	4.8	1.9	3.7	0.26	65	<4.6	<10	800	<22
176							0.3											
177							0.4	77	220	5.6	7.9	4.5	0.56	150	7.6	<10	870	32
178							0.5											
179	0.30	97.92	1.34	0.44	1.78	2.40	0.3	16	300	2.8	<1.0	2.5	0.15	40	<4.6	<10	720	<22
180							0.5											
181	1.30	89.29	7.01	2.40	9.41	2.41	0.7	41	230	7.7	6.0	22	0.36	170	<4.6	<10	1000	48
182							1.1											
183	2.29	76.23	17.06	4.43	21.48	3.13	0.8	52	220	5.2	7.6	5.5	0.55	190	6.9	<10	520	23
184	0.08	44.33	43.46	12.13	55.59	4.94	1.5	69	470	7.6	24	13	1.1	400	11	13	370	27
185							0.7	72	400	8.1	41	16	1.3	450	12	14	370	32
186							0.8											
187							0.6	32	150	4.9	1.5	4.3	0.20	69	<4.6	<10	850	<22
188							0.5	30	220	9.6	2.4	3.6	0.25	70	<4.6	<10	940	<22
189							0.7	30	210	5.6	2.0	3.2	0.18	60	<4.6	<10	930	<22
190							0.3	27	250	2.0	<1.0	2.4	0.17	46	<4.6	<10	420	<22
191							0.3											
192							0.7	40	260	6.6	5.6	4.1	0.25	120	<4.6	<10	1100	<22
193							0.5											
194							0.6	65	240	3.3	5.6	4.9	0.47	160	6.7	<10	390	<22
195							1.0											
196							0.8	27	200	5.3	8.3	4.5	0.46	200	<4.6	<10	300	<22
197							0.4											
198							1.2											
199							0.9	77	290	7.1	30	19	1.7	170	13	16	260	34
200							0.4	63	290	5.7	18	8.6	0.83	330	7.2	<10	550	<22
201							0.4	71	390	8.2	21	17	1.3	430	8.9	15	320	38
202							0.6											
203							0.5	39	290	7.5	4.8	3.6	0.36	200	<4.6	<10	650	<22
204							0.5	45	300	6.5	4.2	3.4	0.39	130	<4.6	<10	630	25
205							0.4											
206							0.4	25	210	3.9	1.7	2.8	0.20	77	<4.6	<10	650	<22
207							0.3											
209							0.6	28	230	7.2	2.7	2.9	0.21	94	<4.6	<10	1000	26
210							0.5											
211							0.5	36	260	6.7	6.0	3.4	0.41	190	<4.6	10	600	22
212							0.6	71	270	5.0	10	7.8	0.70	270	6.2	<10	500	33
213							1.5											
214							0.7	110	240	3.7	15	9.2	0.97	580	7.1	<10	290	41
215	0.72	56.84	28.32	14.12	42.44	4.56	0.6	76	390	5.3	21	12	1.1	440	8.7	11	420	<22
216							0.7											
217	0.14	33.90	35.33	30.63	65.96	5.87	0.8	98	300	6.2	17	10	1.0	450	8.5	11	370	<22
218	0.86	80.91	9.93	8.30	18.24	3.25	0.6	43	280	4.4	4.1	3.4	0.34	210	<4.6	<10	800	<22
219	1.49	91.06	4.88	2.57	7.46	2.26	0.5	48	210	7.0	4.5	4.5	0.33	150	<4.6	<10	860	28
220							0.4											
222							0.9											
223							0.4	55	290	4.0	6.8	4.6	0.47	260	<4.6	<10	450	<22
224							0.6											
225							0.4	76	180	4.2	12	7.7	0.71	430	5.6	<10	220	31

LAGUNA MADRE INTENSIVE SAMPLING AREA, cont.

	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
226							0.9											
227							0.9	55	240	5.1	16	8.2	0.83	350	6.5	<10	340	<22
228							0.6											
229							0.5	57	300	7.7	18	6.6	0.97	320	7.8	14	770	<22
230							0.8	57	320	6.7	17	9.6	1.1	350	8.2	10	450	26
231							0.4											
231B							0.8	110	170	6.4	19	20	0.99	320	8.6	16	710	44
232							0.4	27	190	4.6	2.0	2.7	0.17	40	<4.6	<10	850	<22
233							0.6											
234							0.4	64	220	6.8	6.5	8.6	0.52	230	<4.6	<10	1300	47
235							0.5											
236	0.54	96.90	2.00	0.56	2.56	2.48	0.4	18	250	5.2	1.1	2.5	0.14	33	<4.6	<10	910	<22
237							0.4											
238	0.54	89.19	5.96	4.32	10.27	2.69	0.6	36	190	2.7	3.0	12	0.29	64	<4.6	<10	310	<22
239	1.24	52.40	32.53	13.82	46.36	4.45	0.8	110	340	4.6	14	13	0.99	340	11	<10	270	<22
240							0.7											
241	0.11	51.23	39.04	9.62	48.66	4.44	0.6	47	290	4.2	13	58	0.88	300	8.0	<10	280	<22
242							1.0											
243							0.3											
244							0.3											
245							0.8	37	210	3.9	9.1	11	0.51	250	6.2	<10	320	26
246							0.8											
247							0.6	34	200	6.6	3.5	5.2	0.28	97	<4.6	<10	670	32
248							0.6											
249							0.4	19	170	8.0	1.8	4.0	0.14	58	<4.6	<10	1100	<22
250							0.3											
251							0.2	21	210	4.4	1.5	3.0	0.23	230	<4.6	<10	650	<22
252							0.3											
254							0.3											
255							0.4	16	180	3.0	1.1	7.4	0.14	36	<4.6	<10	550	<22
256							0.9											
257							0.6	48	280	7.3	4.8	4.0	0.37	110	<4.6	<10	770	42
258							0.8	46	230	6.9	9.7	5.3	0.43	230	5.3	<10	820	42
259							0.8											
260							0.7	45	230	7.0	11	6.1	0.52	190	5.9	<10	780	38
261							0.4											
262[a]							0.6		393	6.20	26.1	10.4	0.960	179	17.3[b]	<40.0	741	86.3
263							0.5											
264							0.5											
265							0.7	43	190	6.6	5.3	5.0	0.35	170	<4.6	<10	690	32
266							0.9	47	230	4.8	8.1	9.9	0.52	170	5.8	<10	470	31
267							0.6	31	200	6.7	2.9	5.6	0.25	76	<4.6	<10	910	34
268							0.6											
269							0.5	28	74	3.6	<1.0	2.8	0.10	31	<4.6	<10	800	<22
270							0.4											
271							0.4	19	200	3.6	2.2	2.9	0.25	110	<4.6	<10	630	<22
271.5							0.5											
272							0.3	41	170	1.6	<1.0	2.8	0.15	57	<4.6	<10	580	<22
273							0.4											
274							0.8											

LAGUNA MADRE INTENSIVE SAMPLING AREA, cont.

	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
275							0.5											
276							0.7											
277							0.5											
278							0.3											
279							0.5											
280							0.6											
281							0.6											
282[a]	0.61	64.66			34.73		0.4		367	11.2	32.8	13.1	0.675	165	27.4	<40.0	1380	95.7
283							0.5											
284	3.18	75.64	15.27	5.91	21.18	3.02	0.8	58	290	7.0	15	6.7	0.64	240	4.7	<10	480	43
285							0.8											
286	3.02	89.68	5.67	1.63	7.30	2.33	0.7	24	160	8.6	3.1	3.2	0.19	66	<4.6	<10	1200	<22
287							0.7											
288	0.00	92.95	4.41	2.64	7.05	2.60	0.2	32	230	1.9	1.2	4.2	0.16	34	<4.6	<10	380	<22
289	0.24	95.70	2.88	1.18	4.05	2.57	0.3	15	190	1.4	<1.0	2.6	0.097	47	<4.6	<10	340	<22
290							0.7	26	190	1.1	1.2	2.6	0.17	56	<4.6	<10	270	<22
291							0.5											
292							0.6	59	150	5.6	7.5	5.9	0.52	140	5.8	<10	1000	31
293							0.6											
294							0.7	85	180	6.3	14	19	0.44	200	5.5	<10	950	31
295							1.0											
296							0.6	29	300	2.5	7.6	4.5	0.63	230	5.9	<10	200	<22
297							0.6											
298							0.9											
299							0.9	130	130	4.9	17	16	1.1	390	10	12	640	55
301							0.5											
302							0.5											
303							0.7	53	370	2.9	13	8.2	0.92	300	6.6	11	250	<22
304							0.8											
305							0.7	55	220	6.9	6.3	5.2	0.47	170	6.4	<10	770	36
306							1.2											
307							1.0	49	200	8.5	6.8	7.7	0.56	190	6.3	<10	1600	43
308							2.8											
309							1.6	57	250	8.6	7.5	8.7	0.54	150	6.4	<10	1500	47
312							0.6											
313							1.1											
314							1.6	49	140	11	4.4	4.0	0.29	110	<4.6	<10	2500	54
315							0.7											
316							0.7	58	250	6.2	7.4	4.5	0.48	230	<4.6	<10	590	26
317							0.9											
318							0.9	35	270	6.7	7.1	21	0.32	190	<4.6	<10	580	31
319							0.3											
320							0.4											
321							0.7											
322							0.5											
323	0.33	72.49	18.13	9.05	27.19	3.80	0.5	41	360	6.6	14	8.2	0.77	390	8.3	11	600	<22
324	1.20	64.02	23.55	11.23	34.78	4.06	1.2											
325	0.54	52.27	35.91	11.29	47.19	4.39	0.8	37	390	7.2	14	8.9	0.75	240	7.6	<10	410	<22
326	2.96	74.36	13.62	9.06	22.68	3.47	0.6											
327	1.94	87.67	7.79	2.60	10.39	2.53	0.5	16	280	4.7	4.3	3.1	0.23	74	<4.6	<10	460	27

	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 INTENSIVE SAMPLING AREA, cont.																		
328	3.79	83.99	7.48	4.74	12.21	2.54	0.8											
329	2.47	83.84	10.06	3.63	13.69	2.17	1.5	74	180	11	9.2	5.6	0.50	180	<4.6	<10	1600	57
330	1.51	78.39	13.61	6.48	20.10	2.92	1.4	56	150	11	6.2	6.5	0.41	130	<4.6	<10	1600	59
331	0.88	80.02	13.71	5.39	19.10	3.28	0.8	80	230	8.3	5.9	4.7	0.45	110	<4.6	<10	1500	45
LAGUNA MADRE																		
159							0.3											
163[a]	0.83	95.34	2.45	1.37	3.82	2.44			310	3.29	<4.00	<4.00	0.226	58.8	<10.0	<40.0	298	61.9
164	8.09	69.87	12.04	10.01	22.05	3.40	0.6											
165[a]	6.48	62.90	16.30	14.32	30.62	3.96	0.7		271	15.5	<4.00	15.1	0.638	200	15.2[b]	<40.0	1020	<4.00
166	6.81	75.86	16.90	0.43	17.33	3.01	0.6											
167							0.4											
167A							0.3											
168							0.3											
169							0.6											
170							0.2											
171[a]	0.75	97.66	0.86	0.73	1.59	2.46			286	2.57	6.88[b]	<4.00	0.248	77.5	12.3[b]	<40.0	315	58.2
172	0.44	98.55	0.63	0.37	1.01	2.61	0.8											
173							0.3											
174[a]	1.14	88.57	5.87	4.41	10.28	2.72	0.2		360	1.77	<4.00	30.0	0.506	60.9	<10.0	<40.0	193	62.7
175	14.74	69.60	9.68	5.98	15.66	3.21	0.4											
176[a]	6.07	81.88	7.21	4.85	12.05	1.14	0.5		180	23.4	36.5	<4.00	0.341	159	11.0[b]	<40.0	2660	43.3
177							0.8											
178							0.3											
180	0.23	97.34	1.57	0.87	2.44	2.55	0.2											
181[a]	1.25	98.60	1.26	0.69	1.95	2.42	0.2		254	3.21	<4.00	<4.00	0.195	55.3	<10.0	<40.0	355	21.7
182							0.9											
183							0.9											
184							0.2											
185	4.68	86.38	6.14	2.80	8.94	2.77	0.3											
186[a]	5.91	67.94	16.79	9.36	26.15	3.72	0.6		280	10.8	<4.00	<4.00	0.696	200	<10.0	<40.0	1390	62.3
187	5.54	60.98	19.78	13.70	33.48	4.08	0.7											
188							0.6											
189							0.2											
190	0.17	97.69	1.39	0.76	2.15	2.47	0.2											
191[a]	0.73	96.49	1.61	1.17	2.78	2.60	0.3		210	1.97	<4.00	<4.00	0.206	56.0	<10.0	<40.0	192	15.3
192							0.2											
193							0.6											
194[a]							0.5		249	11.8	<4.00	<4.00	1.81	314	<10.0	<40.0	1150	84.0
195							0.3											
196							0.3											
197							0.5											
198							0.2											
199							0.3											
200	0.36	97.77	1.01	0.86	1.87	2.38	0.3											
201[a]	1.29	95.58	1.75	1.38	3.13	2.63	0.3		457	5.36	39.9	25.4	0.415	108	21.1[b]	<40.0	674	137
202	0.40	84.08	9.79	5.73	15.52	2.77	0.6											

	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.																		
203	0.20	98.89	0.65	0.26	0.91	2.30	0.1											
204[a]	1.24	36.78	36.99	24.99	61.98	5.60	1.1		322	9.92	<4.00	<4.00	1.63	368	<10.0	<40.0	892	69.9
205	0.76	96.06	2.38	0.80	3.18	2.38	0.2											
206[a]	1.48	89.22	6.18	3.12	9.30	2.48	0.5		276	3.68	<4.00	<4.00	0.344	78.6	<10.0	<40.0	350	32.0
207							0.3											
208							0.2											
210							0.4											
211							0.6											
212							0.8											
213							0.4											
214[a]	3.50	86.48	6.59	3.44	10.03	1.96	0.8		420	7.61	38.8	<4.00	0.626	214	43.8	<40.0	1190	<4.00
215[a]	2.91	84.45	8.80	3.84	12.64	2.15	0.6		332	8.33	27.5	<4.00	0.359	67.0	20.3[b]	<40.0	675	<4.00
216	2.97	84.55	8.84	3.63	12.48	2.13	0.5											
217	1.18	89.49	5.61	3.72	9.33	2.44	0.4											
218[a]	0.57	92.06	3.93	3.44	7.37	2.58	0.3		349	5.56	<4.00	<4.00	0.385	63.9	<10.0	<40.0	1170	12.0
219							0.2											
220							0.5											
221							0.6											
222							0.6											
223							0.4											
224	2.65	61.45	26.01	9.90	35.91	3.85	0.5											
225	2.53	79.12	14.03	4.32	18.35	2.67	0.5											
226[a]	2.44	68.15	14.53	14.88	29.41	3.73	1.0		265	17.3	23.0	<4.00	0.613	105	11.6[b]	<40.0	2580	12.9
227	0.35	85.39	7.39	6.86	14.25	2.75	0.4											
229							0.2											
230							0.9											
294							1.5											
295							0.9											
296							0.9											
296.5							0.9											
301							0.8											
302							1.0											
303	1.09	64.75	20.64	13.51	34.16	4.20	0.8											
304	0.80	50.48	31.06	17.67	48.73	4.79	0.9	79	340	6.5	18	11	1.2	270	9.9	12	300	23
305	2.07	58.63	28.66	10.64	39.30	3.94	0.9											
305.5							1.1											
306							1.0											
306.5	1.29	65.89	24.62	8.20	32.82	3.79	1.0											
307	1.63	56.71	28.13	13.53	41.67	4.47	1.3											
308							1.1											
309							1.1											
310	9.88	70.39	13.80	5.94	19.74	3.27	0.7											
311							0.7	68	260	5.7	9.2	7.3	0.70	210	8.0	10	440	32
312	4.01	68.96	14.91	12.12	27.04	4.07	1.1											
313	7.10	70.04	13.73	9.13	22.86	3.74	1.4											
314							1.1	82	220	4.6	12	9.5	0.87	260	8.6	13	330	<22
314.5							1.4											
315	0.72	56.61	22.78	19.89	42.67	4.33	1.1											
316							0.6	93	310	5.9	12	7.6	0.86	240	7.4	<10	400	23
317	4.82	78.71	10.53	5.95	16.48	3.09	0.4	30	350	7.0	7.3	5.4	0.56	240	5.9	11	470	39
318	0.68	56.77	25.23	17.33	42.56	4.54	1.1											

	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.																		
318.5							1.1											
319							1.2											
320							1.1	61	400	5.9	17	14	1.1	540	11	13	360	23
321	3.02	36.87	39.05	21.07	60.12	5.43	1.3											
322	5.49	63.67	18.53	12.31	30.84	4.16	1.0	51	290	6.6	13	7.8	0.77	250	8.0	17	480	35
323	1.06	76.96	13.68	8.31	21.99	3.43	1.0											
324							0.8											
325	4.68	81.72	7.81	5.80	13.60	2.57	1.0											
326							1.2	69	340	6.3	16	9.4	1.0	340	9.1	14	330	<22
327	0.51	71.90	13.28	14.31	27.59	4.17	1.1											
327.5	2.54	81.12	8.34	8.00	16.34	3.95	1.0											
328	0.57	93.73	3.89	1.81	5.70	2.62	0.9	19	230	1.2	3.1	3.6	0.49	160	<4.6	<10	150	23
329							1.4											
340	1.36	61.96	19.74	16.95	36.68	4.47	1.3											
341	1.74	67.03	19.36	11.87	31.23	4.08	0.9											
342	2.17	67.11	19.26	11.45	30.71	4.00	0.5	44	300	6.0	9.0	4.7	0.74	210	5.4	<10	420	<22
343							0.2											
344							0.8	66	350	7.1	19	10	1.2	310	11	<10	530	25
345							1.2											
346							1.4											
347	0.83	31.47	46.77	20.93	67.70	5.57	1.5	93	420	5.8	31	18	1.6	470	15	17	280	43
348	0.39	22.90	51.69	25.02	76.71	5.92	1.2	72	260	5.4	19	16	1.2	380	11	18	280	37
349	7.68	65.35	21.63	5.34	26.97	3.17	0.6											
350	1.68	92.49	4.81	1.02	5.83	3.10	0.2											
351							0.8											
352							1.2											
353	0.64	72.89	16.20	10.27	26.47	3.92	0.9											
354	5.12	66.40	13.89	14.59	28.48	4.30	1.2	110	300	4.8	50	7.3	0.96	190	8.0	12	330	<22
355							1.9											
356							1.1	64	270	3.0	13	9.8	0.98	200	8.4	<10	210	<22
357	3.64	56.39	20.34	19.63	39.97	4.78	1.2											
358	2.08	50.78	28.56	18.58	47.14	4.78	1.1	84	250	4.7	18	12	1.2	270	10	12	300	<22
359							0.3											
360							0.5	65	240	6.7	19	11	1.3	310	9.9	12	330	27
361	7.85	62.18	22.94	7.02	29.96	3.51	1.4	48	280	11	7.7	4.7	0.66	200	7.0	<10	570	<22
362							1.7											
363	0.87	42.00	46.14	10.99	57.13	4.95	1.9	83	440	5.6	24	15	1.3	440	12	15	340	<22
364	2.65	54.40	27.72	15.22	42.95	4.90	1.2											
364A							2.2											
365	2.66	58.06	27.67	11.60	39.27	4.36	1.2	68	300	5.3	20	12	1.2	310	15	10	310	25
366	5.91	66.23	17.93	9.93	27.86	3.99	0.5											
367							0.9											
368							0.9											
369							1.2											
370	17.48	54.73	17.18	10.62	27.79	4.20	1.8											
371							1.5											
372	21.82	64.34	9.76	4.07	13.83	2.85	0.9	30	290	3.8	6.2	3.7	0.41	160	<4.6	<10	210	<22
373	6.58	65.84	19.05	8.54	27.59	3.88	0.9											
374							1.1											
375	6.48	68.62	17.17	7.73	24.90	3.58	0.6	45	350	1.5	28	3.9	0.91	340	8.2	11	100	<22

	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.																		
376							0.6											
377							0.7											
377A	7.61	66.20	21.11	5.08	26.19	3.62	0.8											
378							0.9	54	360	7.4	19	7.9	0.94	310	8.3	12	360	28
379	11.26	62.93	13.84	11.97	25.81	4.41	0.9											
379A							0.3											
380							0.3											
381							1.3											
382							1.1	67	260	5.9	20	12	1.1	340	12	12	330	24
383							1.7											
384	3.88	41.81	36.24	18.07	54.31	5.22	1.8	100	250	4.5	22	15	1.4	280	13	15	280	25
385							0.9											
386							1.8	64	250	5.0	21	16	1.3	290	10	12	240	25
387	6.50	49.12	22.53	21.85	44.38	5.01	0.3											
388	11.84	54.03	22.73	11.40	34.13	4.66	0.3	35	450	9.6	27	6.5	1.8	420	11	12	380	43
389	0.82	59.64	26.77	12.76	39.54	4.57	0.5											
390	25.42	46.14	22.86	5.57	28.44	3.74	0.7											
391	9.81	45.42	31.81	12.96	44.77	4.69	0.9	39	310	6.8	17	9.2	1.2	280	10	<10	270	25
392	0.21	93.18	4.85	1.77	6.61	2.64	0.8											
393	0.24	1.79	56.78	41.18	97.96	7.40	2.5											
394							0.3	38	1100	6.0	21	6.6	1.5	360	9.9	13	260	<22
395	2.37	56.15	34.86	6.62	41.48	4.02	1.3											
396	1.27	82.42	12.49	3.82	16.31	3.18	0.4											
397	0.38	73.89	17.63	8.10	25.73	4.01	0.5	30	380	4.9	15	7.8	1.1	280	9.7	15	220	36
398.5	2.87	36.83	44.01	16.29	60.30	5.24	0.8											
PORT ISABEL CHANNEL																		
1							1.2	150	410	4.2	25	34	1.8	130	15	19	360	53
2							1.4											
3							0.2	65	560	6.4	27	80	1.9	450	14	72	290	150
4							0.4											
PORT MANSFIELD CHANNEL																		
1	0.14	15.46	33.07	51.32	84.39	7.29	1.8	74	370	5.4	25	16	1.7	520	14	16	210	39
1A							2.0											
2							2.0											
3	0.00	2.48	54.96	42.55	97.52	7.41	2.0	110	210	3.7	23	15	1.3	510	12	13	260	25
4							3.1											
5	0.59	86.93	7.48	5.00	12.48	2.61	0.5											
6	0.26	81.20	10.08	8.46	18.53	3.25	1.0	20	310	1.3	3.1	4.1	0.26	83	<4.6	<10	150	<22
7	0.09	77.46	13.81	8.64	22.45	3.57	0.8											
7A							0.7											
8	0.02	78.90	15.57	5.51	21.08	3.13	0.4	40	290	1.6	7.8	6.0	0.64	230	7.1	<10	140	24

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
PORT MANSFIELD CHANNEL, cont.																		
9	0.03	99.63	0.24	0.10	0.34	2.34	0.1	44	170	0.47	<1.0	3.5	0.24	60	<4.6	<10	46	<22
10	0.01	94.77	3.12	2.10	5.22	2.44	0.2											
11	4.23	90.81	3.52	1.44	4.96	2.55	0.2	27	410	3.6	6.6	5.6	0.63	230	5.6	<10	250	<22
SOUTH INTRACOASTAL WATERWAY																		
1							1.8											
2							0.6	110	240	8.6	42	19	2.3	540	19	19	220	76
3	4.56	55.14	26.83	13.47	40.30	4.30	0.3	40	450	13	17	8.1	1.4	390	11	13	590	54
4							1.5											
5	0.00	10.03	59.33	30.65	89.97	6.66	1.8											
6							2.4	160	330	6.4	35	18	2.1	870	23	25	370	82
7	0.00	2.60	63.79	33.61	97.40	6.96	2.0											
8							1.7	160	370	6.8	36	19	2.2	800	18	24	350	53
9	0.00	4.36	60.67	34.97	95.64	7.03	1.8											
10	2.45	40.11	38.27	19.17	57.44	5.23	1.1	96	390	7.1	20	18	1.6	570	14	20	480	45
11	0.56	7.65	53.38	38.41	91.78	7.06	1.8											
12							2.1	140	220	5.0	24	21	1.7	530	16	16	410	45
13	5.45	7.67	53.52	33.36	86.88	7.05	1.2	120	240	6.5	24	19	1.6	550	14	17	430	51
14							0.7	94	600	1.3	73	81	4.3	960	32	810	130	1300
15	3.76	15.67	56.87	23.70	80.56	6.30	1.1	120	390	8.1	34	21	2.1	710	18	22	510	67
16							2.0	120	350	6.3	26	19	1.7	970	16	20	370	50
17	0.11	12.30	60.32	27.28	87.60	6.41	2.2	75	250	3.4	17	16	1.0	410	11	10	210	<22
18							1.7	92	220	4.3	20	15	1.3	460	12	12	250	37
19	0.00	5.88	60.78	33.34	94.12	6.87	1.4	83	220	4.2	20	17	1.3	490	12	13	220	35
20							0.7	96	210	3.2	15	15	0.93	370	8.4	26	200	71
21	0.02	3.05	58.54	38.39	96.93	7.15	1.7	82	260	4.4	23	16	1.3	480	13	14	260	34
22	0.32	45.87	31.42	22.39	53.81	5.20	2.4	46	300	2.9	16	7.1	0.71	280	8.0	<10	250	30
23	0.62	25.11	45.47	28.80	74.27	6.01	2.1	88	240	4.0	15	10	0.87	370	8.0	<10	340	<22
24							0.8	60	210	4.0	11	8.2	0.78	290	6.9	<10	390	39
25	0.04	34.87	42.04	23.05	65.09	5.68	1.5	77	260	4.5	18	11	1.0	420	9.3	<10	300	<22
26							2.0	110	240	4.1	21	17	1.3	560	12	14	280	28
27	0.36	7.15	56.12	36.38	92.49	6.94	2.1	100	200	3.4	23	16	1.4	540	13	16	240	27
28							1.6	87	250	4.7	20	17	1.1	530	11	16	300	30
29	0.00	5.83	52.48	41.69	94.17	7.11	1.8	130	210	4.3	22	16	1.5	570	13	13	270	32
30							1.4	100	220	4.2	18	15	1.2	580	12	13	270	30
31	0.00	3.02	58.81	38.17	96.98	7.17	2.0											
32[a]							1.9		386	7.70	23.2	11.5	2.55	723	16.5[b]	<40.0	491	114
33	0.29	9.33	49.05	41.34	90.39	7.27	1.8											
34[a]							1.8		380	7.99	10.9	11.7	2.54	611	<10.0	<40.0	553	107
35	0.16	5.30	52.20	42.35	94.55	7.37	1.8											
36[a]							1.7		367	6.84	<4.00	9.11[b]	2.84	678	<10.0	<40.0	436	118
37	0.00	2.05	52.07	45.88	97.95	7.56	2.2											
38[a]							2.2		371	7.88	17.1	12.1	2.84	769	12.8[b]	<40.0	586	123
40	0.12	4.13	57.57	38.18	95.75	7.14	2.3											
41[a]							0.9		354	13.4	<4.00	<4.00	1.06	284	10.3[b]	<40.0	901	69.6
42	0.07	10.70	45.88	43.35	89.23	7.30	2.3											

Sample No.*	Textural Analysis							Geochemistry										
	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
SOUTH INTRACOASTAL WATERWAY, cont.																		
43[a]							2.4		391	7.26	32.9	17.6	2.76	767	21.1[b]	<40.0	613	175
44	0.00	1.16	38.80	60.04	98.84	8.08	2.1											
45[a]							2.3		396	7.66	23.9	24.4	2.73	948	22.5[b]	<40.0	644	242
46	0.00	1.26	43.68	55.06	98.74	7.96	2.3											
SOUTH BAY																		
1	0.02	45.98	47.80	6.20	54.00	4.37	0.5											
2[a]	0.14	40.28	48.30	11.28	59.58	4.96	0.9		481	5.12	48.7	15.1	1.65	262	27.8	<40.0	239	131
3[a]	0.03	51.25	35.04	13.68	48.72	4.61	0.9		405	4.19	43.2	14.4	1.51	239	29.9	<40.0	221	144
4	1.69	51.21	34.00	13.10	47.10	4.55	0.7											
5	2.64	8.69	66.77	21.90	88.67	6.26	1.5											
6[a]	0.00	75.09	20.04	4.87	24.91	3.56	1.0		480	9.60	77.4	6.68[b]	1.25	314	45.5	<40.0	437	49.1
7	0.94	40.82	38.21	20.03	58.24	5.48	0.7											
8	0.06	32.31	51.86	15.77	67.63	5.46	1.0											
9	0.72	40.97	41.99	16.33	58.31	5.16	1.3											
10[a]	0.22	41.90	42.77	15.11	57.88	5.14	1.0		467	6.42	65.5	18.9	2.56	370	34.0	<40.0	289	194
SHELF																		
1	10.33	84.35	3.20	2.12	5.32	3.22	0.1											
2							0.9											
3	1.35	14.98	51.76	31.91	83.67	6.75	0.9											
4							0.9											
5	0.21	17.58	39.56	42.64	82.20	6.93	1.0											
6							0.4											
7	0.72	65.69	19.09	14.50	33.59	4.13	0.4											
8							0.6											
9							0.5											
10							0.6											
11	0.90	62.06	19.36	17.68	37.04	4.40	0.5											
12	2.71	68.84			28.44		0.5	45	470	2.7	26	11	6.2	830	14	20	340	86
13							0.6											
14							0.5	130	500	3.2	30	13	2.5	420	13	15	320	32
15							0.5											
16							0.7	75	500	4.2	24	13	3.4	490	9.6	12	300	32
17							0.8											
18	0.20	35.45			64.36		0.7	96	340	3.9	20	17	2.0	390	11	9.1	280	41
19							0.8											
20	0.16	8.53			91.31		1.0	95	350	5.4	25	<32	2.8	600	15	16	340	99
21							0.9											
22	0.00	1.93			98.07		1.0	110	300	6.5	22	<32	2.7	680	14	16	350	96
23							0.9											
24							0.9											

SHELF, cont.

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
25	0.33	18.55	54.07	27.05	81.12	6.42	0.9											
26							0.8											
27	0.23	15.24	67.82	16.71	84.53	5.96	0.6											
28							0.8											
29	5.21	58.08	12.11	24.59	36.70	4.85	0.9											
30							0.7											
31	0.45	61.26	16.95	21.33	38.28	4.64	0.8											
32							0.5											
33	0.41	49.47	20.99	29.13	50.12	5.26	0.6											
34							0.6	54	440	2.5	28	15	2.5	500	12	15	270	34
35							0.5											
36							0.6	69	390	2.2	24	13	2.3	400	12	14	240	26
37							1.0											
38							0.6	53	370	2.1	18	10	2.4	570	9.8	12	250	24
39							0.6											
40							0.4	42	370	1.9	16	7.8	1.7	290	6.5	11	270	<15
41							0.8											
42							0.8	65	320	5.4	28	31	2.6	630	14	19	290	60
43							0.5											
44							0.2	12	330	1.4	6.9	3.9	1.3	380	3.1	<6.8	220	<15
45							0.2											
46							0.9											
47	0.08	6.26	36.73	56.93	93.66	8.18	1.0											
48							0.5											
49	0.32	61.95	26.09	11.64	37.73	4.25	0.5											
50							0.5											
51	1.77	62.02	17.21	19.01	36.22	4.41	0.4											
52							0.5											
53	1.79	65.26	14.06	18.88	32.94	4.37	0.5											
54							0.5											
55	0.30	68.25	20.31	11.15	31.46	3.98	0.7											
56							0.5	83	390	1.9	26	14	2.3	400	12	15	230	31
57							0.5											
58							0.6	37	340	1.6	14	8.8	2.3	400	7.1	10	230	18
59							0.5											
60	0.90	55.86			43.25		0.6	51	360	2.4	62	10	2.0	350	8.5	12	250	15
61							0.8											
62							0.6	45	370	2.6	21	11	1.9	380	10	12	260	24
63							0.4											
64	0.31	16.11			83.59		0.7	71	350	5.4	36	33	2.5	570	14	19	300	72
65							0.1											
66	6.19	87.69			6.12		0.1	25	360	1.9	90	5.2	3.0	570	4.7	10	310	37
67	8.41	86.83	3.73	1.04	4.77	3.04	0.4											
68							0.3											
69	0.30	61.15	23.10	15.45	38.55	4.59	0.7											
70							0.4											
71	0.29	60.84	15.68	23.19	38.87	4.88	0.4											
72							0.4											
73	3.63	60.32	18.88	17.18	36.06	4.48	0.6											

	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
								SHELF, cont.										
74							0.5											
75	3.35	62.13	16.90	17.62	34.52	4.40	0.4											
76							0.5											
77	0.89	58.45	16.52	24.14	40.66	4.86	0.5											
78							0.5	53	310	1.3	21	12	2.0	350	11	12	200	18
79							0.5											
80							0.5	69	350	1.5	12	9.1	2.1	360	7.3	11	230	17
81							0.7											
82							0.5	77	350	1.8	14	9.4	2.0	430	7.7	7.2	310	19
83							0.2											
84							0.4	39	430	2.6	19	8.2	1.7	310	7.9	9.7	310	20
85							0.3											
86							0.6	37	420	3.0	13	8.1	1.5	360	6.0	8.1	310	16
87							0.1											
88							0.2	29	430	2.4	6.1	4.5	0.89	2.60	4.3	<6.8	250	27
89	0.18	89.41	7.78	2.63	10.41	3.50	0.1											
90							0.2											
91	1.34	67.33	13.06	18.27	31.33	4.47	0.4											
92							0.4											
93	0.83	67.05	18.22	13.90	32.12	4.27	0.4											
94							0.6											
95	1.32	65.53	18.38	14.77	33.15	4.18	0.4											
96							0.4											
97	1.27	63.92	15.75	19.06	34.81	4.46	0.5											
98							0.4											
99	4.70	53.45	17.29	24.56	41.85	4.98	0.9											
100	3.12	59.82			37.06		0.3	58	410	1.8	19	9.4	1.9	330	9.9	11	250	<15
101							0.6											
102							0.6	43	400	2.0	21	12	2.6	380	11	11	230	26
103							0.7											
104							0.6	52	410	2.3	16	9.5	2.0	320	8.0	12	250	44
105							0.5											
106							0.4	38	350	2.4	15	7.4	1.7	320	7.1	8.0	290	17
107							0.5											
108							0.6	66	460	4.2	30	16	2.4	540	13	13	310	38
109							0.7											
110							0.1	38	500	3.1	10	5.8	1.5	410	5.7	13	380	24
111	0.00	90.38	8.60	1.02	9.62	3.48	0.1											
112							0.3											
113	1.30	72.86	18.34	7.50	25.84	3.72	0.4											
114							0.4											
115	0.26	77.13	12.10	10.51	22.61	3.84	0.4											
116							0.4											
117	0.79	62.06	21.25	15.90	37.15	4.47	0.7											
118							0.5											
119	3.20	63.89	17.35	15.56	32.91	4.28	0.5											
120							0.5											
121	1.86	58.75	20.76	18.63	39.39	4.53	0.5											
122							0.4	40	390	1.6	15	10	1.9	300	7.9	7.4	220	<15

	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
SHELF, cont.																		
123							0.6											
124							0.4	51	370	1.5	20	12	2.6	500	11	11	250	32
125							0.5											
126							0.4	44	410	2.5	22	10	2.5	500	9.2	13	260	21
127							0.4											
128	2.91	79.29			17.80		0.4	46	380	2.5	11	8.0	1.5	400	5.3	11	250	<15
129							0.4											
130							0.3	46	420	2.8	17	8.7	2.0	370	6.9	9.2	280	18
131							0.6											
132							0.2	29	420	2.0	40	7.2	4.1	710	6.2	13	280	49
133	1.46	93.27	4.53	0.74	5.27	3.07	0.2											
134							0.6											
135	0.26	77.89	14.49	7.37	21.86	3.69	0.4											
136							0.4											
137	0.59	79.82	11.48	8.10	19.58	3.58	0.4											
138							0.3											
139	2.40	70.31	16.52	10.77	27.29	3.99	0.4											
140							0.5											
141	0.77	64.72	20.99	13.52	34.51	4.16	0.5											
142							0.5											
143	2.87	62.34	21.45	13.34	34.79	4.11	0.7											
144							0.5	50	380	2.2	21	10	2.0	330	10	7.6	260	18
145							0.3											
146							0.5	63	330	1.5	24	10	3.2	480	9.0	9.1	230	36
147							0.4											
148							0.3	35	340	1.6	8.6	6.0	1.6	320	4.1	9.1	240	<15
149							0.3											
150							0.3	28	370	1.5	11	5.5	1.5	340	5.0	8.8	240	<15
151							0.5											
152							0.4	42	390	2.6	12	6.7	1.6	290	5.9	9.9	240	25
153							0.4											
154	3.12	93.25			3.63		0.2	31	380	2.6	78	11	3.5	790	6.0	12	250	45
155	3.00	90.35	5.30	1.35	6.65	3.16	0.2											
156							0.3											
157	0.77	68.04	19.80	11.39	31.19	4.10	0.3											
158							0.3											
159	1.23	82.45	10.06	6.26	16.32	3.26	0.2											
160							0.3											
161	0.75	76.05	14.28	8.92	23.20	3.72	0.4											
162							0.4											
163	3.38	64.73	20.05	11.84	31.89	4.05	0.5											
164							0.6											
165	4.65	59.82	18.97	16.55	35.52	4.38	0.4											
166	3.01	18.68			78.32		0.5	80	420	4.5	50	38	4.0	620	25	24	290	77
167							0.5											
168							0.3	41	390	3.0	21	63	3.8	700	11	13	350	51
169							0.4											
170	0.76	81.29			17.94		0.3	33	500	2.7	16	22	2.2	530	7.5	13	270	<15
171							0.2											

	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
SHELF, cont.																		
172	7.51	77.24			15.25		0.5	35	420	2.6	24	11	4.8	1100	10	13	290	55
173							0.4											
174							0.4	49	460	3.4	14	11	2.3	446	9.0	15	340	31
175	0.00	36.17	47.01	15.38	62.39	4.80	0.2											
176							0.5	32	460	3.4	62	5.3	1.5	480	4.1	12	280	<15
177							0.1											
178							0.2											
179	0.94	72.23	16.38	10.45	26.83	3.75	0.3											
180							0.2											
181	5.31	78.94	9.74	6.01	15.75	3.34	0.3											
182							0.1											
183	0.94	80.18	11.98	6.90	18.88	3.45	0.3											
184							0.3											
185	2.43	66.44	17.67	13.46	31.13	4.15	0.4											
186							0.6											
187							1.2											
188							0.4	69	600	3.2	36	16	2.6	490	19	22	350	46
189							0.6											
190							0.6	52	380	2.4	28	12	3.9	660	11	19	310	59
191							0.4											
192							0.2	31	430	1.5	6.5	4.9	2.5	650	4.3	13	280	22
193							0.2											
194							0.7	61	440	2.8	17	11	2.1	370	10	12	300	22
195							0.2											
196							0.3	42	400	3.6	15	7.6	2.1	440	8.1	14	390	25
197							0.4											
198	4.37	90.68			4.95		0.2	22	400	2.4	18	8.0	3.6	840	5.8	15	280	29
199	1.01	93.86	3.97	1.16	5.13	3.20	0.1											
200							0.4											
201	1.91	86.26	6.97	4.86	11.83	2.95	0.8											
202							0.4											
203	2.55	76.33	12.88	8.24	21.12	3.62	0.3											
204							0.5											
205	0.80	89.13	5.88	4.18	10.06	3.04	0.2											
206							0.4											
207	2.49	69.81	15.11	12.60	27.71	3.88	0.4											
208							0.4											
209	3.68	45.83	30.25	20.24	50.49	4.97	0.6											
210							0.7	74	530	3.5	40	17	3.9	630	16	17	320	63
211							0.6											
212							0.3	62	420	2.6	27	11	3.9	830	12	16	340	49
213							0.3											
214							0.2	48	460	1.8	7.2	4.0	2.7	650	7.1	12	270	<15
215							0.6											
216							0.3	26	460	2.2	8.4	4.5	1.6	450	5.1	11	240	<15
217							0.6											
218							0.3	46	460	2.9	21	6.0	1.8	340	5.9	12	300	<15
219							0.4											
220							0.2	45	570	3.8	13	5.6	1.9	430	5.8	12	300	17
221	0.89	93.94	3.82	1.35	5.17	3.31	0.2											

			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
SHELF, cont.																		
222							0.1											
223	5.28	71.22	13.47	10.03	23.50	2.76	0.4											
224							0.5											
225	6.83	85.16	5.62	2.36	7.98	2.99	0.2											
226							0.4											
227	1.88	95.38	1.59	1.15	2.74	2.70	0.3											
228							0.2											
229	3.15	75.60	13.00	8.25	21.25	3.59	0.3											
230							0.5											
231	0.27	23.12	28.95	47.66	76.61	6.95	0.6											
232							0.6	73	440	2.4	29	13	2.7	440	15	14	280	34
233							0.4											
234	3.32	74.19			22.48		0.3	37	500	3.1	120	42	3.5	1100	13	15	330	83
235							0.1											
236							0.5	52	440	2.1	120	8.6	2.3	400	8.7	14	280	28
237							0.4											
238							0.1	11	440	2.7	5.7	4.2	2.0	520	2.7	12	280	<15
239							0.7											
240							0.6	53	410	5.0	22	17	2.4	510	14	17	400	56
241							0.1											
242							0.1	38	470	3.0	61	8.0	2.2	490	5.1	12	270	20
243	7.94	87.11	3.82	1.13	4.95	3.00	0.1											
244							0.1											
245	2.66	71.08	16.72	9.54	26.26	3.76	0.4											
246							0.5											
247	4.86	67.97	15.82	11.35	27.17	3.92	0.2											
248							0.4											
249	0.19	72.33	17.33	10.16	27.49	3.95	0.4											
250							0.1											
251	4.21	82.79	7.75	5.26	13.01	3.09	0.5											
252							0.7											
253	8.60	38.62	36.47	16.30	52.77	5.00	0.6											
254							0.8	68	440	1.9	24	14	2.3	300	15	17	250	34
255							0.5											
256							0.2	33	370	1.6	12	6.0	3.8	690	7.6	14	270	27
257							0.1											
258	4.03	82.98			12.99		0.2	34	530	5.2	82	7.4	2.0	310	7.5	13	370	24
259							0.3											
260							0.3	39	450	3.7	19	9.0	2.4	420	7.6	12	340	33
261							0.2											
262							0.2	25	520	2.9	4.8	4.3	2.0	520	3.7	10	300	<15
263							0.3											
264							0.2	36	410	2.3	16	3.9	1.9	420	4.0	11	290	22
265	0.03	43.42	33.73	22.82	56.55	5.40	0.8											
266							0.6											
267	0.32	92.73	4.63	2.32	6.95	2.94	0.1											
268							0.1											
269	2.83	81.55	10.48	5.15	15.63	3.44	0.2											
270							0.2											

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.																		
271	2.96	72.06	15.06	9.92	24.98	3.90	0.4											
272							0.5											
273	0.66	95.00	2.40	1.94	4.36	2.92	0.1											
274							0.5											
275	8.54	52.52	26.95	11.98	38.93	4.30	0.5											
276							0.7	61	450	3.4	100	8.8	2.4	380	9.5	13	340	26
277							1.0											
278	5.38	92.86			1.76		0.1	28	420	2.7	9.0	4.4	4.3	1000	5.5	11	350	39
279							0.4											
280							0.3	29	430	4.5	67	6.4	2.3	630	5.9	12	380	22
281							0.2											
282							0.2	23	420	2.5	3.7	4.1	1.8	380	4.5	10	310	<15
283							0.3											
284							<0.1	12	390	1.4	1.6	2.8	0.76	120	2.1	9.0	200	<15
285							0.1											
286							0.2	38	480	2.2	30	4.5	2.0	450	4.6	11	280	17
287	0.09	95.19	3.89	0.83	4.72	3.26	0.2											
288							0.2											
289	0.68	69.32	20.44	9.56	30.00	3.95	0.4											
290							0.1											
291	0.62	88.13	7.79	3.46	11.25	3.16	0.2											
292							0.2											
293	5.19	80.20	9.62	4.98	14.60	3.30	0.3											
294							0.3											
295	1.48	82.45	9.68	6.38	16.06	3.43	0.3											
296							0.3											
297	2.58	45.67	35.57	16.18	51.75	4.81	0.6											
298							0.6	59	450	4.6	24	12	2.3	300	13	15	370	33
299							0.5											
300							0.4	53	360	1.4	19	8.5	3.4	580	8.1	14	270	33
301							0.3											
302							0.5	36	360	1.9	8.9	7.7	2.0	310	5.6	12	280	<15
303							0.1											
304							0.4	12	470	1.6	6.0	3.2	1.4	350	3.2	12	270	<15
305							0.1											
306							0.3	11	410	1.0	2.7	3.1	0.61	110	4.4	11	230	19
307							0.6											
308	0.02	63.83			36.16		1.1	57	560	6.8	26	13	2.4	650	14	20	470	68
309	1.06	90.36	5.84	3.03	8.87	3.35	0.2											
310							0.6											
311	0.40	90.58	7.11	1.91	9.02	3.05	1.2											
312							0.5											
313	1.48	96.99	1.13	0.40	1.53	2.49	0.3											
314							0.2											
315	5.62	75.51	11.60	7.26	18.86	3.59	0.2											
316							0.4											
317							0.3											
318							0.3											
319	5.15	50.79	30.35	13.71	44.06	4.47	0.5											

		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
								SHELF, cont.										
320							0.4	71	450	8.3	26	12	2.8	380	14	17	580	63
321							0.2											
322							0.3	46	380	1.5	16	7.8	1.9	350	8.0	14	250	28
323							0.3											
324							0.2	19	480	2.0	4.5	4.2	1.5	370	3.9	16	310	<15
325							0.1											
326							0.1	12	430	1.4	2.0	4.6	0.93	240	2.6	12	260	23
327							0.2											
328							0.3	25	450	1.6	6.4	4.1	1.7	490	5.4	11	260	<15
329							0.1											
330							0.1	30	430	2.0	15	4.8	1.4	370	5.3	13	260	<15
331	0.12	77.52	13.67	8.69	22.36	4.07	0.4											
332							0.2											
333	0.02	96.76	2.25	0.97	3.22	2.67	0.1											
334							0.3											
335	0.01	98.25	1.38	0.36	1.74	2.39	0.2											
336							0.2											
337	3.06	94.11	1.59	1.24	2.83	2.61	0.2											
338							0.3											
339	0.85	64.98	17.90	16.27	34.17	4.45	0.4											
340							0.4											
341	7.56	56.49	23.53	12.42	35.95	4.15	0.6											
342	11.19	52.22			36.59		0.5	62	360	2.1	24	13	2.1	330	13	17	280	240
343							0.4											
344							0.6	59	460	2.1	32	13	2.2	450	15	20	230	29
345							0.3											
346							0.2	26	420	1.6	3.7	3.7	2.0	540	6.3	12	310	<15
347							0.3											
348							0.1	43	390	3.8	15	8.4	2.2	610	8.8	15	410	34
349							0.6											
350							0.9	19	510	2.1	2.6	3.7	1.3	300	2.9	11	250	<15
351							0.4											
352							0.1	38	410	1.9	7.1	6.9	2.0	480	6.0	12	300	21
353	0.56	96.65	2.29	0.51	2.79	2.46	0.2											
354							0.1											
355	0.68	96.35	2.14	0.83	2.97	2.62	0.1											
356							0.3											
357	1.66	88.10	6.61	3.63	10.24	2.76	0.2											
358							0.1											
359	0.49	97.57	1.37	0.57	1.94	2.58	0.1											
360							0.1											
361	0.92	79.11	11.96	8.01	19.97	2.53	0.5											
362							0.5											
363	7.70	46.64	32.06	13.60	45.66	4.63	0.5											
364	10.01	44.77			45.22		0.5	64	400	2.0	160	13	2.6	450	17	17	280	39
365							0.4											
366							0.2	37	390	1.7	5.5	4.5	2.4	790	5.0	11	280	17
367							0.1											
368							0.1	15	360	1.9	4.2	3.6	1.3	310	3.5	11	280	<15
369							0.4											

	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
SHELF, cont.																		
370	1.91	59.35			38.73		0.5	56	390	1.6	16	9.8	2.4	420	11	15	260	34
371							0.1											
372							0.1	21	360	2.3	5.3	3.3	1.4	440	3.9	9.3	310	<15
373							0.5											
374	0.18	98.20			1.62		0.1	13	420	1.9	1.8	3.6	0.96	160	6.7	10	230	26
375	0.89	80.37	9.94	8.80	18.74	3.57	0.5											
376							0.5											
377	0.10	97.48	1.93	0.49	2.42	2.52	<0.1											
378							0.1											
379	1.13	83.07	11.70	4.10	15.80	3.03	0.3											
380							0.8											
381	0.67	90.65	4.30	4.38	8.68	2.73	0.3											
382							0.3											
383	4.45	85.58	6.64	3.33	9.97	2.44	0.3											
384							0.5											
385	6.68	52.70	27.49	13.13	40.62	4.29	0.4											
386	10.88	37.31			51.81		0.5	56	440	9.6	23	9.7	2.3	410	15	12	670	63
387							0.4											
388							0.4	41	500	2.7	23	8.1	3.1	620	11	18	420	51
389							0.1											
390							0.1	13	490	1.5	4.0	3.5	1.3	320	3.2	12	260	<15
391							0.2											
392							0.1	18	500	1.8	3.3	3.6	1.2	260	3.4	14	300	<15
393							0.1											
394							0.2	56	490	2.8	19	8.8	2.3	520	21	17	310	33
395							0.3											
396							0.3	27	500	2.5	25	4.8	2.0	410	4.5	13	330	23
397	0.05	97.66	1.61	0.68	2.29	2.72	0.1											
398							0.2											
399	0.75	76.66	16.05	6.54	22.59	3.47	0.4											
400							0.2											
401	0.92	95.32	2.62	1.14	3.76	2.68	0.2											
402							0.3											
403	0.27	97.65	1.61	0.47	2.08	2.43	0.1											
404							0.2											
405	4.98	77.58	12.55	4.89	17.44	3.13	0.4											
406							0.2											
407	13.71	59.53	19.17	7.59	26.76	3.71	0.3											
408							0.5	52	400	2.0	35	11	2.1	360	12	14	280	31
409							0.4											
410	1.98	75.41			22.62		0.4	56	530	2.5	16	7.5	2.0	490	8.6	14	370	82
411							0.3											
412							0.2	14	500	1.8	3.6	3.4	1.1	270	6.9	12	260	<15
413							0.1											
414							0.4	41	490	3.3	20	6.2	1.8	300	7.9	16	360	28
415							0.4											
416							0.3	49	430	2.4	19	8.0	2.4	480	11	14	300	32
417							0.1											
418							0.2	40	450	2.7	5.0	4.8	2.0	380	4.3	15	300	22

SHELF, cont.

Sample No.*	Gravel %	Sand %	Textural Analysis 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
419	1.95	95.03	2.26	0.76	3.02	2.85	0.1											
420							0.2											
421	1.45	92.92	4.91	0.72	5.63	2.58	0.3											
422							0.3											
423	4.72	71.99	16.23	7.06	23.29	3.65	0.3											
424							0.4											
425	1.50	90.17	5.61	2.72	8.33	2.64	0.2											
426							0.2											
427	0.21	34.27	42.91	22.61	65.52	5.70	0.4											
428							0.4											
429	11.77	55.55	24.00	8.68	32.67	3.80	0.5											
430							0.6	69	360	1.9	21	12	2.4	350	14	16	260	27
431							0.4											
432							0.3	34	360	1.0	7.0	6.6	1.5	270	8.9	12	190	<15
433							0.4											
434							0.3	62	410	3.2	22	8.6	2.0	380	10	14	400	34
435							0.3											
436							0.2	30	500	2.9	25	5.5	1.5	280	5.7	12	350	<15
437							0.2											
438							0.1											
439							0.1											
440	0.23	92.97			6.81		0.1	48	520	1.9	6.6	4.2	1.3	290	3.7	12	250	<15
441							0.1											
442							0.1											
443	0.26	81.96	12.77	5.01	17.78	3.25	0.1											
444							0.1											
445	2.39	79.13	13.78	4.70	18.48	3.22	0.3											
446							0.4											
447	8.72	70.59	15.13	5.56	20.69	3.42	0.3											
448							0.5											
449	8.13	61.93	21.84	8.10	29.94	3.77	0.4											
450							0.3											
451	7.60	51.36	28.09	12.94	41.04	4.38	0.4											
452							0.4	52	380	4.0	37	8.2	1.8	350	9.6	13	430	24
453							0.5											
454							0.5	58	400	1.9	23	9.1	2.0	320	9.8	14	250	18
455							0.4											
456							0.4	30	400	1.1	6.9	5.9	1.2	230	5.4	13	230	<15
457							0.3											
458							0.3	49	460	2.5	23	8.2	1.7	340	8.6	13	300	20
459							0.1											
460							0.1	32	440	3.4	27	4.9	2.2	560	4.0	12	300	<15
461							0.1											
462							0.2											
463	0.76	94.89	3.27	1.08	4.35	3.10	0.1											
464							0.1											
465	0.25	97.99	1.17	0.59	1.76	2.41	0.2											
466							0.2											
467	3.97	73.83	15.66	6.54	22.20	3.38	0.3											
468							0.3											

	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
SHELF, cont.																		
469	10.42	64.64	17.06	7.88	24.94	3.71	0.3											
470							0.4											
471	4.25	64.70	23.02	8.03	31.05	3.78	0.4											
472							0.5											
473	10.66	59.18	19.96	10.20	30.16	4.09	0.4											
474							0.5	32	280	1.1	10	7.7	1.3	250	5.7	10	200	37
475							0.4											
476	9.91	16.43			28.66		0.4	50	370	3.8	14	10	1.4	220	6.9	12	340	26
477							0.4											
478							0.3	36	380	1.4	10	7.0	1.5	260	6.9	13	230	<15
479							0.3											
480							0.2	17	340	1.3	5.6	5.5	2.0	320	5.3	9.5	230	<15
481							0.1											
482	0.65	83.65			15.70		0.2	45	340	1.8	39	6.6	2.7	520	8.3	12	280	43
483							0.2											
484							0.1	17	270	0.68	12	3.5	0.96	280	4.0	7.9	170	<15
485	0.66	94.26	4.14	0.94	5.08	3.07	0.2											
486							0.3											
487	0.38	94.72	3.84	1.06	4.90	2.68	0.2											
488							0.1											
489	1.70	85.67	8.73	3.90	12.63	2.86	0.2											
490							0.4											
491	3.43	70.95	18.81	6.81	25.62	3.49	0.3											
492							0.3											
493	8.96	67.06	17.04	6.94	23.98	3.68	0.3											
494							0.3											
495	9.84	57.02	21.58	11.56	33.14	4.03	0.4											
496							0.5	44	340	2.5	29	11	2.1	560	12	12	280	27
497							0.3											
498							0.3											
499							0.3											
500							0.4	37	350	2.2	20	8.6	1.6	260	9.0	14	250	18
501							0.3											
502							0.5	29	320	1.8	9.7	7.5	1.8	320	5.7	11	230	<15
503							0.2											
504							0.1	19	330	1.6	8.7	3.9	2.8	420	4.1	8.8	250	<15
505							0.2											
506	0.62	97.59			1.79		0.1	27	350	2.3	57	6.5	3.8	990	5.6	11	270	33
507	1.13	95.36	2.73	0.78	3.51	2.84	0.1											
508							0.1											
509	0.29	95.43	3.15	1.13	4.28	2.40	0.1											
510							0.2											
511	0.39	84.18	10.43	5.00	15.43	2.94	0.3											
512							0.3											
513	3.11	69.69	19.05	8.15	27.20	3.73	0.3											
514							0.3											
515	5.80	70.66	15.93	7.61	23.54	3.55	0.4											
516							0.3											
517	6.51	59.69	24.21	9.59	33.80	3.85	0.4											

Sample		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
SHELF, cont.																		
518							0.4	68	370	2.0	23	14	2.2	340	16	13	250	28
519							0.6											
520	7.12	72.90			19.98		0.3	37	380	1.4	9.6	6.5	1.2	270	5.5	10	210	30
521							0.3											
522							0.3	34	430	2.1	16	8.0	1.4	260	6.8	13	240	<15
523							0.3											
524							0.1	21	370	1.9	58	5.6	1.8	310	6.5	12	230	<15
525							0.1											
526							0.1	25	580	3.5	10	4.8	3.0	610	4.5	12	310	25
527							0.1											
528							0.1	44	340	1.5	42	5.0	4.3	680	6.6	15	220	36
529	0.99	94.27	3.90	0.84	4.74	3.04	0.1											
530							0.1											
531	0.14	96.05	2.82	1.00	3.81	2.56	0.1											
532							0.2											
533	1.20	86.98	8.35	3.47	11.82	2.76	0.3											
534							0.3											
535	0.74	65.06	11.91	22.29	34.20	4.74	0.4											
536							0.4											
537	1.66	82.00	10.77	5.57	16.34	3.08	0.3											
538							0.5											
539	5.59	59.89	23.00	11.52	34.52	3.99	0.5											
540	7.05	56.00			36.94		0.4	41	350	3.7	31	10	1.6	290	10	12	340	20
541							0.4											
542							0.5	41	280	8.1	17	8.7	1.4	280	7.3	7.9	540	66
543							0.4											
544							0.3	20	410	2.4	9.3	5.5	1.2	250	5.4	11	250	<15
545							0.3											
546							0.1	19	400	2.3	8.6	3.8	1.7	430	2.0	8.5	270	<15
547							0.2											
548	0.41	97.33			2.26		0.1	17	410	1.2	120	3.4	1.8	500	3.6	<6.8	260	<15
549							0.1											
550	0.09	95.41			4.50		0.1	47	280	1.1	97	6.1	3.6	750	5.6	11	190	30
551	0.05	93.62	4.56	1.77	6.33	3.20	0.2											
552							0.2											
553	0.02	94.91	3.97	1.10	5.07	2.47	0.3											
554							0.1											
555	0.49	85.31	9.34	4.86	14.20	2.89	0.2											
556							0.2											
557	0.62	94.32	3.53	1.53	5.06	2.70	0.1											
558							0.2											
559	4.86	77.47	12.59	5.08	17.67	2.98	0.3											
560							0.6											
561	8.04	60.78	21.95	9.23	31.18	3.94	0.5											
564							0.4	39	400	1.2	24	5.8	1.2	260	5.9	8.0	220	<15
565							0.4											
566							0.1	24	350	0.81	1.2	3.2	0.54	100	<1.5	<6.8	180	<15
567							0.1											
568							0.1	41	340	1.3	4.6	3.4	1.4	370	2.1	<6.8	200	<15

	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
SHELF, cont.																		
569							0.1											
570							0.4	66	450	2.7	19	9.2	1.8	380	9.8	14	260	22
571							0.3											
572							0.1	31	370	1.3	3.8	3.9	1.2	330	3.5	9.7	220	<15
573	1.72	96.15	1.74	0.39	2.13	2.99	0.1											
574							0.2											
575	0.41	83.20	5.41	10.99	16.40		0.3											
576							0.1											

APPENDIX C: DISTRIBUTION OF BENTHIC MACROINVERTEBRATES IN THE BROWNSVILLE-HARLINGEN AREA

Distribution of Molluscan Species

Phylum Mollusca	L*	Z	S
Class Polyplacophora Blainville, 1816			
Family Ischnochitonidae Dall, 1889			
Ischnochiton papillosus (C. B. Adams, 1845)	5	1	
Class Gastropoda Cuvier, 1797			
Family Fissurellidae			
Diodora cayenensis (Lamarck, 1822)	1	D	D
Diodora listeri (Orbigny, 1842)			D
Lucapinella limatula (Reeve, 1850)	D		D
Family Trochidae Rafinesque, 1815			
Calliostoma cf. *bairdii oregon* Clench and Turner, 1960			D
Calliostoma jujubinum (Gmelin, 1791)			D
Tegula fasicata (Born, 1778)			D
Family Phasianellidae Swainson, 1840			
Tricolia affinis cruenta Robertson, 1958	D		D
Family Neritidae Rafinesque, 1815			
Neritina reclivata (Say, 1822)	D		D
Neritina virginea (Linné, 1758)	1	D	D
Smaragdia viridis viridemaris Maury, 1917	D	D	
Family Littorinidae Gray, 1840			
Littorina lineolata Orbigny, 1840	D		
Littorina ziczac (Gmelin, 1791)			D
Family Rissoidae Gray, 1847			
Alvania auberiana (Orbigny, 1842)			D
Family Rissoinidae Stimpson, 1865			
Rissoina catesbyana Orbigny, 1842	D		
Rissoina decussata (Montagu, 1803)			D
Rissoina multicostata (C. B. Adams, 1850)			D
Zebina browniana (Orbigny, 1842)	D		
Family Assimineidae Fleming, 1828			
Assiminea succinea (Pfeiffer, 1840)	D		
Family Littoridinidae Thiele, 1929			
Texadina barretti (Morrison, 1965)	1		D
Texadina sphinctostoma (Abbott and Ladd, 1951)	D		D
cf. *Littoridinops* sp.	D		
Family Stenothyridae Fischer, 1885			
Probythinella louisianae (Morrison, 1965)	D		D
Family Truncatellidae Gray, 1840			
Truncatella caribaeensis Reeve, 1842	D		
Family Vitrinellidae Bush, 1897			
Vitrinella floridana Pilsbry and McGinty, 1946	12	D	33
Cyclostremiscus cf. *beaui* (Fischer, 1857)			D
Cyclostremiscus cf. *jeannae* (Pilsbry and McGinty, 1945)			D
Cyclostremiscus pentagonus (Gabb, 1873)			1
Cyclostremiscus suppressus (Dall, 1889)	D		D
Cyclostremiscus sp. A			1
Cyclostremiscus sp. B			D
Episcynia inornata (Orbigny, 1842)			1
Parviturboides interruptus (C. B. Adams, 1850)			D
Solariorbis infracarinata Gabb, 1881			3
Solariorbis cf. *mooreana* Vanatta, 1904			D
Teinostoma biscaynense Pilsbry and McGinty, 1945	D	D	D
Teinostoma parvicallum Pilsbry and McGinty, 1945			4
Anticlimax pilsbryi McGinty, 1945	D		D
Aorotrema cf. *pontogenes* (Schwengel and McGinty, 1942)			1
Family Tornidae Sacco, 1896			
Cochliolepis parasitica Stimpson, 1858			D
Cochliolepis striata Dall, 1889	D		
Family Caecidae Gray, 1850			
Caecum bipartitum Folin, 1870			D
Caecum cooperi S. Smith, 1860			10
Caecum johnsoni Winkley, 1908			D
Caecum nitidum Stimpson, 1851	D		D
Caecum pulchellum Stimpson, 1851	542	2	1
Family Turritellidae Clarke, 1851			
Vermicularia fargoi Olsson, 1951	D		D
Family Architectonidae Gray, 1850			
Architectonica nobilis Röding, 1798			D
Heliacus bisulcatus (Orbigny, 1842)			1

L = Lower Laguna Madre; Z = South Bay; S = Inner Shelf; D = Dead

*Includes Arroyo Colorado River, Brownsville Ship Channel, Port Mansfield Channel, Laguna Madre Intracoastal Waterway

Phylum Mollusca	L*	Z	S
Philippia sp.			D
Family Modulidae Fischer, 1884			
Modulus modulus (Linné, 1758)	D		D
Family Potamididae H. and A. Adams, 1854			
Cerithidea pliculosa (Menke, 1829)	D	D	D
Family Cerithiidae Fleming, 1822			
Cerithium cf. *atratum* (Born, 1778)	D		
Cerithium lutosum Menke, 1828	D		D
Cerithiopsis emersoni (C. B. Adams, 1838)	D		D
Cerithiopsis greeni (C. B. Adams, 1839)	D		D
Bittium varium (Pfeiffer, 1840)	114	9	D
Seila adamsi (H. C. Lea, 1845)	D		D
Alaba incerta (Orbigny, 1842)	D		D
Alabina cerithidioides (Dall, 1889)	D		D
Litiopa melanostoma Rang, 1829			D
Family Triphoridae Gray, 1847			
Triphora nigrocincta (C. B. Adams, 1839)	D	D	D
Family Epitoniidae S. S. Berry, 1910			
Epitonium angulatum (Say, 1830)			D
Epitonium apiculatum (Dall, 1889)	2	D	D
Epitonium humphreysi (Kiener, 1838)			D
Epitonium multistriatum (Say, 1826)	D		D
Epitonium novangliae (Couthouy, 1838)	D		3
Epitonium rupicola (Kurtz, 1860)	2		D
Epitonium sericifilum (Dall, 1889)			D
Amaea mitchelli (Dall, 1896)			D
Family Eulimidae Risso, 1826			
Eulima bilineata (Alder, 1848)			7
Eulima hemphilli (Dall, 1884)			5
Balcis arcuata (C. B. Adams, 1850)			D
Balcis jamaicensis (C. B. Adams, 1845)	D	D	2
Niso aeglees Bush, 1885			2
Family Aclididae G. O. Sars, 1878			
Aclis sp. A			D
Aclis sp. B			D
Henrya goldmani Bartsch, 1947	D	D	
Family Calyptraeidae Blainville, 1824			
Crepidula convexa Say, 1822	104	8	1
Crepidula fornicata (Linné, 1758)	D	D	D
Crepidula plana Say, 1822	D	8	D
Family Strombidae Rafinesque, 1815			
Strombus alatus Gmelin, 1791			D
Family Ovulidae Gray, 1853			
Simnalena marferula Cate, 1973			D
Simnalena uniplicata (Sowerby, 1848)			D
Family Atlantidae Wiegmann and Ruthe, 1832			
Atlanta brunnea Gray, 1840			D
Family Naticidae Gray, 1840			
Natica canrena (Linné, 1758)			D
Natica pusilla Say, 1822	3		128
Polinices duplicatus (Say, 1822)	6		7
Sigatica semisulcata (Gray, 1839)			D
Sinum perspectivum (Say, 1831)			2
Family Cymatiidae Iredale, 1913			
Cymatium cingulatum (Lamarck, 1822)			D
Family Tonnidae Peile, 1926			
Tonna galea (Linné, 1758)			D
Family Muricidae da Costa, 1776			
Murex sp.			D
Thais haemastoma (Linné, 1767)		D	
Family Columbellidae Swainson, 1815			
Costoanachis cf. *avara* (Say, 1821)	22	4	
Costoanachis lafresnayi (Fischer and Bernardi, 1856)			D
Cosmioconcha calliglypta (Dall and Simpson, 1901)			D
Parvanachis obesa (C. B. Adams, 1845)	D		7
Parvanachis ostreicola (Melvill, 1881)	6		D
Suturoglypta iontha (Ravenel, 1861)			D
Mitrella lunata (Say, 1826)	32	D	D
Family Buccinidae Rafinesque, 1815			
Cantharus cancellarius (Conrad, 1846)			10.
Family Melongenidae Gill, 1867			
Busycon perversum (Linné, 1758)			D
Busycon spiratum (Lamarck, 1816)			D
Family Nassariidae Iredale, 1916			
Nassarius acutus (Say, 1822)	D		9
Nassarius albus (Say, 1826)			D
Nassarius vibex (Say, 1822)			D

Phylum Mollusca	L*	Z	S
Family Fasciolariidae Gray, 1853			
Fasciolaria lilium G. Fischer, 1807			D
Family Olividae Latreille, 1825			
Oliva sayana Ravenel, 1834			9
Olivella dealbata (Reeve, 1850)			D
Olivella minuta (Link, 1807)			D
Family Cancellariidae Forbes and Hanley, 1853			
Trigonostoma rugosum (Lamarck, 1822)			D
Family Marginellidae Fleming, 1828			
Prunum apicina (Menke, 1828)	D		
Family Terebridae H. and A. Adams, 1854			
Terebra concava Say, 1827			1
Terebra dislocata (Say, 1822)			D
Terebra protexta Conrad, 1845			40
Family Turridae Swainson, 1840			
Agathotoma metrica (Dall, 1903)			D
cf. *Bellaspira* sp.			D
Pyrgospira tampaensis (Bartsch and Rehder, 1939)			D
Cryoturris adamsi (E. A. Smith, 1884)			D
Cryoturris cf. *cerinella* (Dall, 1889)			2
Cryoturris serga (Dall, 1881)			D
cf. *Drillia acurugata* (Dall, 1890)			D
Glyphostoma epicasta Bartsch, 1934			D
Ithycythara lanceolata (C. B. Adams, 1850)			D
Kurtziella dorvilliae (Reeve, 1845)			D
Kurtziella fargoi (McGinty, 1955)			1
Kurtziella rubella (Kurtz and Stimpson, 1851)			D
Nannodiella oxia (Bush, 1885)			2
Nannodiella vespuciana (Orbigny, 1842)			D
Splendrillia woodringi (Bartsch, 1934)			D
Pilsbryspira albocinta (C. B. Adams, 1845)			D
Pyrgocythara plicosa (C. B. Adams, 1850)	D	D	D
Pyrgospira ostrearum (Stearns, 1872)			D
Family Pyramidellidae Gray, 1840			
Pyramidella crenulata (Holmes, 1859)	D		3
Eulimastoma cf. *canaliculata* (C. B. Adams, 1850)	2		D
Eulimastoma engonia (Bush, 1885)	D	D	1
Eulimastoma harbisonae Bartsch, 1955	6		D
Eulimastoma weberi (Morrison, 1965)	D		D
Odostomia bushiana Bartsch, 1909	D		D
Odostomia dianthophila Wells and Wells, 1961	D		D
Odostomia gibbosa Bush, 1909	3		1
Odostomia impressa (Say, 1821)	D	15	D
Odostomia seminuda (C. B. Adams, 1837)	D		5
Odostomia (cf. *Pyrgulina*) sp.			D
Peristichia toreta Dall, 1889			D
Sayella crosseana (Dall, 1885)	17	D	D
Sayella livida Rehder, 1935	8	D	D
Turbonilla (cf. *Turbonilla*) sp. A			4
Turbonilla (cf. *Mormula*) sp. A			D
Turbonilla (*Chemnitzia*) sp. A			3
Turbonilla (*Chemnitzia*) sp. B			D
Turbonilla (*Chemnitzia*) sp. C			D
Turbonilla (*Chemnitzia*) sp. D			7
Turbonilla (*Chemnitzia*) sp. F	2	D	3
Turbonilla unilirata Bush, 1899			D
Turbonilla elegans (Orbigny, 1842)			D
Turbonilla speira Ravenel, 1859			D
Turbonilla (*Pyrgiscus*) sp. B	D		3
Turbonilla (*Pyrgiscus*) sp. C			D
Turbonilla (*Pyrgiscus*) sp. D	26	1	14
Turbonilla (*Pyrgiscus*) sp. F			1
Turbonilla (*Pyrgiscus*) sp. I			2
Turbonilla (*Pyrgiscus*) sp. J			D
Turbonilla (*Pyrgiscus*) sp. K			D
Turbonilla (*Strioturbonilla*) sp. A			1
Turbonilla (*Strioturbonilla*) sp. D			18
Family Acteonidae Orbigny, 1842			
Acteon punctostriatus (C. B. Adams, 1840)	6	1	15
Ringicula semistriata Orbigny, 1842			D
Family Acteocinidae Pilsbry, 1921			
Acteocina canaliculata (Say, 1822)	38	D	8
Family Cylichnidae A. Adams, 1850			
Cylichnella bidentata (Orbigny, 1841)	5		2
Family Bullidae Rafinesque, 1815			
Bulla striata Bruguière, 1792	1	1	D
Family Haminoeidae Pilsbry, 1895			
Haminoea antillarum (Orbigny, 1841)	D	D	
Haminoea succinea (Conrad, 1846)	D		D
Atys riiseana Mörch, 1875			D
Family Retusidae Thiele, 1926			
Pyrunculus caelatus (Bush, 1885)			1
Volvulella persimilis (Mörch, 1875)			5
Volvulella texasiana Harry, 1967			D
Family Cuvieridae Gray, 1840			
Cavolina longirostris (Blainville, 1821)			D

Phylum Mollusca	L*	Z	S
Cavolina uncinata (Rang, 1829)			D
Creseis acicula (Rang, 1828)			1
Family Siphonariidae Gray, 1840			
Siphonaria pectinata (Linné, 1758)			D
Class Bivalvia Linné, 1758			
Family Nuculidae Gray, 1824			
Nucula proxima Say, 1822			55
Family Nuculanidae Meek, 1864			
Nuculana acuta (Conrad, 1831)	300	3	14
Nuculana concentrica (Say, 1834)	D		10
Family Arcidae Lamarck, 1809			
Arca imbricata Bruguière, 1789			D
Anadara brasiliana (Lamarck, 1819)	D		D
Anadara chemnitzii (Philippi, 1851)			D
Anadara transversa (Say, 1822)	79	4	62
Barbatia domingensis (Lamarck, 1819)			D
Lunarca ovalis (Bruguière, 1789)	D	D	1
Family Noetiidae Stewart, 1930			
Noetia ponderosa (Say, 1822)	D		1
Family Mytilidae Rafinesque, 1815			
Amygdalum papyrium (Conrad, 1846)	28	1	D
Brachidontes exustus (Linné, 1758)	6	2	D
Ischadium recurvum (Rafinesque, 1820)	D		D
Modiolus americanus (Leach, 1815)			2
Musculus lateralis (Say, 1822)			2
Lioberus castaneus (Say, 1822)			3
Family Pinnidae Leach, 1819			
Atrina serrata (Sowerby, 1825)			1
Family Pectinidae Rafinesque, 1815			
Pecten raveneli Dall, 1898			D
Aequipecten muscosus (Wood, 1828)			D
Argopecten gibbus (Linné, 1758)			D
Argopecten irradians amplicostatus Dall, 1898		D	D
Family Plicatulidae Watson, 1930			
Plicatula gibbosa Lamarck, 1801			D
Family Anomiidae Rafinesque, 1815			
Anomia simplex Orbigny, 1842	D	D	D
Family Limidae Rafinesque, 1815			
Lima cf. *locklini* McGinty, 1955			D
Family Ostreidae Rafinesque, 1815			
Ostrea equestris Say, 1834	D	1	D
Crassostrea virginica (Gmelin, 1791)	D	2	D
Family Lucinidae Fleming, 1828			
Lucina pectinata (Gmelin, 1791)	8	4	
Anodontia alba Link, 1807			D
Divaricella quadrisulcata (Orbigny, 1842)			D
Linga amiantus (Dall, 1901)	6		259
Parvilucina multilineata (Tuomey and Holmes, 1857)	31		132
Pseudomiltha floridana (Conrad, 1833)			D
Family Ungulinidae H. and A. Adams, 1857			
Diplodonta semiaspera (Philippi, 1836)	D		1
Diplodonta soror C. B. Adams, 1852			189
Family Chamidae Lamarck, 1809			
Chama congregata Conrad, 1833			1
Chama macerophylla (Gmelin, 1791)			D
Arcinella cornuta Conrad, 1866			D
Pseudochama radians (Lamarck, 1819)			D
Family Kelliidae Forbes and Hanley, 1848			
Aligena texasiana Harry, 1969	19	1	9
Family Montacutidae Clark, 1855			
Mysella planulata (Stimpson, 1857)	141	D	193
Pythinella cuneata (Verrill and Bush, 1898)			1
Family Sportellidae Dall, 1899			
Ensitellops sp.	D		D
Family Carditidae Fleming, 1820			
Carditamera floridana Conrad, 1838	D		D
Family Crassatellidae Férussac, 1822			
Crassinella lunulata (Conrad, 1834)	5		14
Family Cardiidae Oken, 1818			
Dinocardium robustum (Lightfoot, 1786)	D		D
Laevicardium laevigatum (Linné, 1758)			D
Laevicardium mortoni (Conrad, 1830)	79	1	D
Trachycardium muricatum (Linné, 1758)	D		D
Family Mactridae Lamarck, 1809			
Mactra fragilis Gmelin, 1791	1	D	D
Anatina anatina (Spengler, 1802)			1
Mulinia lateralis (Say, 1822)	321	4	3

Phylum Mollusca	L*	Z	S
Raeta plicatella (Lamarck, 1818)	D		D
Rangia cuneata (Sowerby, 1831)	D		D
Rangia flexuosa (Conrad, 1839)			D
Family Mesodesmatidae Gray, 1839			
Ervilia concentrica (Holmes, 1860)		D	D
Family Solenidae Lamarck, 1809			
Solen viridis Say, 1821			6
Ensis minor Dall, 1900	105		2
Family Tellinidae Blainville, 1814			
Tellina aequistriata Say, 1824			1
Tellina alternata Say, 1822	D	D	6
Tellina iris Say, 1822			11
Tellina lineata Turton, 1819	D		
Tellina squamifera Deshayes, 1855			D
Tellina tampaensis Conrad, 1866	205		
Tellina texana Dall, 1900	59	D	D
Tellina versicolor DeKay, 1843	6		135
Tellidora cristata (Récluz, 1842)	D		D
Strigilla mirabilis (Philippi, 1841)			62
Macoma brevifrons (Say, 1834)	D		
Macoma constricta (Bruguière, 1792)		D	
Macoma tageliformis Dall, 1900			1
Macoma tenta (Say, 1834)	39	20	D
Family Donacidae Fleming, 1828			
Donax texasianus Philippi, 1847			D
Donax variabilis Say, 1822	D		D
Family Semelidae Schumacher, 1817			
Semele bellastriata (Conrad, 1837)			D
Semele nuculoides (Conrad, 1841)			D
Semele proficua (Pulteney, 1799)			D
Abra aequalis (Say, 1822)	169	6	259
Cumingia tellinoides (Conrad, 1831)	62	D	D
Family Solecurtidae Orbigny, 1846			
Solecurtis cumingianus Dunker, 1861			D
Tagelus divisus (Spengler, 1794)	2	D	D
Tagelus plebeius (Lightfoot, 1786)	106	D	
Family Dreissenidae Gray, 1840			
Mytilopsis leucophaeata (Conrad, 1831)	D		
Family Trapeziidae Lamy, 1920			
Coralliophaga coralliophaga (Gmelin, 1791)	D		
Family Corbiculidae Gray, 1847			
Polymesoda maritima (Orbigny, 1842)	11	D	D
Family Veneridae Rafinesque, 1815			
Agriopoma texasiana (Dall, 1892)	2		D
Anomalocardia auberiana (Orbigny, 1842)	26	D	D
Callista eucymata (Dall, 1890)			1
Chione cancellata (Linné, 1767)	60	3	D
Chione clenchi Pulley, 1952			3
Chione grus (Holmes, 1858)	D		3
Chione intapurpurea (Conrad, 1849)			D
Cyclinella tenuis (Récluz, 1852)	2	D	4
Dosinia elegans Conrad, 1846			D
Dosinia discus (Reeve, 1850)	D		5
Gouldia cerina (C. B. Adams, 1845)			2
Mercenaria campechiensis (Gmelin, 1791)	2		D
Pitar sp.			D
Family Petricolidae Deshayes, 1831			
Petricola pholadiformis (Lamarck, 1818)	D		D
Family Corbulidae Lamarck, 1818			
Corbula caribaea Orbigny, 1842		D	17
Corbula contracta Say, 1822	D	1	67
Corbula dietziana C. B. Adams, 1852			3
Varicorbula operculata (Philippi, 1848)	D		D
Family Gastrochaenidae Gray, 1840			
Gastrochaena hians (Gmelin, 1791)			1
Family Hiatellidae Gray, 1824			
Hiatella arctica (Linné, 1767)		1	
Family Pholadidae Lamarck, 1809			
Pholas campechiensis Gmelin, 1791	D		D
Barnea truncata (Say, 1822)	D		D
Cyrtopleura costata (Linné, 1758)	1		D
Diplothyra smithii Tryon, 1862			D
Martesia cuneiformis (Say, 1822)			D
Family Lyonsiidae Fischer, 1887			
Lyonsia hyalina floridana Conrad, 1849	340	3	4
Family Pandoridae Rafinesque, 1815			
Pandora bushiana Dall, 1886			2

Phylum Mollusca	L*	Z	S
Pandora trilineata Say, 1822	D		1
Family Periplomatidae Dall, 1895			
Periploma margaritaceum (Lamarck, 1801)	3		20
Periploma orbiculare Guppy, 1878			D
Periploma sp.			D
Family Cuspidariidae Dall, 1886			
Cardiomya ornatissima (Orbigny, 1842)			D
Family Verticordiidae Stoliczka, 1871			

Phylum Mollusca	L*	Z	S
Verticordia ornata (Orbigny, 1842)			D
Class Scaphopoda Bronn, 1862			
Family Dentaliidae Gray, 1834			
Dentalium eboreum Conrad, 1846			26
Dentalium texasianum Philippi, 1848	D		35
Family Siphonodentaliidae Simroth, 1894			
Cadulus carolinensis Bush, 1885	D		51

Distribution of Polychaete Species

Species	L*	Z	S	TOTAL
Phylum Annelida				
Class Polychaeta				
Family Spionidae Grube, 1850	2	1	5	8
Paraprionospio pinnata (Ehlers, 1901)	18	2	732	752
Apoprionospio pygmaea (Hartman, 1961)	1		202	203
Spiophanes bombyx (Claparède, 1870)	14		136	150
Prionospio steenstrupi Malmgren, 1867			59	59
Prionospio heterobranchia Moore, 1907	703	54	37	794
Spio pettiboneae Foster, 1971	45		5	50
Scolelepis texana Foster, 1971			3	3
Streblospio benedicti Webster, 1879	304	17	1	322
Aonides mayaguezensis Foster, 1969			1	1
Laonice cirrata (Sars, 1851)			80	80
Malacoceros vanderhorsti (Augener, 1927)	2		18	20
Carazziella hobsonae Blake, 1979	4		1	5
Minuspio cirrobranchiata (Day, 1961)			4	4
Polydora socialis (Schmarda, 1861)	4		2	6
Polydora ligni Webster, 1879	95		5	100
Polydora websteri Hartman, 1943			1	1
Polydora cf. *aggregata*			3	3
Prionospio sp.			19	19
Prionospio cf. *steenstrupi*			5	5
Prionospio cf. *heterobranchia*			3	3
Minuspio sp.			14	14
Minuspio cf. *cirrobranchiata*			9	9
Spiophanes sp. A			2	2
Spiophanes sp.		1	9	10
Spio sp.			1	1

L = Lower Laguna Madre; Z = South Bay; S = Inner Shelf
*Includes Arroyo Colorado River, Brownsville Ship Channel, Port Mansfield Channel, Laguna Madre Intracoastal Waterway

Species	L*	Z	S	TOTAL
Polydora sp. A			1	1
Polydora sp.	6	6	3	15
Malacoceros sp.			16	16
Scolelepis sp.	14		7	21
Polydora cf. *socialis*	7	3		10
Family Nereidae Johnston, 1845	11	1	2	14
Nereis micromma Harper, 1979			448	448
Ceratonereis irritabilis (Webster, 1879)	4		12	16
Nereis succinea Frey and Leuckart, 1847	1		13	14
Nereis falsa Quatrefages, 1865			1	1
Nereis sp.			6	6
Ceratocephale sp.			19	19
Ceratonereis sp.			3	3
Nereis cf. *succinea*	5			5
Laeonereis culveri (Webster, 1880)	58			58
Platynereis dumerilii (Audouin and Milne-Edwards, 1833)	33	1		34
Family Capitellidae Grube, 1862	13		9	22
Notomastus latericeus Sars, 1851	1		28	29
Notomastus hemipodus Hartman, 1947			13	13
Notomastus americanus Day, 1973			27	27
Notomastus lobatus Hartman, 1947	4	1	1	6
Notomastus cf. *daueri*			1	1
Notomastus sp.			52	52
Capitella capitata (Fabricius, 1780)	308	19	1	328
Mediomastus californiensis Hartman, 1944	349	34	87	470
Capitomastus sp.	1			1
Family Lumbrineridae Malmgren, 1867				
Lumbrineris verrilli Perkins, 1979	3		537	540
Lumbrineris tenuis Verrill, 1873			86	86
Lumbrineris latreilli (Audouin and Milne-Edwards, 1833)			14	14

Species	L*	Z	S	TOTAL
Ninoe nigripes Verrill, 1873			3	3
Lumbrineris ernesti Perkins, 1979			122	122
Lumbrineris januarii (Grube, 1878)			12	12
Lumbrineris cf. *magalhaensis*			10	10
Lumbrineris cf. *ernesti*			1	1
Lumbrineris cf. *tenuis*			44	44
Lumbrineris sp. D			2	2
Lumbrineris sp.			13	13
Family Paraonidae Cerruti, 1909			6	6
Aricidea taylori Pettibone, 1965	7		139	146
Aricidea fragilis Webster, 1879			21	21
Aricidea wassi Pettibone, 1965			17	17
Cirrophorus branchiatus Ehlers, 1908			6	6
Levinsenia gracilis Tauber, 1879			5	5
Cirrophorus sp.			63	63
Aricidea sp.	2		33	35
Aricidea cf. *wassi*			3	3
Aricidea cf. *taylori*			3	3
Aricidea cf. *fragilis*			10	10
Family Maldanidae Malmgren, 1867	38		23	61
Clymenella torquata (Leidy, 1855)	20	5	85	110
Asychis elongata Verrill, 1873	16	1	12	29
Euclymene lombricoides (Quatrefages, 1865)	33		8	41
Axiothella mucosa (Andrews, 1891)	15		12	27
Euclymene cf. *lombricoides*	5			5
Euclymene sp.		23	10	33
Asychis sp.	1		3	4
Praxillella sp.			7	7
Axiothella sp.	2		7	9
Family Oweniidae Rioja, 1917				
Owenia fusiformis Delle Chiaje, 1844			43	43
Family Goniadidae Kinberg, 1866	2		4	6
Glycinde solitaria (Webster, 1879)	1			1
Goniada littorea Hartman, 1950			13	13
Goniada teres Treadwell, 1931			3	3
Goniada maculata Oersted, 1843	6		1	7
Goniada sp.			4	4
Ophioglycera sp.			3	3
Glycinde cf. *nordmanni*	11			11
Glycinde cf. *solitaria*	18			18
Glycinde sp.	12	2		14
Family Cossuridae Day, 1963				
Cossura delta Reish, 1958	13		33	46
Family Amphinomidae Savigny, 1818	1		1	2
Pseudeurythoe ambigua (Monro, 1933)			9	9
Family Pilargidae Saint-Joseph, 1899				
Cabira incerta Webster, 1879			5	5
Sigambra tentaculata (Treadwell, 1941)	12		12	24

Species	L*	Z	S	TOTAL
Sigambra cf. *bassi*			2	2
Ancistrosyllis jonesi Pettibone, 1966			1	1
Litocorsa stremma Pearson, 1970			18	18
Pilargis berkeleyae Monro, 1933			3	3
Pilargis cf. *verrucosa*			2	2
Cabira cf. *incerta*			1	1
Family Glyceridae Grube, 1850				
Glycera americana Leidy, 1855	7	1	68	76
Glycera oxycephala Ehlers, 1887			31	31
Glycera papillosa Grube, 1857			1	1
Glycera capitata Oersted, 1843			2	2
Glycera sp. A	1		6	7
Glycera cf. *oxycephala*			13	13
Glycera cf. *americana*			1	1
Glycera sp.	9		27	36
Family Pectinariidae Quatrefages, 1865				
Pectinaria gouldii Verrill, 1873	1		3	4
Family Orbiniidae Hartman, 1942				
Haploscoloplos fragilis (Verrill, 1873)	8		6	14
Haploscoloplos foliosus Hartman, 1951	88	4	62	154
Scoloplos rubra (Webster, 1879)	6		23	29
Scoloplos acmeceps Chamberlin, 1919			3	3
Haploscoloplos sp.	6		6	12
Scoloplos sp.			4	4
Family Nephtyidae Grube, 1850	9		8	17
Aglaophamus verrilli (McIntosh, 1885)			257	257
Nephtys bucera Ehlers, 1868			17	17
Nephtys incisa Malmgren, 1865	1		3	4
Nephtys cf. *incisa*			5	5
Nephtys picta Ehlers, 1868			4	4
Aglaophamus cf. *circinata*			1	1
Nephtys sp.			29	29
Family Sigalionidae Malmgren, 1867			3	3
Sthenelais boa (Johnston, 1833)	2		47	49
Sthenolepis japonica (McIntosh, 1885)			1	1
Sthenolepis sp.	3		3	6
Family Dorveillidae Chamberlin, 1919				
Schistomeringos rudolphi (Delle Chiaje, 1828)	3		5	8
Family Polynoidae Malmgren, 1867				
Harmothoe trimaculata (Treadwell, 1924)			2	2
Harmothoe imbricata (Linné, 1767)			3	3
Lepidasthenia maculata Potts, 1910			4	4
Lepidasthenia varia Treadwell, 1917			1	1
Lepidonotus sublevis Verrill, 1873			8	8
Eunoe sp.			2	2

Species	L*	Z	S	TOTAL
Lepidasthenia sp.			3	3
Lepidasthenia sp. A			1	1
Lepidonotus sp.			2	2
Harmothoe sp.			2	2
Lepidasthenia cf. *maculata*			1	1
Family Cirratulidae Carus, 1863			3	3
Tharyx setigera Hartman, 1945			29	29
Tharyx marioni (Saint-Joseph, 1894)	10	20	124	154
Caulleriella sp.			2	2
Cirratulus sp.			2	2
Tharyx cf. *marioni*	32		4	36
Tharyx sp.	2	1	39	42
Family Polyodontidae Buchanan, 1894				
Polyodontes lupinus (Stimpson, 1856)			1	1
Eupanthalis sp. A			5	5
Family Magelonidae Cunningham and Ramage, 1888				
Magelona cf. *phyllisae*	8		605	613
Magelona pettiboneae Jones, 1963	21		102	123
Magelona riojai Jones, 1963	15		27	42
Magelona sp. A	2		68	70
Magelona sp. C			1	1
Magelona sp.	2		11	13
Family Phyllodocidae Williams, 1851	2		1	3
Eteone heteropoda Hartman, 1951	100	4		104
Eulalia sanguinea (Oersted, 1843)	12		1	13
Phyllodoce arenae Webster, 1879	1		13	14
Phyllodoce castanea (Marenzeller, 1879)			3	3
Phyllodoce mucosa Oersted, 1843	2		13	15
Phyllodoce sp. D	2			2
Phyllodoce sp.	1		10	11
Eteone sp.	1		1	2
Paranaitis sp.			1	1
Family Arabellidae Hartman, 1944				
Drilonereis magna (Webster and Benedict, 1887)		2	6	8
Arabella iricolor (Montagu, 1804)			3	3
Drilonereis sp. A			4	4
Arabella sp. A			1	1
Notocirrus sp. A			1	1
Drilonereis cf. *magna*			1	1
Drilonereis sp.			1	1
Family Hesionidae Sars, 1862	2			2
Gyptis brevipalpa (Hartmann-Schröder, 1959)	9	2	16	27
Family Eulepethidae Chamberlin, 1919				
Grubeulepis mexicana (Berkeley and Berkeley, 1939)			1	1
Grubeulepis sp.			1	1
Family Sabellidae Malmgren, 1867	2		5	7
Chone duneri Malmgren, 1867	400		34	434
Chone sp.	54		2	56
Potamilla reniformis (Leuckart, 1849)	4	4	36	44
Megalomma bioculatum (Ehlers, 1887)	3	6		9
Family Syllidae Grube, 1850				
Exogone dispar Webster, 1879	113	2		115
Syllis gracilis Grube, 1840			1	1
Syllis cornuta Rathke, 1843	110	6		116
Brania clavata (Claparède, 1863)	5			5
Exogone cf. *dispar*		6		6
Syllis cf. *cornuta*	14			14
Syllis sp.	4		2	6
Exogone sp.			1	1
Family Chaetopteridae Malmgren, 1867			1	1
Spiochaetopterus costarum oculatus Webster, 1879	3		19	22
Chaetopterid sp. B			1	1
Family Trichobranchidae Malmgren, 1866				
Terebellides stroemi Sars, 1835	4		39	43
Family Eunicidae Savigny, 1818	1			1
Marphysa sanguinea (Montagu, 1815)			9	9
Lysidice ninetta Audouin and Milne-Edwards, 1833	2			2
Marphysa cf. *depressa*	1			1
Marphysa sp. A	4		2	6
Marphysa cf. *sanguinea*	1	7	2	10
Marphysa sp.			4	4
Eunicid sp. A	1			1
Family Chrysopetalidae Ehlers, 1864				
Paleanotus heteroseta Hartman, 1945	7		24	31
Family Ampharetidae Malmgren, 1867	1		7	8
Melinna maculata Webster, 1879	306	2	46	354
Isolda pulchella Müller, 1858			262	262
Ampharete americana Day, 1973			4	4
Ampharete acutifrons Grube, 1860			39	39
cf. *Amythasides* sp.			2	2
Family Terebellidae Malmgren, 1867			3	3
Pista palmata (Verrill, 1873)	19		18	37
Pista brevibranchia Caullery, 1915			2	2
Pista quadrilobata (Augener, 1918)			3	3
Pista cf. *palmata*	11			11
Pista cristata (Müller, 1776)	1		9	10
Loimia medusa (Savigny, 1818)			4	4
Lanice cf. *conchilega*			5	5
Pista cf. *quadrilobata*			2	2
Pista sp.			11	11
Polycirrus sp.			3	3
Streblosoma sp.	2		1	3
Polycirrinae			1	1
cf. *Eupolymnia* sp.	25			25
Family Serpulidae Johnston, 1865			1	1
Hydroides dianthus (Verrill, 1873)	3	2	1	6

Species	L*	Z	S	TOTAL
Hydroides protulicola Benedict, 1887			33	33
Hydroides sp.			1	1
Serpula sp.	2			2
Family Opheliidae Malmgren, 1867				
Armandia agilis (Andrews, 1891)			369	369
Armandia maculata (Webster, 1884)	54	1	21	76
Armandia sp.			3	3
Family Onuphidae Kinberg, 1865	1			1
Diopatra cuprea (Bosc, 1802)	26		242	268
Onuphis texana Fauchald, 1982			91	91
Onuphis eremita oculata Hartman, 1951	1		145	146
Diopatra tridentata Hartman, 1947			34	34
Kinbergonuphis virgata (Fauchald, 1980)			63	63
Onuphis sp.			1	1
Diopatra sp.			1	1
Diopatra cf. *cuprea*			2	2
Family Sabellariidae Johnston, 1865				
Sabellaria vulgaris vulgaris Verrill, 1873			3	3
Sabellaria sp.	1			1
Family Flabelligeridae Saint-Joseph, 1894				
Piromis sp.	1			1
Family Trochochaetidae Pettibone, 1963				
Poecilochaetus sp.			3	3

Distribution of Crustacean Species

Species	L*	Z	S	TOTAL
Subclass Cirripedia				
Balanus sp.	162			162
Lepas sp.			1	1
Order Mysidacea			2	2
Bowmaniella cf. *dissimilis* Coifmann, 1937	1		7	8
Mysidopsis almyra Bowman, 1964	1			1
Mysidopsis bigelowi Tattersall, 1926			2	2
Order Cumacea				
Cyclaspis varians Calman, 1912	17		21	38
Oxyurostylis salinoi Da Silva Brum, 1966	212		15	227
Order Apseudidae				
Apseudes sp.			69	69
Order Tanaidacea				
Hargeria rapax (Harger, 1879)	88		1	89
Order Isopoda				
Ancinus depressus (Say, 1818)			2	2
Anthelura sp.			1	1
Apanthura magnifica Menzies and Frankenberg, 1966			2	2
Chiridotea excavata Harper, 1974			8	8
Cirolana parva Hansen, 1890			1	1
Cymodoce faxoni (Richardson, 1905)	43		1	44
Edotea montosa (Stimpson, 1853)	26	2		28
Erichsonella attenuata (Harger, 1873)	4			4
Erichsonella filiformis isabellensis Menzies, 1951	61			61
Ptilanthura tricarina Menzies and Frankenberg, 1966			17	17
Xenanthura brevitelson Barnard, 1925	17		18	35
Order Amphipoda				
Family Ampeliscidae				
Ampelisca agassizi (Judd, 1896)			125	125
Ampelisca verrilli Mills, 1967			40	40
Ampelisca cristoides Barnard, 1954			134	134
Ampelisca sp.			9	9
Ampelisca abdita Mills, 1964	856	33		889
Family Ampithoidae				
Cymadusa compta (Smith, 1873)	150	21		171
Family Amphilochidae				
Amphilochus casahoya McKinney, 1978			3	3
Gitanopsis laguna McKinney, 1978		1	2	3
Gitanopsis sp.			1	1
Family Aoridae				
Grandidierella bonnieroides Stephensen, 1948	77	7		84
Lembos sp.	4			4
Unciola irrorata Say, 1818			38	38
Family Corophiidae	16			16
Cerapus tubularis Say, 1818	22		1	23
Corophium acherusicum Costa, 1857	27		2	29
Corophium louisianum Shoemaker, 1934	6			6
Corophium cf. *simile* Shoemaker, 1934	15	4		19
Corophium sp.	39		2	41
Erichthonius brasiliensis (Dana, 1853)	16		31	47
Family Gammaridae				
Gammarus mucronatus (Say, 1818)	35			35
Family Haustoriidae				
Acanthohaustorius sp.	3		19	22
Protohaustorius cf. *bousfieldi* Robertson and Shelton, 1978			95	95

L = Lower Laguna Madre; Z = South Bay; S = Inner Shelf
*Includes Arroyo Colorado River, Brownsville Ship Channel, Port Mansfield Channel, Laguna Madre Intracoastal Waterway

Species	L*	Z	S	TOTAL
Parahaustorius cf. *obliquus* Robertson and Shelton, 1978			3	3
Platyschnopus sp.			141	141
Family Isaidae				
Microprotopus raneyi Wigley, 1966	2		8	10
Photis macromanus McKinney, Kalke, and Holland, 1978			8	8
Photis sp.			9	9
Family Liljeborgiidae				
Listriella barnardi Wigley, 1963	4		4	8
Family Melitidae				
Elasmopus levis (Smith, 1873)	117	12		129
Melita nitida Smith, 1873	11		3	14
Family Oedicerotidae				
Monoculodes nyei Shoemaker, 1935			43	43
Synchelidium americanum Bousfield, 1973			10	10
Family Phoxocephalidae				
Trichophoxus floridanus (Shoemaker, 1933)			276	276
Family Pontogeneiidae				
Pontogeneia bartschi Shoemaker, 1948	25	1	4	30
Family Stenethoidae				
Stenethoe cf. *minuta* Holmes, 1905			1	1
Stenethoe sp.			2	2
Family Synopiidae				
Tiron tropakis Barnard, 1972			5	5
Suborder Caprellidea	58		9	67
Suborder Hyperiidea			2	2
Order Stomatopoda				
Squilla empussa Say, 1818			1	1
Order Decapoda				
Family Sergestidae				
Acetes americanus Ortmann, 1893			10	10
Family Pasaphaeidae				
Leptochela cf. *bermudensis* Gurney, 1939			1	1
Leptochela serratorbita Bate, 1888			7	7
Family Alpheidae				
Automate cf. *evermanni* Rathbun, 1901			25	25
Alpheopsis sp.			1	1
Alpheus sp.			2	2
Family Thalassinidae				
Callianassa cf. *biformis* Biffar, 1971			2	2
Callianassa sp.			1	1
Family Paguridae	1			1
Pagurus brevidactylus Stimpson, 1859			2	2
Pagurus longicarpus Say, 1817			5	5
Pagurus sp.	3		6	9
Family Porcellanidae				
Euceramus praelongus Stimpson, 1860	1		42	43
Family Albuneidae				
Albunea paretii Guérin, 1853			13	13
Lepidopa websteri Benedict, 1903			1	1
Family Portunidae				
Callinectes sp.	6		5	11
Ovalipes guadalupensis (Saussure, 1858)			1	1
Family Xanthidae				
Eurypanopeus depressus (Smith, 1869)	6			6
Menippe mercenaria (Say, 1818)			1	1
Micropanope nuttingii (Rathbun, 1898)			6	6
Micropanope cf. *sculptides* Stimpson, 1871			1	1
Neopanope texana (Stimpson, 1859)	9			9
Panopeus herbstii Milne-Edwards, 1834			4	4
Rhithropanopeus harrisii (Gould, 1841)	16		4	20
Family Gonoplacidae				
Chasmocarcinus mississippiensis Rathbun, 1931			4	4
Speocarcinus lobatus (Say, 1817)			9	9
Family Pinnotheridae				
Pinnixa cf. *retinens* Rathbun, 1918	1		3	4
Pinnixa sp.	16		2	18
Pinnotheres ostreum Say, 1817			1	1
Family Raninidae				
Raninoides louisianensis Rathbun, 1933			14	14
Family Penaeidae				
Metapenaeopsis sp.	1			1
Penaeus sp.			1	1
Trachypenaeus constrictus (Stimpson, 1871)			1	1
Family Palaemonidae				
Periclimenes sp.			3	3
Family Sicyoniidae				
Sicyonia dorsalis Kingsley, 1878			1	1
Family Leucosidae				
Persephona crinata Rathbun, 1931			1	1
Persephona sp.			1	1
Family Calappidae				
Hepatus pudibundus (Herbst, 1785)			1	1
Family Processidae				
Processa cf. *bermudensis* (Rankin, 1900)			1	1
Processa cf. *hemphilli* Manning and Chace, 1971			1	1
Family Majidae				
Collodes leptocheles Rathbun, 1894			1	1
Order Pycnogonidea			5	5

Distribution of Other Phyla

Species	L*	Z	S	TOTAL
Phylum Cnidaria				
Class Anthozoa				
Order Zoantharia				
cf. *Palythoa texaensis*			122	122
Order Actiniaria	75		47	122
Anemones (unidentified)				
Order Pennatulacea				
Family Renillidae				
Renilla mülleri Kölliker, 1872			2	2
Family Pennatulacea (Sea Pen)			1	1
Class Hydrozoa				
Hydroid polyps			NC	
Phylum Platyhelminthes				
Class Turbellaria				
Order Polycladida	14		2	16
Phylum Nemertinea				
Nemerteans (unidentified)	27	8	156	191
Phylum Aschelminthes				
Class Nematoda			3	3
Phylum Chaetognatha				
Chaetognaths (unidentified)	1		2	3
Phylum Bryozoa				
Bryozoans (unidentified)			NC	
Phylum Brachiopoda			1	1
Phylum Phoronida				
Phoronis architecta Andrews, 1890	32		22	54
Phylum Annelida				
Class Oligochaeta	52		1	53
Phylum Sipunculida				
Phascolion strombi (Montagu, 1804)	24		43	67
Family Aspidosiphonidae			99	99
Sipunculida (unidentified)			40	40
Phylum Echinodermata				
Class Ophiuroidea				
Hemipholis elongata (Say, 1825)			9	9
Micropholis atra (Stimpson, 1852)	5		3	8
Ophiophragmus septus Lütken, 1859			4	4
Ophiophragmus cf. *moorei*			1	1
Ophiolepis elegans Lütken, 1859			1	1
Brittlestars (unidentified)	2		32	34
Class Echinoidea				
cf. *Lytechinus variegatus*			2	2
Sea urchin (unidentified)			1	1
Class Holothuroidea				
Holothurians (unidentified)	2			2
Leptosynapta crassipatina (Clark, 1924)	11			11
Pentamera pulcherrima Ayres, 1854	6			6
Phylum Echiurida	1			1
Phylum Hemichordata				
Class Enteropneusta				
Phylum Chordata				
Subphylum Tunicata	4			4
Tunicates (unidentified)				
Subphylum Cephalochordata				
Branchiostoma sp.	1		51	52
Subphylum Vertebrata				
Class Osteichthyes				
Family Sygnathidae				
Hippocampus sp.	1			1
Family Ophichthidae				
Eel (unidentified)	1			1
Fish (unidentified)			2	2
Unknown phylum			1	1

L = Lower Laguna Madre; Z = South Bay; S = Inner Shelf; NC = Not Counted
*Includes Arroyo Colorado River, Brownsville Ship Channel, Port Mansfield Channel, Laguna Madre Intracoastal Waterway

Table 13. Characteristic species in macroinvertebrate assemblages of the Brownsville-Harlingen area.

- Bay-Estuary-Lagoon
- Lower Laguna Madre
  - Bay Margin
  - Mollusca
    - Bivalvia
    - *Tellina tampaensis*
    - *Anomalocardia auberiana*
  - Polychaeta
    - *Scoloplos foliosus*
  - Crustacea
    - *Hargeria rapax*
  - Grassflat
    - Mollusca
    - Bivalvia
    - *Laevicardium mortoni*
    - *Tagelus plebeius*
    - *Cumingia tellinoides*
    - *Chione cancellata*
    - *Amygdalum papyrium*
  - Gastropoda
    - *Caecum pulchellum*
    - *Bittium varium*
  - Polychaeta
    - *Capitella capitata*
    - *Melinna maculata*
    - *Chone duneri*
    - *Prionospio heterobranchia*
    - *Syllis cornuta*
    - *Eteone heteropoda*
    - *Polydora ligni*
    - *Mediomastus californiensis*
    - *Streblospio benedicti*
    - *Exogone dispar*
  - Crustacea
    - *Ampelisca abdita*
    - *Hargeria rapax*
    - *Cymadusa compta*
    - *Oxyurostylis salinoi*
    - *Erichsonella filiformis isabelensis*
    - *Cymodoce faxoni*
  - Bay Center
  - Mollusca
    - Bivalvia
    - *Lyonsia hyalina floridana*
    - *Mulinia lateralis*
    - *Nuculana acuta*
    - *Ensis minor*
  - Polychaeta
    - *Mediomastus californiensis*
  - Inlet influenced
  - Mollusca

- Bivalvia
  - *Abra aequalis*

- Polychaeta
  - *Armandia maculata*
  - *Cossura delta*
  - *Sigambra tentaculata*
  - *Mediomastus californiensis*

South Bay

- Grassflat
- Mollusca
- Bivalvia
  - *Macoma tenta*
- Gastropoda
  - *Bittium varium*
- Polychaeta
  - *Prionospio heterobranchia*
  - *Mediomastus californiensis*
- Crustacea
  - *Ampelisca abdita*
  - *Cymadusa compta*
- Oyster reef
- Mollusca
- Bivalvia
  - *Crassostrea virginica*
  - *Brachidontes exustus*
- Gastropoda
  - *Odostomia impressa*
- Polychaeta
  - *Tharyx marioni*
  - *Hydroides dianthus*
  - *Prionospio heterobranchia*
- Arroyo Colorado
- River influenced
- Polychaeta
  - *Streblospio benedicti*
  - *Laeonereis culveri*

Inner Shelf

- Nearshore
- Mollusca
- Bivalvia
  - *Tellina versicolor*
  - *Parvilucina multilineata*
  - *Strigilla mirabilis*
- Gastropoda
  - *Natica pusilla*
  - *Polinices duplicatus*
- Scaphopoda
  - *Dentalium eboreum*
- Polychaeta
  - *Spiophanes bombyx*
  - *Apoprionospio pygmaea*
  - *Magelona pettiboneae*

    - *Onuphis eremita oculata*
    - *Armandia agilis*
    - *Scoloplos foliosus*
    - *Scoloplos fragilis*
  - Crustacea
    - *Trichophoxus floridanus*
    - *Platyschnopus* sp. "A"
    - *Protohaustorius* cf. *P. bousfieldi*
    - *Monoculodes* cf. *M. nyei*
    - *Tiron tropakis*
    - *Synchelidium americanum*
    - *Bowmaniella* cf. *dissimilis*
- Transitional
  - Mollusca
  - Bivalvia
    - *Abra aequalis*
    - *Linga amiantus*
    - *Diplodonta* cf. *D. soror*
    - *Tellina versicolor*
    - *Parvilucina multilineata*
  - Gastropoda
    - *Natica pusilla*
  - Scaphopoda
    - *Dentalium texasianum*
  - Polychaeta
    - *Isolda pulchella*
    - *Clymenella torquata*
    - *Sthenelais boa*
    - *Magelona* cf. *M. phyllisae*
    - *Aglaophamus verrilli*
    - *Lumbrineris tenuis*
    - *Diopatra cuprea*
    - *Laonice cirrata*
    - *Paraprionospio pinnata*
    - *Nereis micromma*
    - *Glycera americana*
    - *Lumbrineris ernesti*
    - *Lumbrineris verrilli*
    - *Spiophanes bombyx*
  - Crustacea
    - *Euceramus praelongus*
    - *Uniciola irrorata*
- Outer
  - Mollusca
  - Bivalvia
    - *Linga amiantus*
    - *Nucula proxima*
  - Polychaeta
    - *Magelona* cf. *M. phyllisae*
    - *Diopatra cuprea*
    - *Paraprionospio pinnata*
    - *Prionospio steenstrupi*
    - *Nereis micromma*

Lumbrineris ernesti
Lumbrineris verrilli

Table 7. Abundance of the major taxonomic groups, Brownsville-Harlingen area.

	Number of Stations Examined	All Species	All Individuals	Polychaete Species	Polychaete Individuals	Molluscan Species	Molluscan Individuals	Crustacean Species	Crustacean Individuals
Lower Laguna Madre*	93	173	9,146	80	3,780	57	3,191	36	2,175
South Bay	10	62	430	28	241	26	108	8	81
Inner Shelf	113	322	10,432	150	6,969	95	2,074	76	1,389
Total	216	391	20,008	168	10,990	132	5,373	91	3,645

*includes Arroyo Colorado River, Brownsville Ship Channel, Port Mansfield Channel, Laguna Madre Intracoastal Waterway

Table 8. Most abundant mollusk species of the Brownsville-Harlingen area.

Inner Shelf	Number of individuals	Percent of all (392) gastropod individuals
Gastropoda		
Natica pusilla	128	32.7
Terebra protexta	40	10.2
Vitrinella floridana	33	8.4
Bivalvia		Percent of all (1570) bivalve individuals
Linga amiantus	259	35.6
Abra aequalis	259	12.9
Diplodonta cf. *D. soror*	189	10.4
Tellina versicolor	135	9.9
Scaphopoda		Percent of all (112) scaphopod individuals
Cadulus carolinensis	51	45.6
Dentalium texasianum	35	31.2
Dentalium eboreum	26	23.2
Lower Laguna Madre		
Gastropoda		Percent of all (962) gastropod individuals
Caecum pulchellum	542	56.3
Bittium varium	114	11.9
Crepidula convexa	104	10.8
Bivalvia		Percent of all (2224) bivalve individuals
Lyonsia hyalina floridana	340	15.3
Mulinia lateralis	321	14.4
Nuculana acuta	300	13.5
Tellina tampaensis	205	9.2
Abra aequalis	169	7.6
Mysella planulata	141	6.3
Tagelus plebeius	106	4.8
Ensis minor	105	4.7
South Bay		
Gastropoda		Percent of all (50) gastropod individuals
Odostomia impressa	16	32.0
Bittium varium	9	18.0
Crepidula convexa	8	16.0
Crepidula plana	8	16.0
Bivalvia		Percent of all (57) bivalve individuals
Macoma tenta	20	35.1

Table 9. Most abundant polychaete species of the Brownsville-Harlingen area.

Inner Shelf	Number of individuals	Percent of all (6,969) individuals
Paraprionospio pinnata	732	10.5
Magelona cf. *M. phyllisae*	605	8.7
Lumbrineris verrilli	542	7.8
Nereis micromma	448	6.4
Armandia agilis	369	5.3
Isolda pulchella	262	3.8
Aglaophamus verrilli	257	3.7
Diopatra cuprea	242	3.5
Apoprionospio pygmaea	202	2.9
Onuphis eremita oculata	145	2.1

Lower Laguna Madre	Number of individuals	Percent of all (3,780) individuals
Prionospio heterobranchia	703	18.6
Chone duneri	400	10.6
Mediomastus californiensis	349	9.2
Capitella capitata	308	8.1
Melinna maculata	306	8.1
Streblospio benedicti	304	8.0
Exogone dispar	113	3.0
Syllis cornuta	110	2.9

South Bay	Number of individuals	Percent of all (241) individuals
Prionospio heterobranchia	54	22.4
Mediomastus californiensis	34	14.1
Euclymene sp.	23	9.5
Tharyx marioni	20	8.3
Capitella capitata	19	7.9
Streblospio benedicti	17	7.1

Table 10. Most abundant crustacean species of the Brownsville-Harlingen area.

Inner Shelf	Number of individuals	Percent of all (1,389) individuals
Trichophoxus floridanus	276	19.9
Platyschnopus sp.	141	10.1
Ampelisca cristoides	134	9.6
Ampelisca agassizi	125	9.0
Protohaustorius cf. *P. bousfieldi*	95	6.8

Lower Laguna Madre	Number of individuals	Percent of all (2,175) individuals
Ampelisca abdita	856	39.4
Oxyurostylis salinoi	212	9.7
Balanus sp.	162	7.4
Cymadusa compta	150	6.9
Elasmopus levis	117	5.4

South Bay	Number of individuals	Percent of all (81) individuals
Ampelisca abdita	33	40.7
Cymadusa compta	21	25.9

Table 11. 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)	11.3	48-72 (14.6-21.9)	17.4	72-96 (21.9-29.3)	13.1
Mollusca	24-48 (7.3-14.6)	5.9	48-72 (14.6-21.9)	8.7	72-96 (21.9-29.3)	4.0
Crustacea	24-48 (7.3-14.6)	5.4	48-72 (14.6-21.9)	4.7	72-96 (21.9-29.3)	1.7
Other Groups	24-48 (7.3-14.6)	2.0	48-72 (14.6-21.9)	3.1	72-96 (21.9-29.3)	2.2
Total	24-48 (7.3-14.6)	24.6	48-72 (14.6-21.9)	36.9	72-96 (21.9-29.3)	21.5

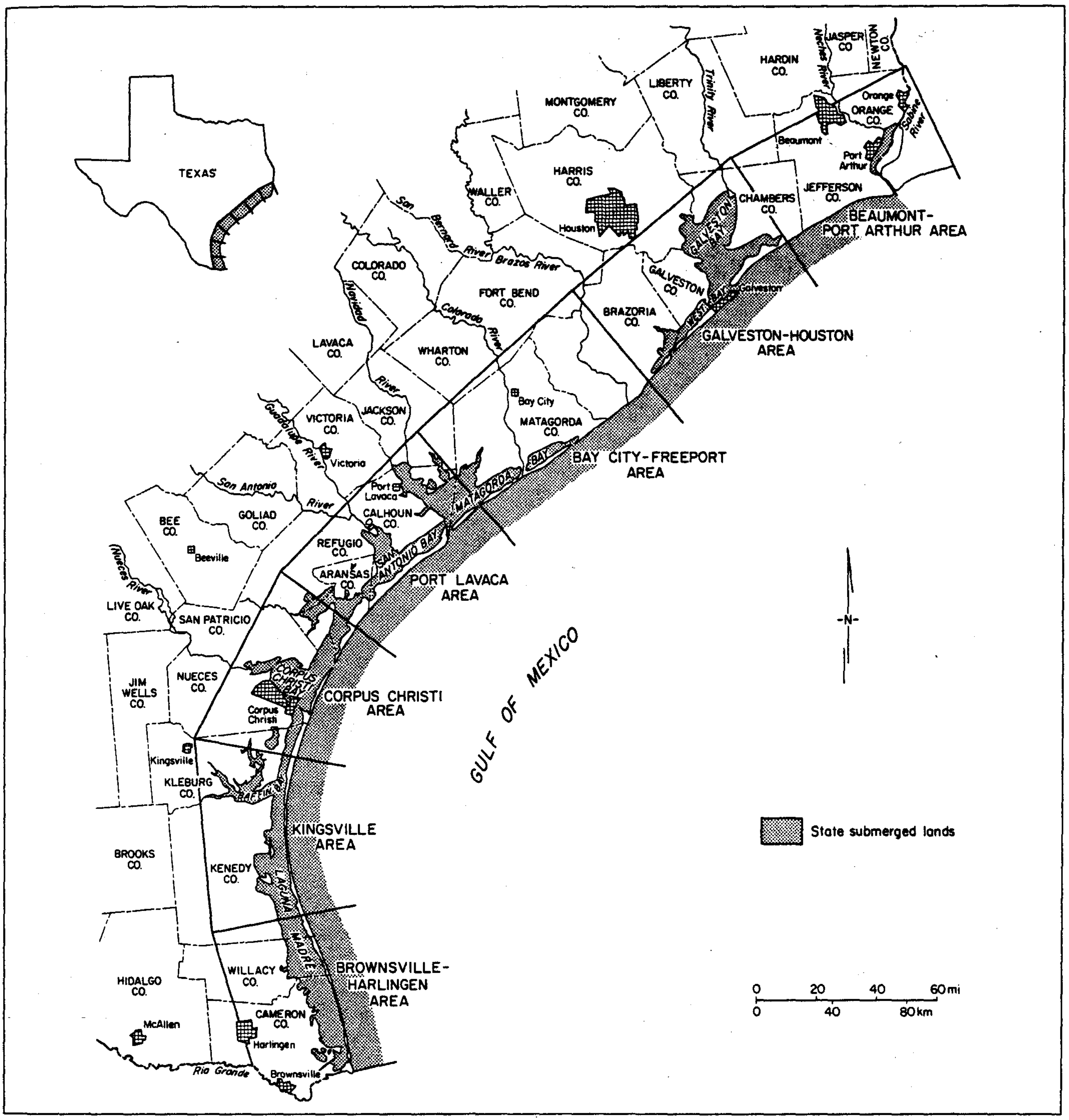


Figure 1. Index map showing seven area maps that cover the submerged coastal lands of Texas (modified from McGowen and Morton, 1979, and Brown, 1972-80).

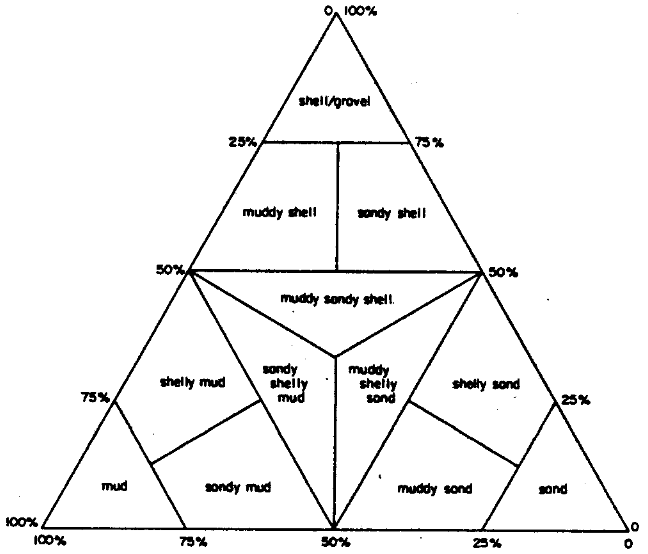


Figure 2. Classification of sediment types: shell(gravel)-sand-mud, submerged lands of Texas (from McGowen and Morton, 1979).

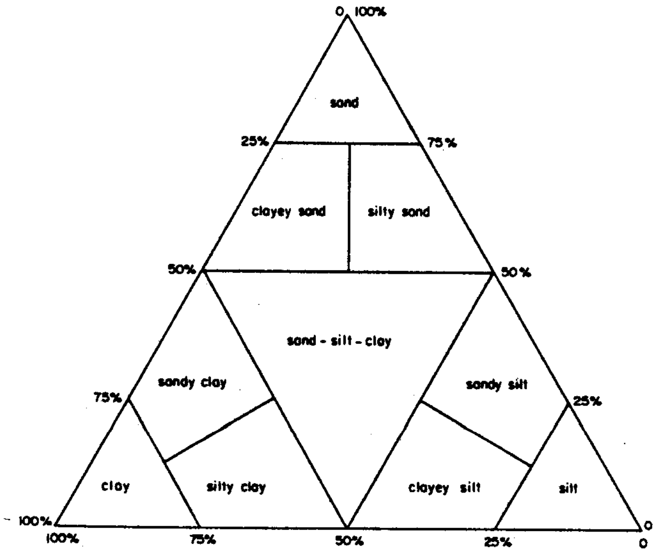


Figure 3. Classification of sediment types: sand-silt-clay, submerged lands of Texas (modified from Shepard and Moore, 1955).

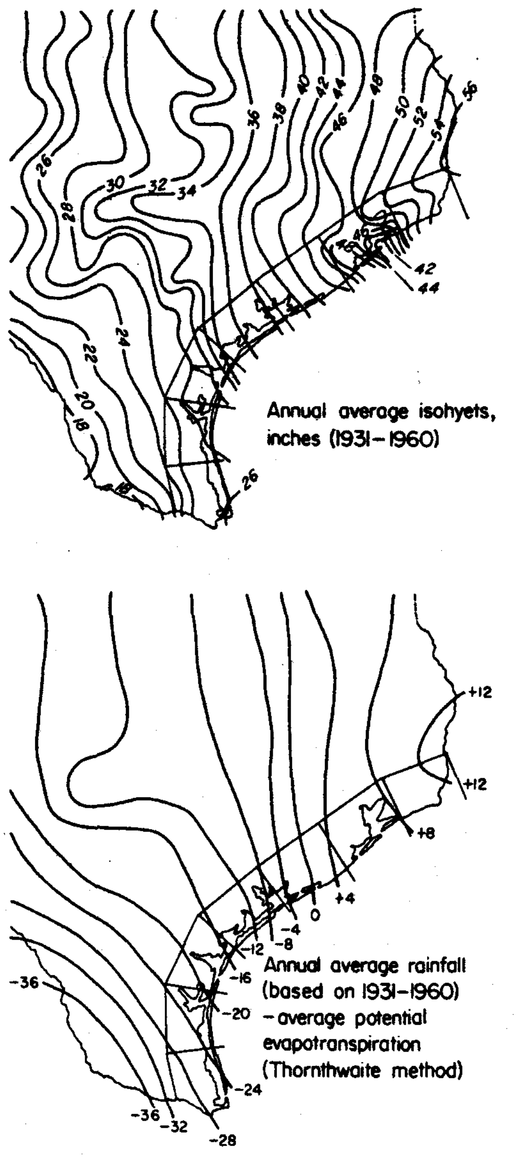


Figure 5. Regional climate data, Texas Coastal Zone (after Brown and others, 1976). Calculations of average potential evapotranspiration from Thornthwaite and Mather, 1957.

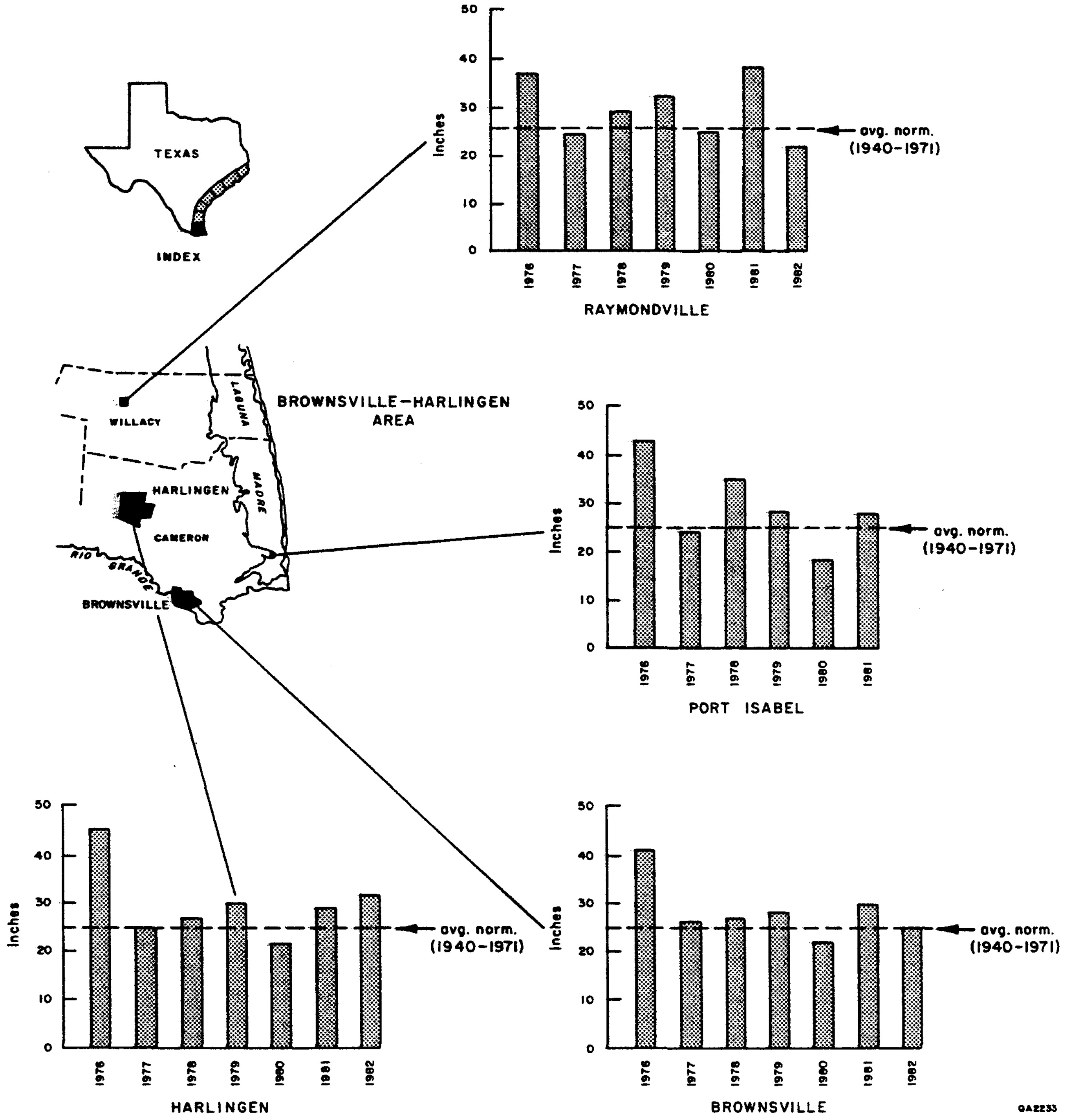


Figure 6. Annual precipitation of Brownsville, Harlingen, Port Isabel, and Raymondville, Texas, 1976-1982. Compiled from records of the National Weather Service, U.S. Department of Commerce.

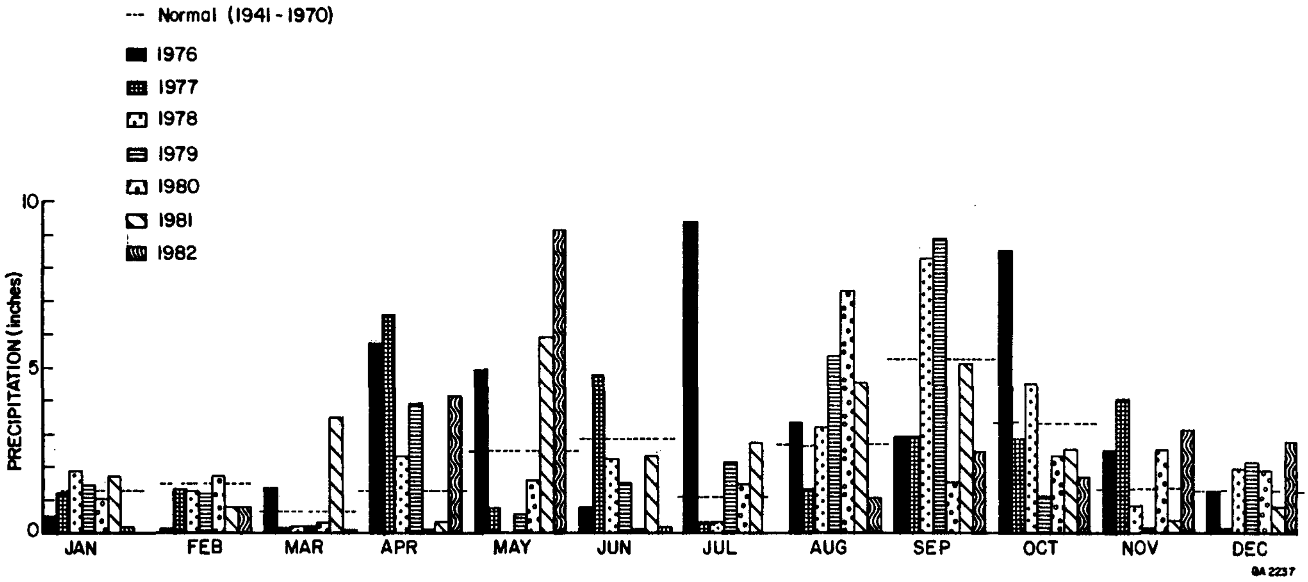


Figure 7. Monthly precipitation for Brownsville, Texas, 1976-1982. Compiled from records of the National Weather Service, U.S. Department of Commerce.

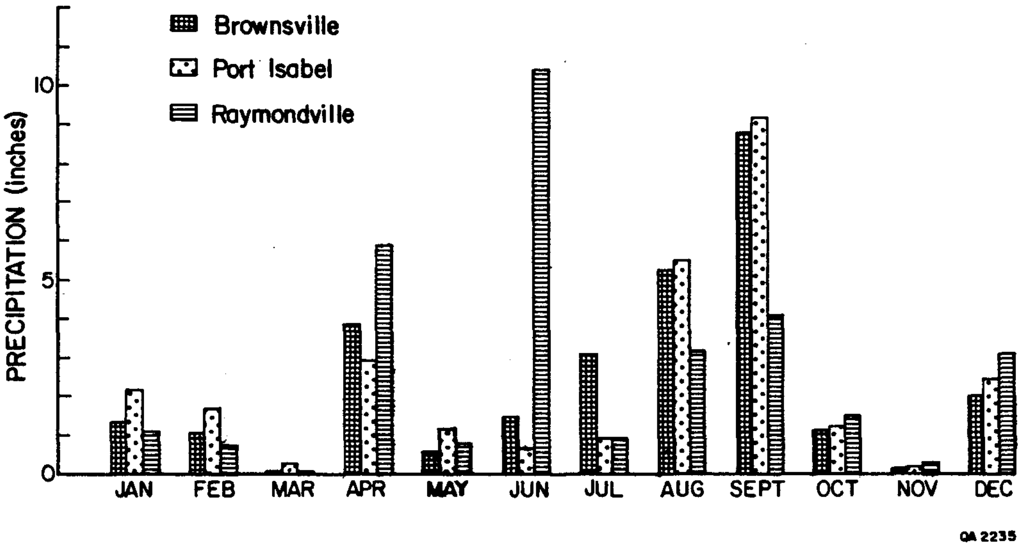


Figure 8. Monthly precipitation for Brownsville, Port Isabel, and Raymondville, 1979. Compiled from records of the National Weather Service, U.S. Department of Commerce.

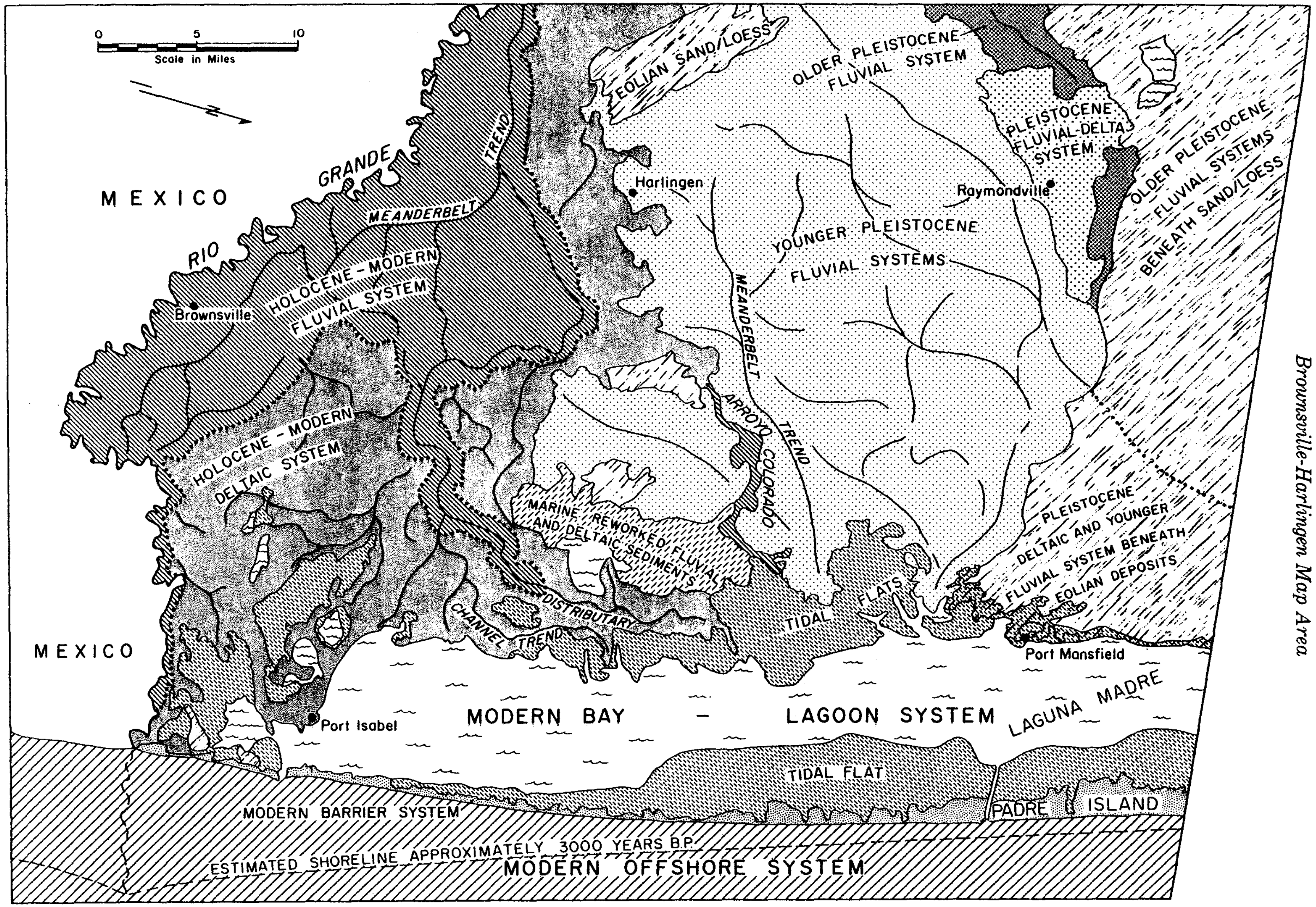


Figure 9. Natural systems defined by environmental mapping in the Brownsville-Harlingen area.

Brownsville-Harlingen Map Area

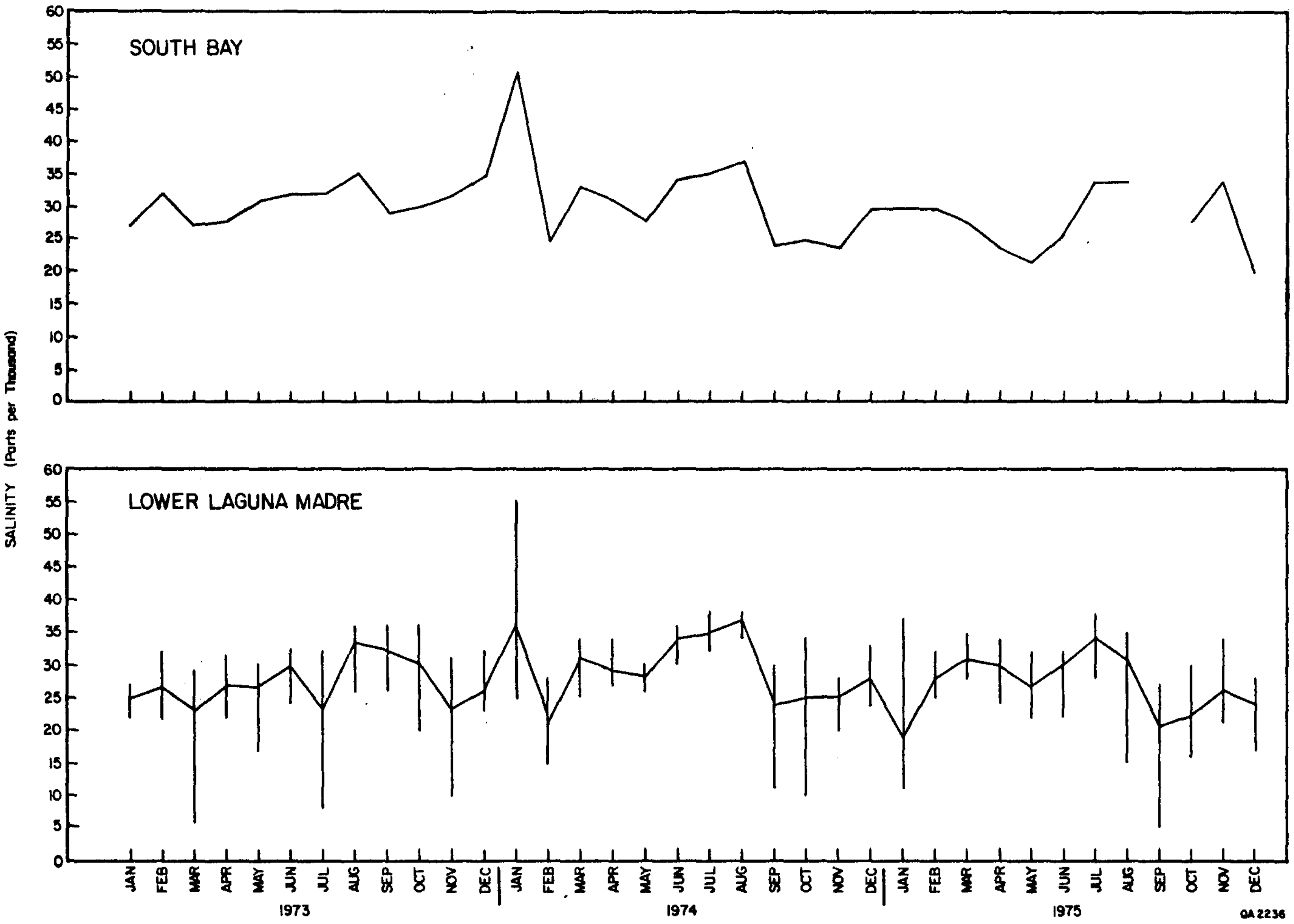


Figure 10. Monthly means and ranges in salinities in South Bay and lower Laguna Madre, Brownsville-Harlingen area. (Compiled from Martinez, 1973, 1974, 1975.)

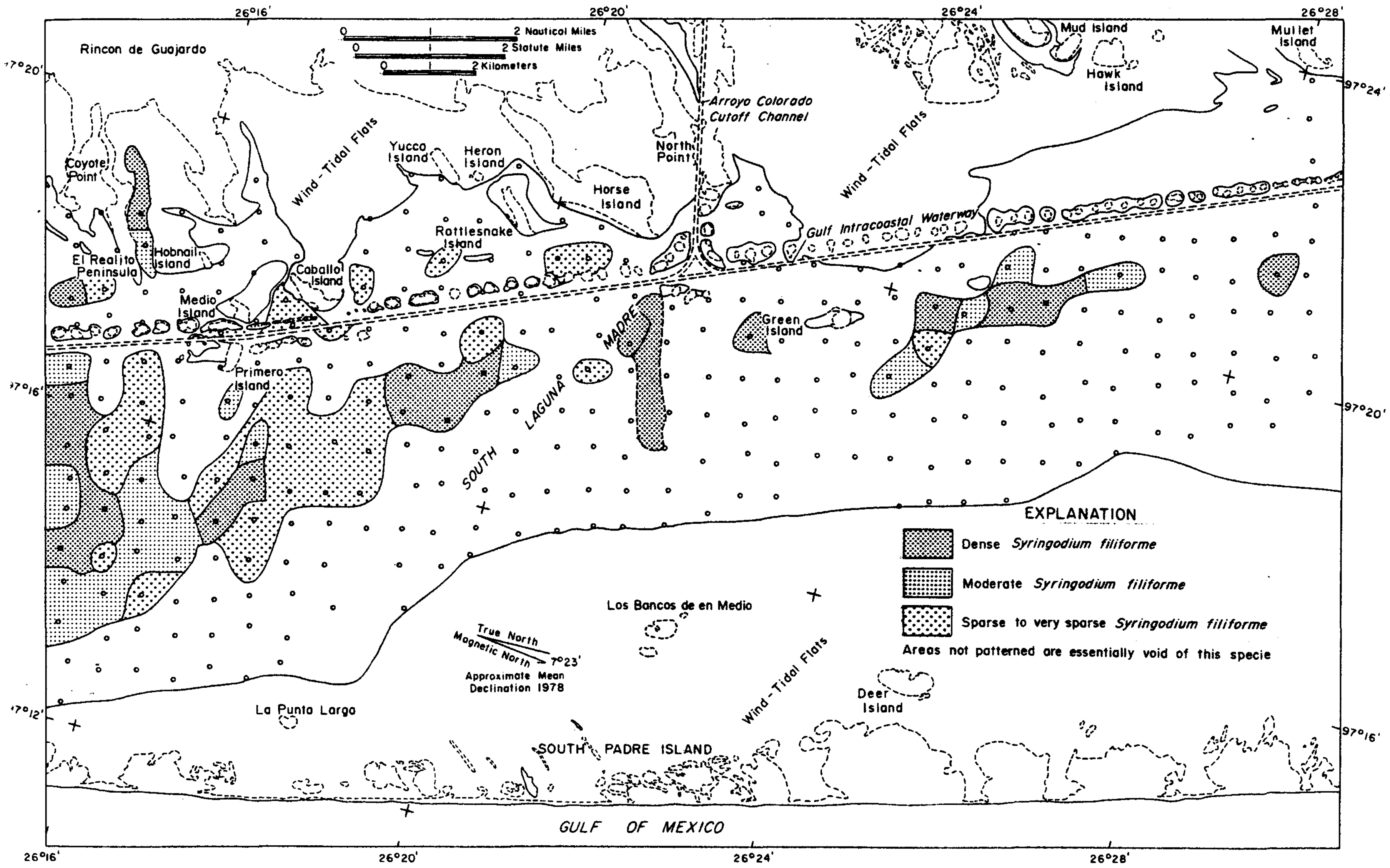


Figure 12. Distribution of Syringodium (Cymodocea) for a segment of Laguna Madre, Brownsville-Harlingen area (after Chin, unpublished manuscript).

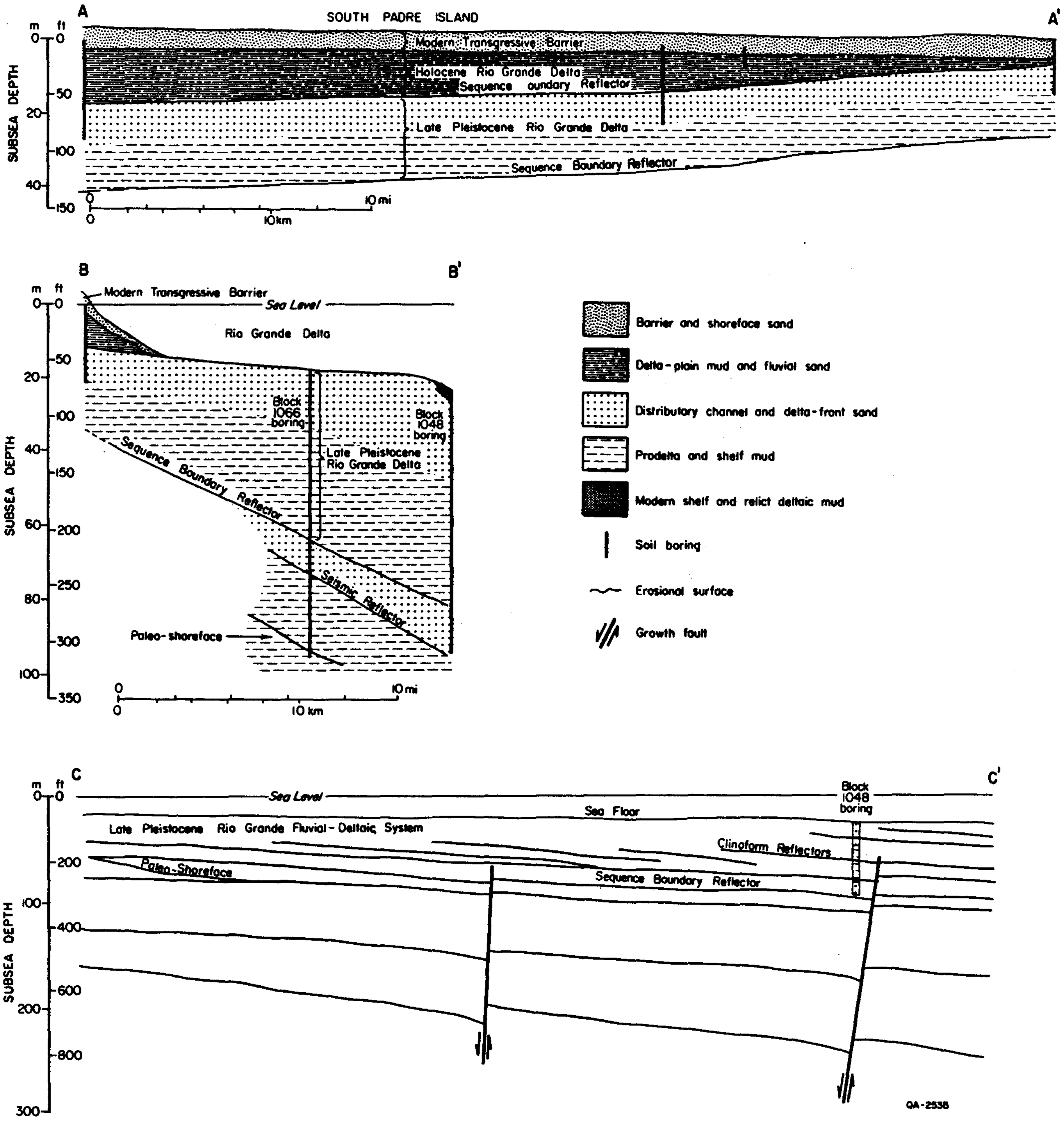
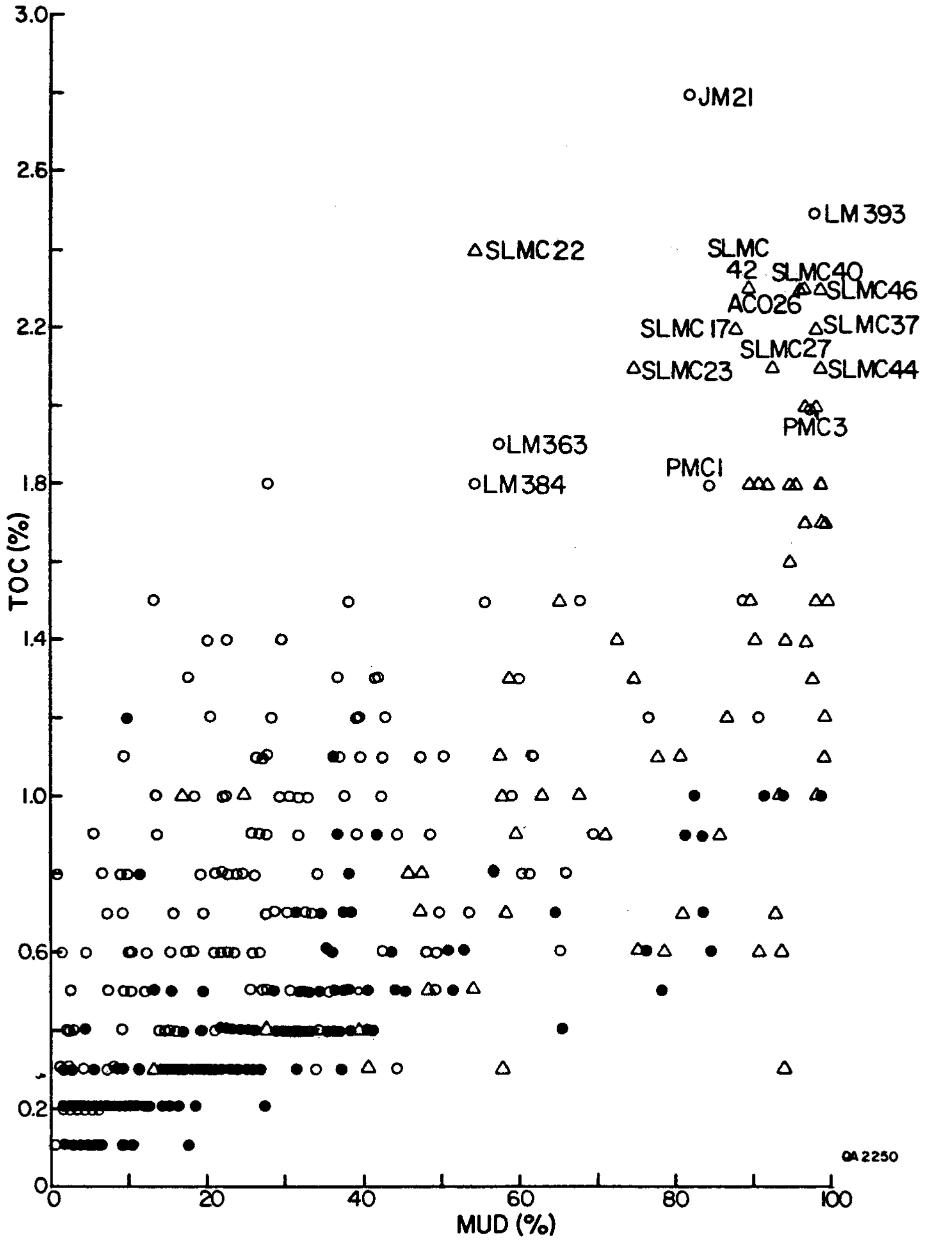
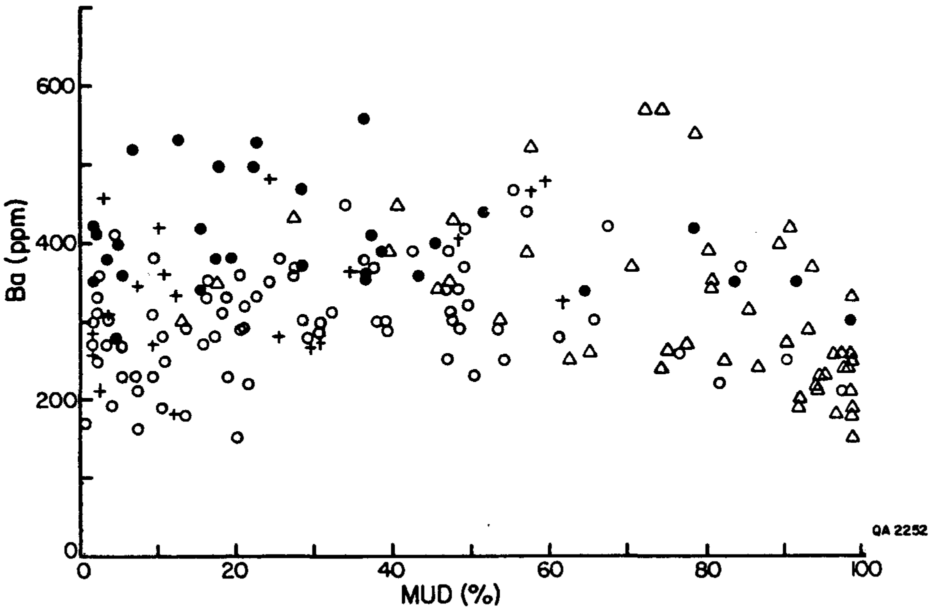


Figure 14. Late Quaternary facies relationships near South Padre Island shown by a (A) stratigraphic strike section, (B) stratigraphic dip section, and (C) high-resolution seismic profile. Locations of diagrams shown on figure 13. Stratigraphic cross sections based on published data (U.S. Army Corps of Engineers, 1958; Fulton, 1975; Morton and McGowen, 1980; Morton and other, 1983) as well as unpublished soil borings.



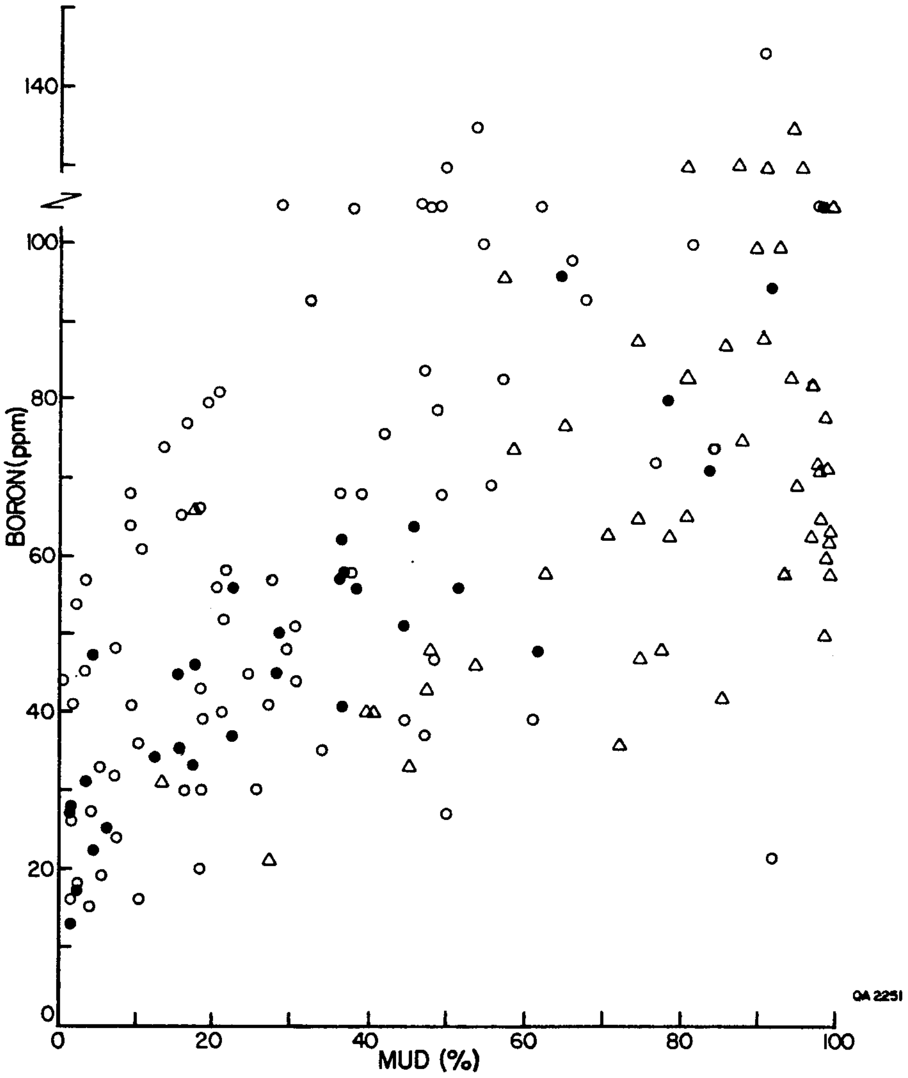
o	Bay sediments
Δ	Channel sediments; r (for bay and channel sediments) = 0.655; n = 144
•	Shelf sediments; r = 0.830; n = 32

Figure 16. Scattergram of total organic carbon and mud, Brownsville-Harlingen area. (Letters and numbers next to plotted points on the above and succeeding scattergrams are sample station numbers for sediments that plot above the trend set by other sediments--ACO = Arroyo Colorado, BSC = Brownsville Ship Channel, JM = intensive sampling area of Laguna Madre, LM = Laguna Madre, PMC = Port Mansfield Channel, SLMC = Intracoastal Waterway, Z = South Bay; numbers without letter prefixes = shelf stations--see plate VI and appendix B; r = correlation coefficients and n = number of samples.)



o	Bay sediments; Ba analyses by USGS; r = 0.263; n = 71
+	Bay sediments; Ba analyses by Bureau of Economic Geology; r = 0.424; n = 19
Δ	Channel sediments; Ba analyses by USGS r (for USGS analyzed bay and channel sediments) = -0.048; n = 126
•	Shelf sediments; Bay analyses by USGS; r = 0.285; n = 32

Figure 17. Scattergram of barium and mud (r = correlation coefficient; n = number of samples).



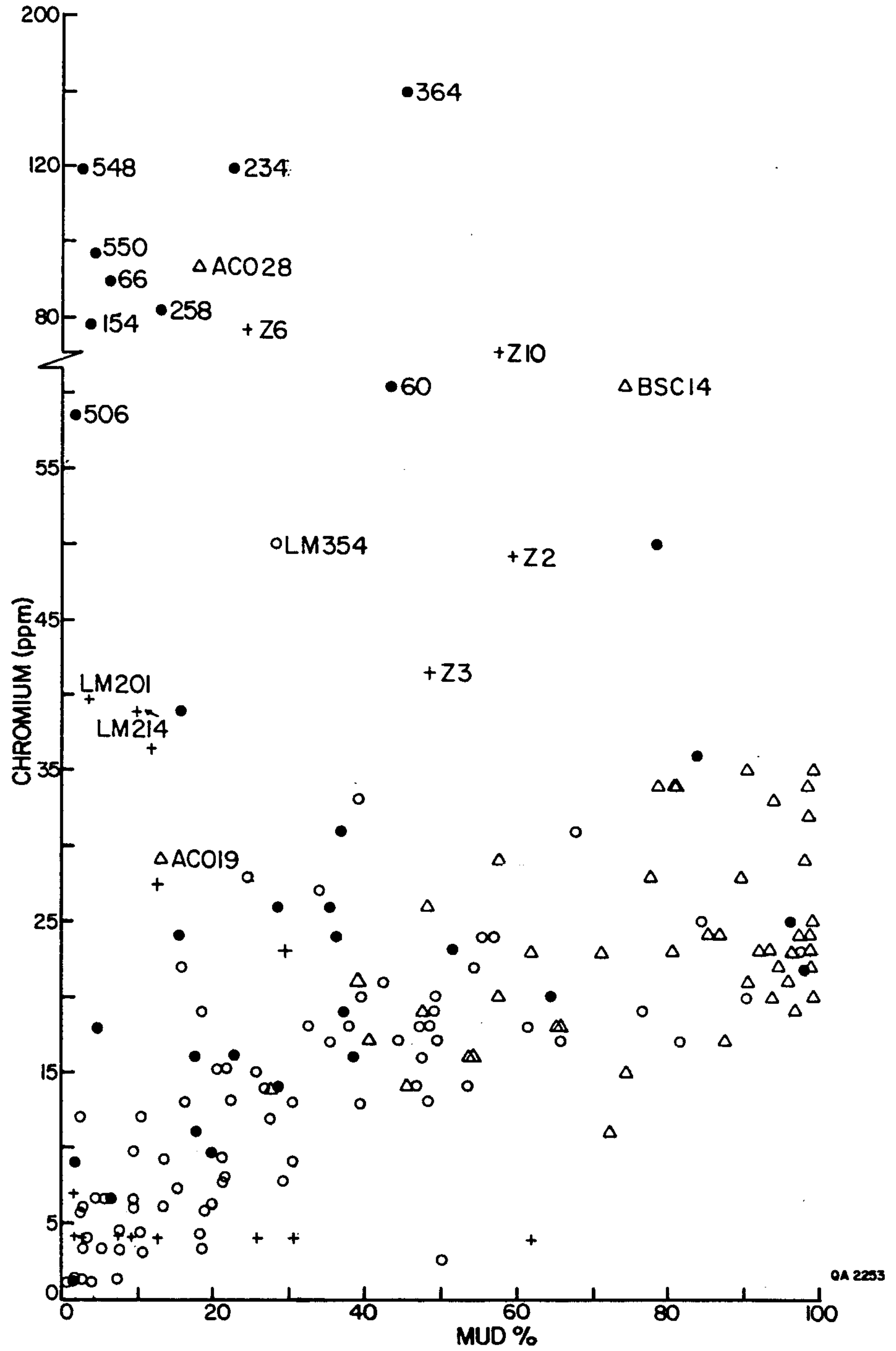
o Bay sediments; r = 0.677; n = 71

Δ Channel sediments

r (for bay and channel sediments) = 0.539; n = 126

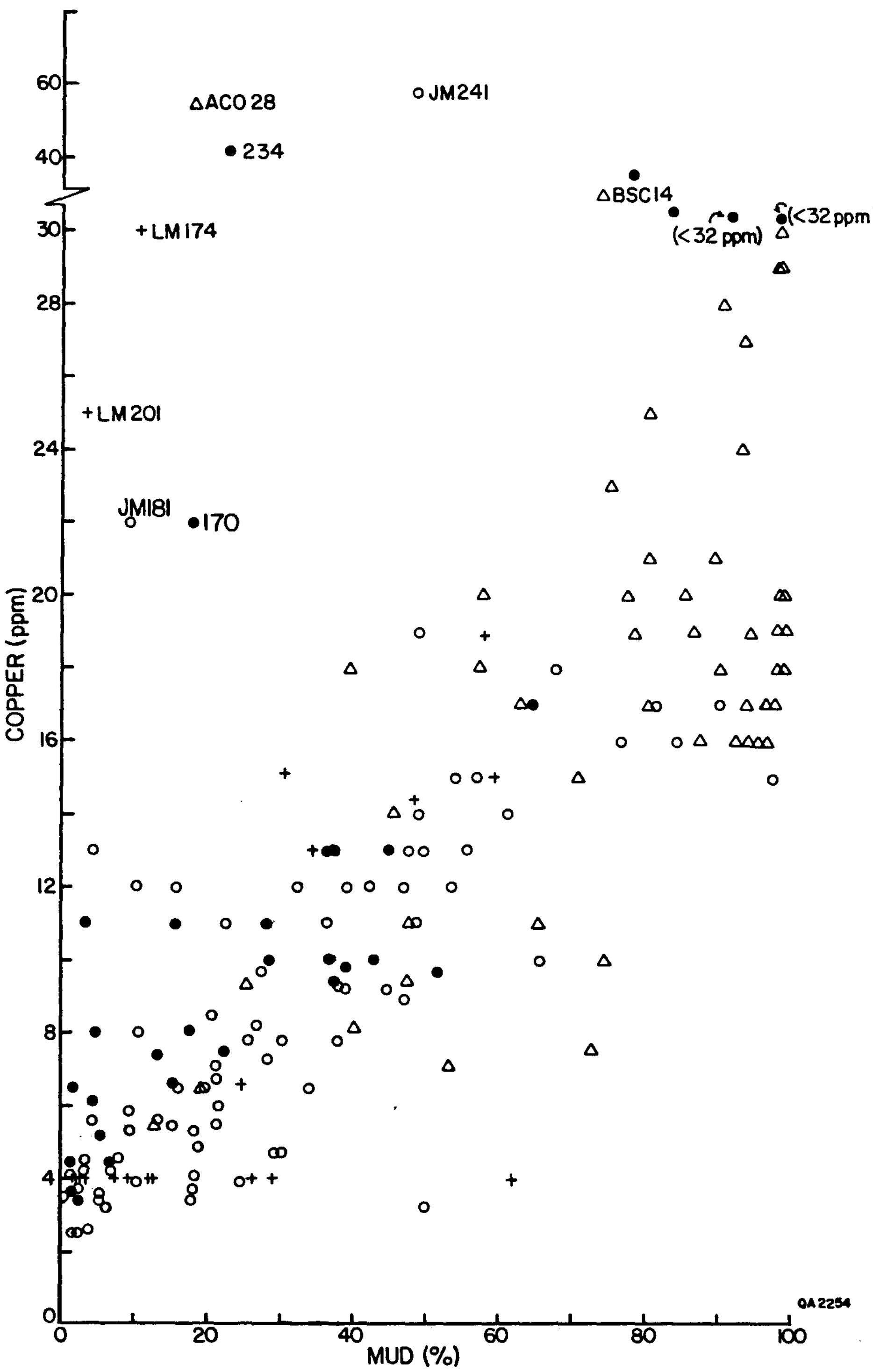
• Shelf sediments; r = 0.912; n = 32

Figure 18. Scattergram of boron and mud (r = correlation coefficient; n = number of samples).



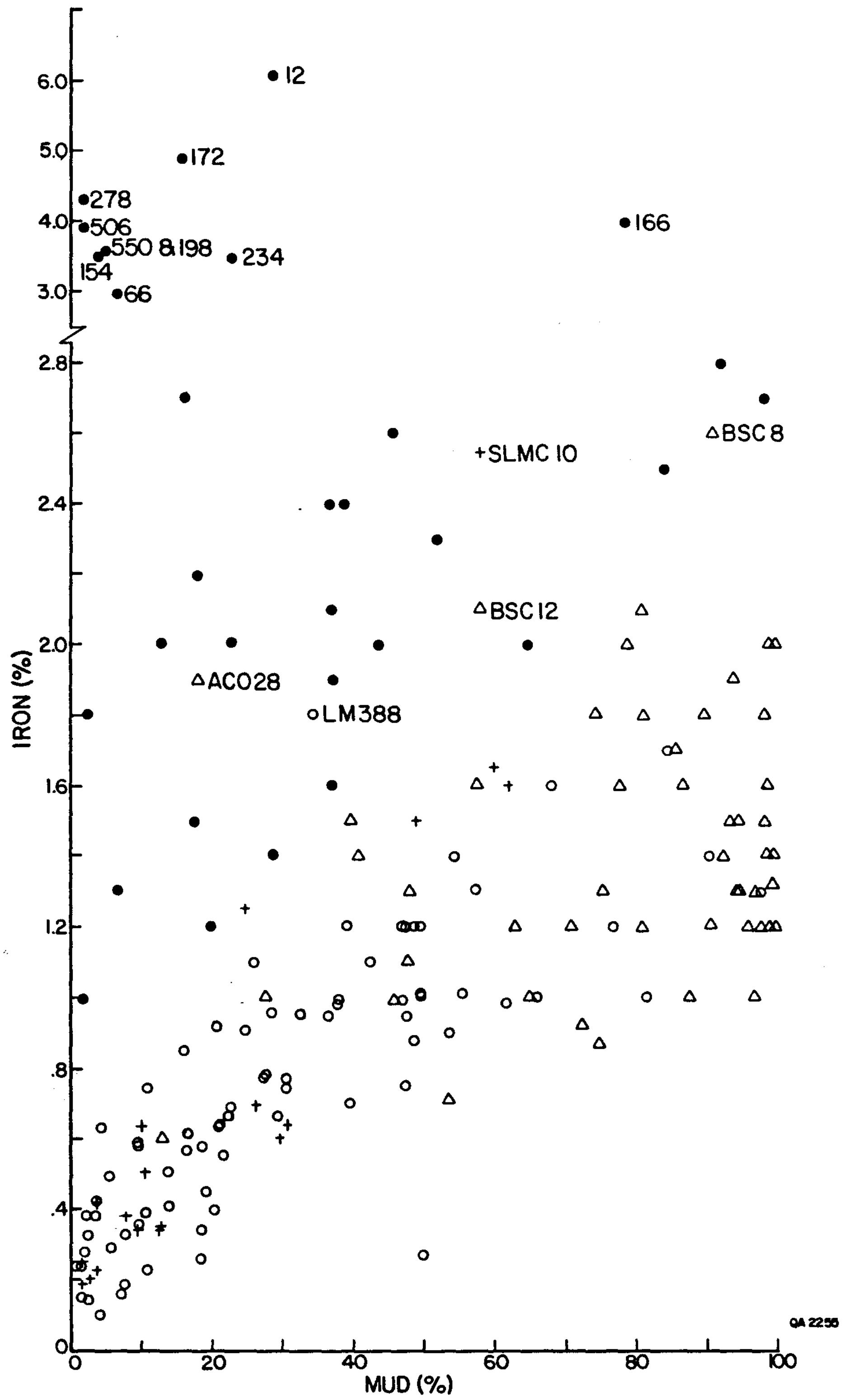
o	Bay sediments; Cr analyses by USGS; r = 0.576; n = 70
+	Bay sediments; Cr analyses by Bureau of Economic Geology; r = 0.527; n = 10
Δ	Channel sediments; Cr analyses by USGS r (for USGS analyzed bay and channel sediments) = 0.492; n = 124
•	Shelf sediments; Cr analyses by USGS; r = -0.132; n = 32

Figure 19. Scattergram of chromium and mud. (Letters and numbers shown next to plotted points are sample station numbers for sediments that plot above the trend set by other sediments--see figure 16 for explanation; r = correlation coefficient; n = number of samples.)



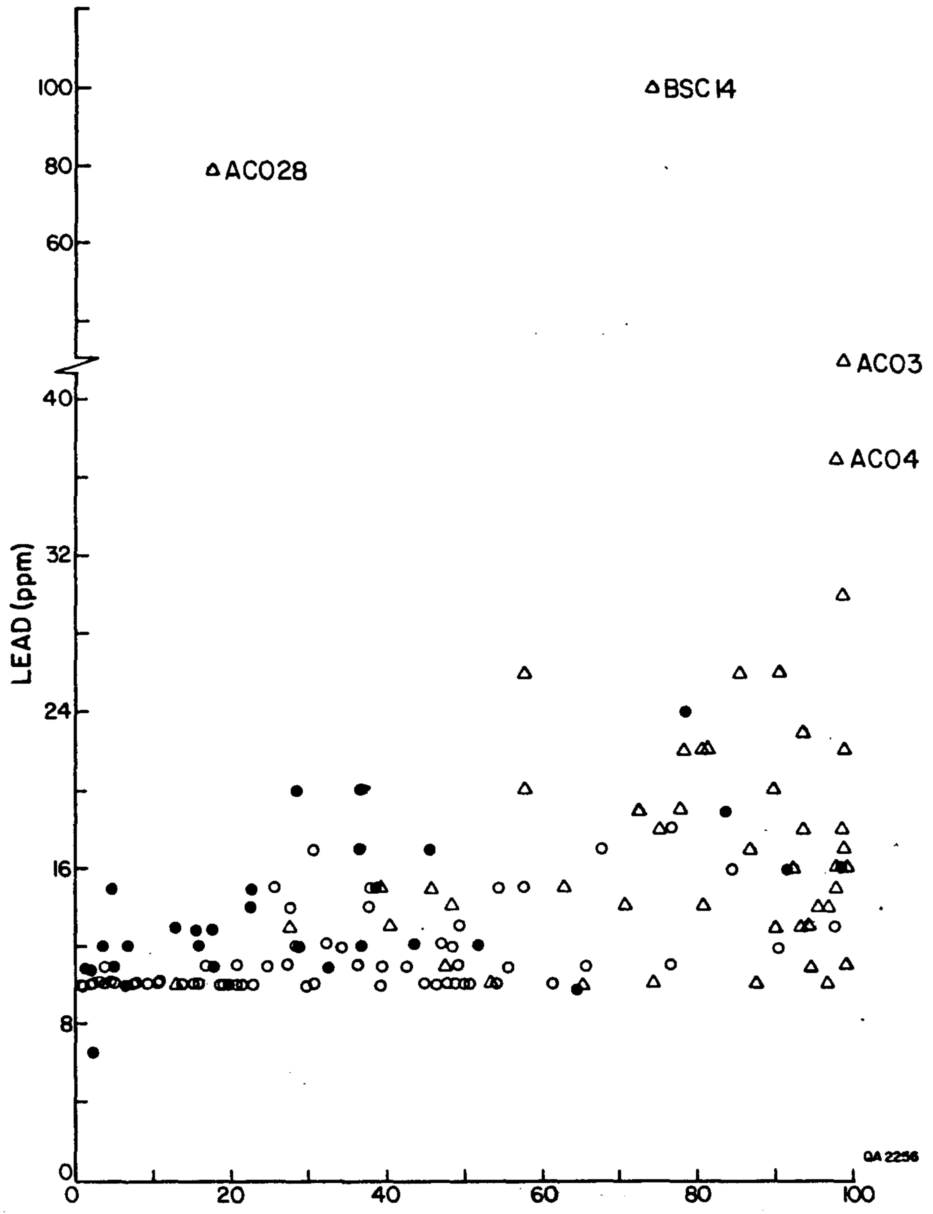
o Bay sediments; Cu analyses by USGS; r = 0.536; n = 71
+ Bay sediments; Cu analyses by Bureau of Economic Geology; r = 0.485; n = 7
Δ Channel sediments; Cu analyses by USGS
r (for USGS analyzed bay and channel sediments) = 0.607; n = 126
• Shelf sediments; Cu analyses by USGS; r = 0.724; n = 32

Figure 20. Scattergram of copper and mud. (Letters and numbers shown next to plotted points are sample station numbers for sediments that plot above the trend set by other sediments--see figure 16 for explanation; r = correlation coefficient; n = number of samples.)



o Bay sediments; Fe analyses by USGS; r = 0.788; n = 71
+ Bay sediments; Fe analyses by Bureau of Economic Geology; r = 0.910; n = 19
Δ Channel sediments; Fe analyses by USGS
r (for USGS analyzed bay and channel sediments) = 0.776; n = 126
• Shelf sediments; Fe analyses by USGS; r = 0.379; n = 32

Figure 21. Scattergram of iron and mud. (Letters and numbers shown next to plotted points are sample station numbers for sediments that plot above the trend set by other sediments--see figure 16 for explanation; r = correlation coefficient; n = number of samples.)



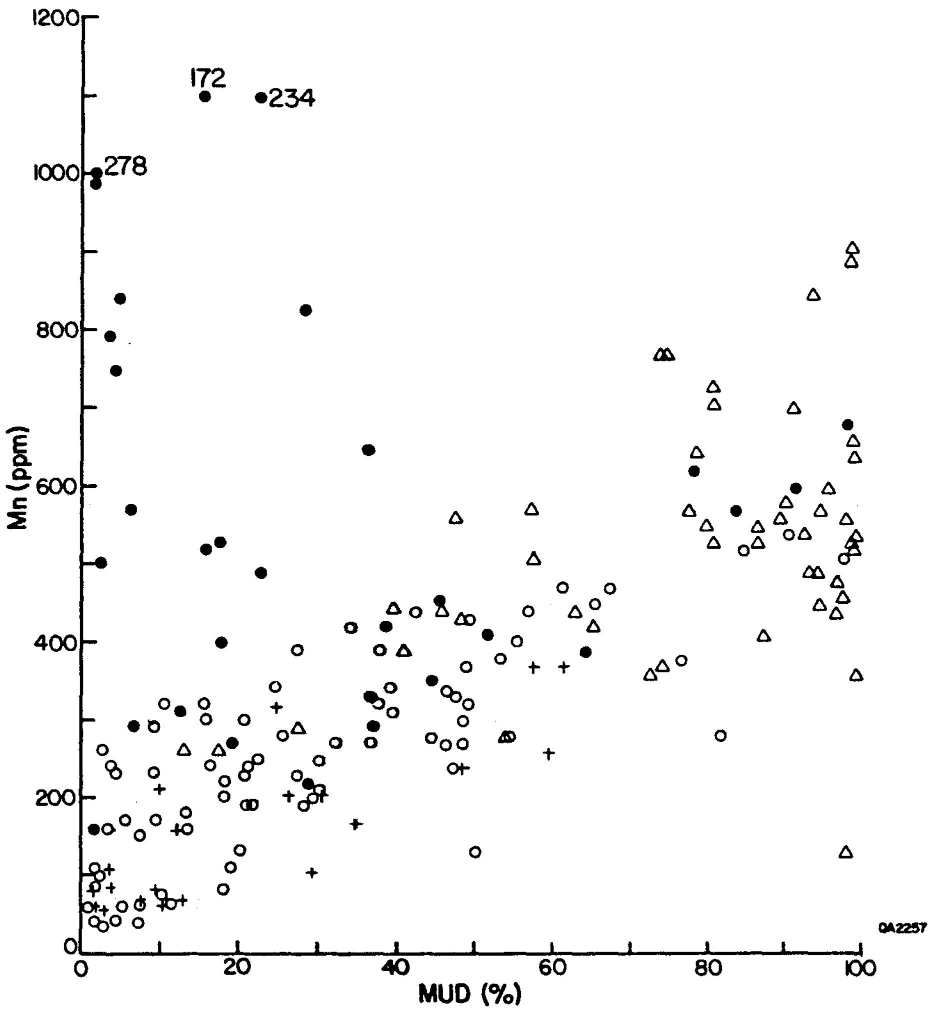
o Bay sediments; r= 0.479; n = 71

Δ Channel sediments

r (for bay and channel sediments) = 0.288; n = 126

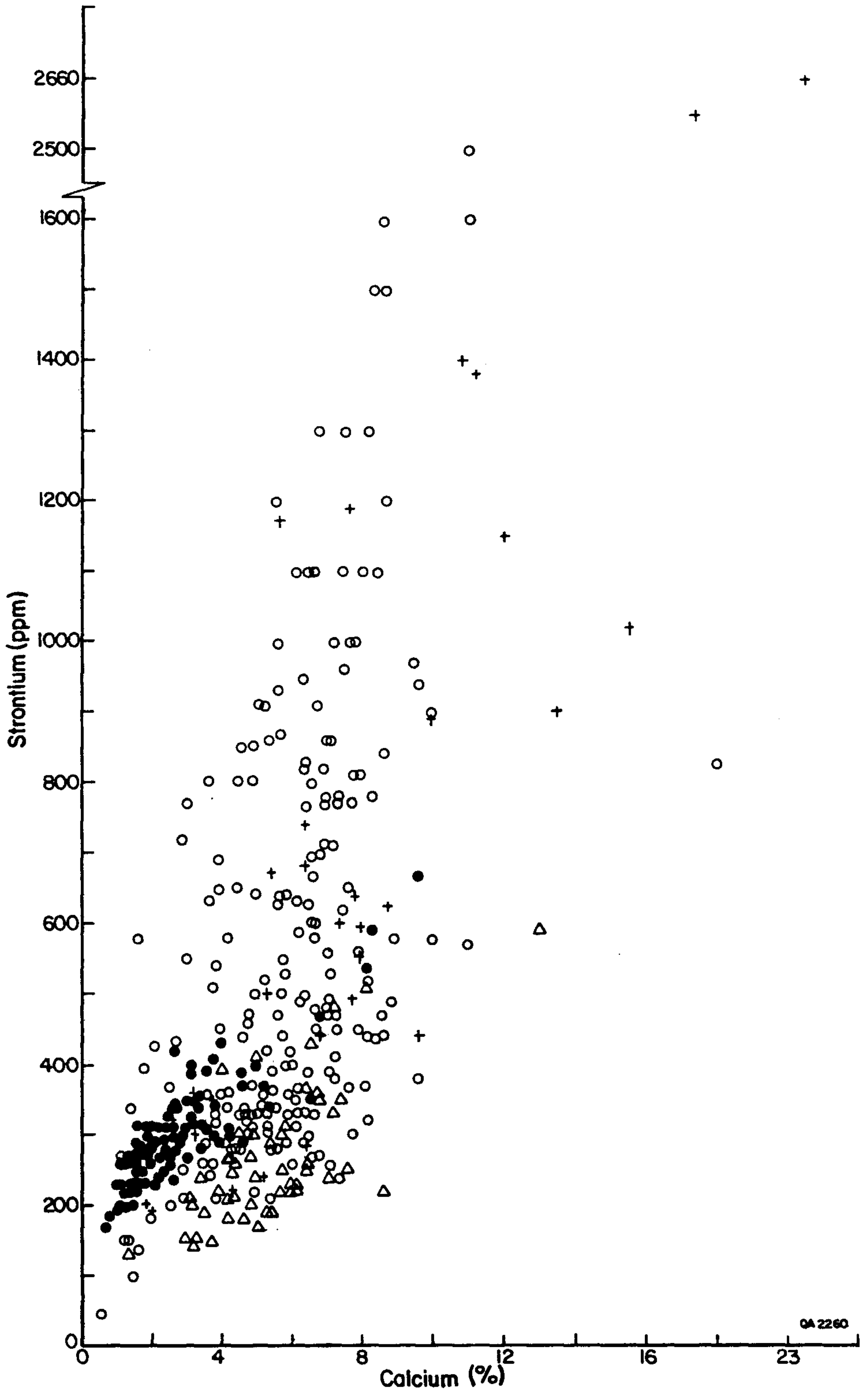
• Shelf sediments; r = 0.541; n = 32

Figure 22. Scattergram of lead and mud. (Letters and numbers shown next to plotted points are sample station numbers for sediments that plot above the trend set by other sediments--see figure 16 for explanation; r = correlation coefficient; n = number of samples.)



o Bay sediments; Mn analyses by USGS; r = 0.751; n = 71
+ Bay sediments; Mn analyses by Bureau of Economic Geology; r = 0.850; n = 19
Δ Channel sediments; Mn analyses by USGS
r (for USGS analyzed bay and channel sediments) = 0.807; n = 126
• Shelf sediments; Mn analyses by USGS; r = -0.132; n = 32

Figure 23. Scattergram of manganese and mud. (Letters and numbers shown next to plotted points are sample station numbers for sediments that plot above the trend set by other sediments--see figure 16 for explanation; r = correlation coefficient; n = number of samples.)



o Bay sediments; analyses by USGS; r = 0.537; n = 68

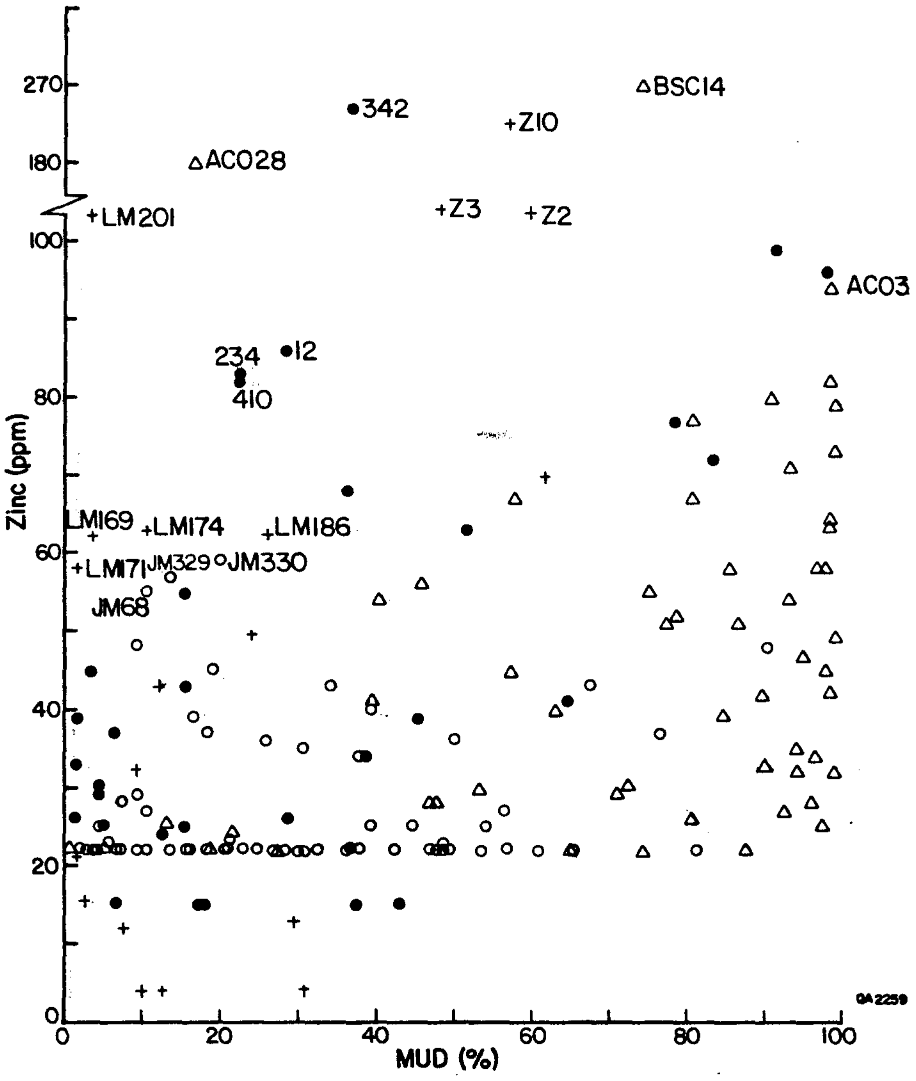
+ Bay sediments; analyses by Bureau of Economic Geology; r = 0.697; n = 16

Δ Channel sediments; analyses by USGS

r (for USGS analyzed bay and channel sediments) = 0.535; n = 123

• Shelf sediments; analyses by USGS; r = 0.838; n = 32

Figure 25. Scattergram of strontium and calcium (r = correlation coefficient; n = number of samples).



o Bay sediments; Zn analyses by USGS; r = -0.055; n = 29

\+ Bay sediments; Zn analyses by Bureau of Economic Geology; r = 0.605; n = 16

Δ Channel sediments; Zn analyses by USGS
r (for USGS analyzed bay and channel sediments) = 0.164; n = 77

• Shelf sediments; Zn analyses by USGS; r = 0.391; n = 32

Figure 26. Scattergram of zinc and mud. (Letters and numbers shown next to plotted points are sample station numbers for sediments that plot above the trend set by other sediments--see figure 16 for explanation; r = correlation coefficient; n = number of samples.)

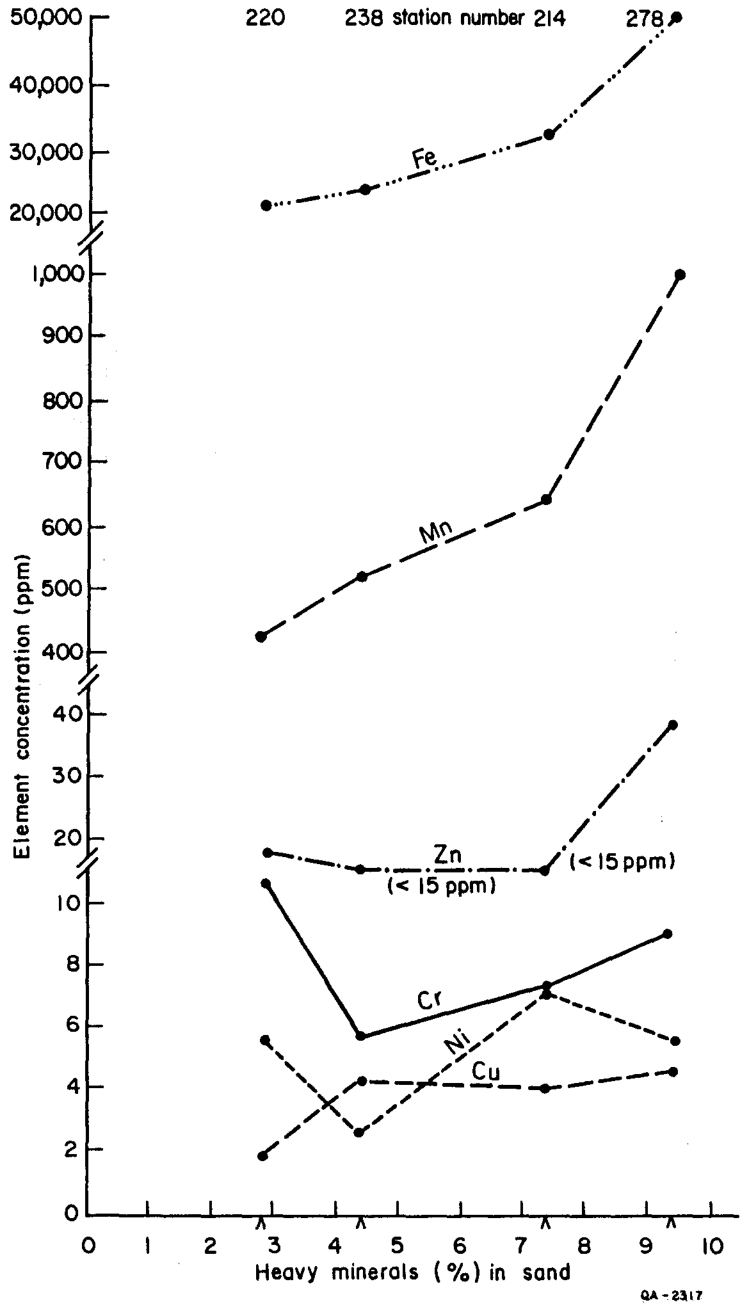


Figure 27. Relationships between trace element concentration in sediments and percentage of heavy minerals estimated in sands for four shelf stations (station number 214, 7.4% heavy minerals; 220, 2.8%; 238, 4.4%; 278, 9.4%).

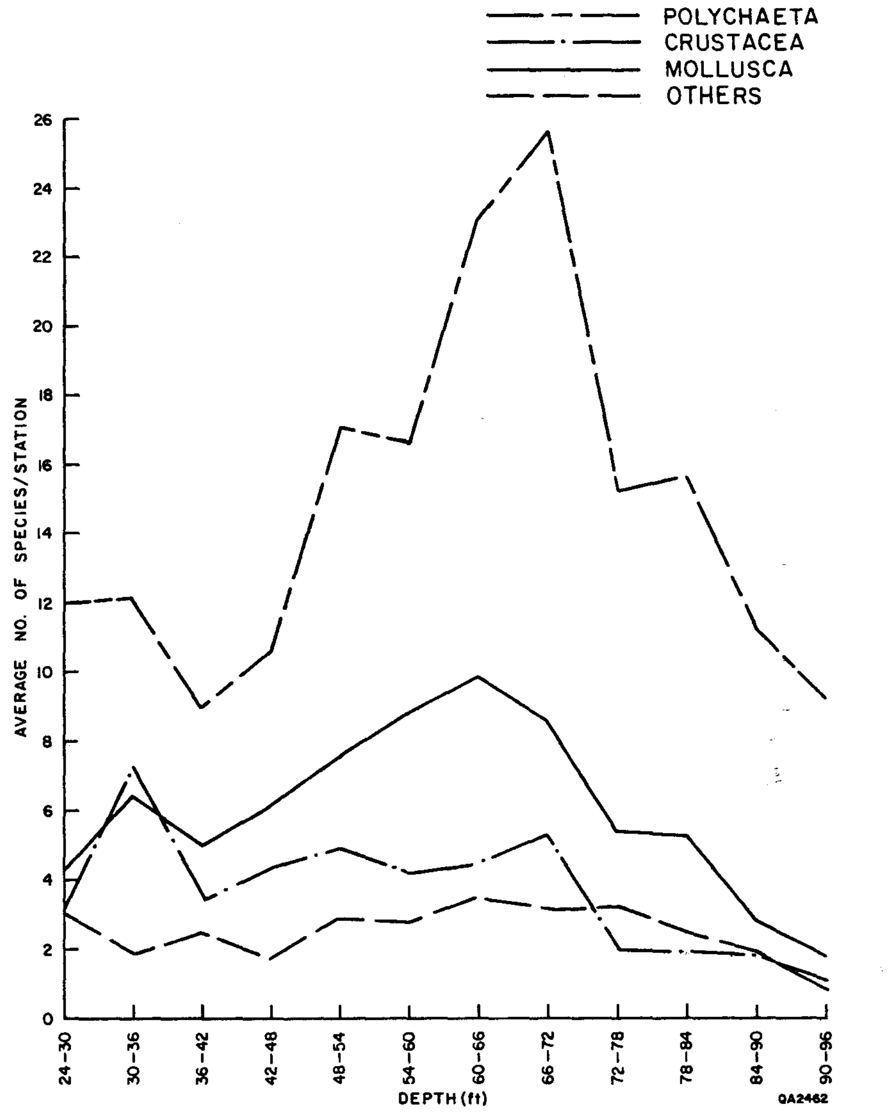


Figure 28. Distribution by depth of the average number of live species per station of the major groups.

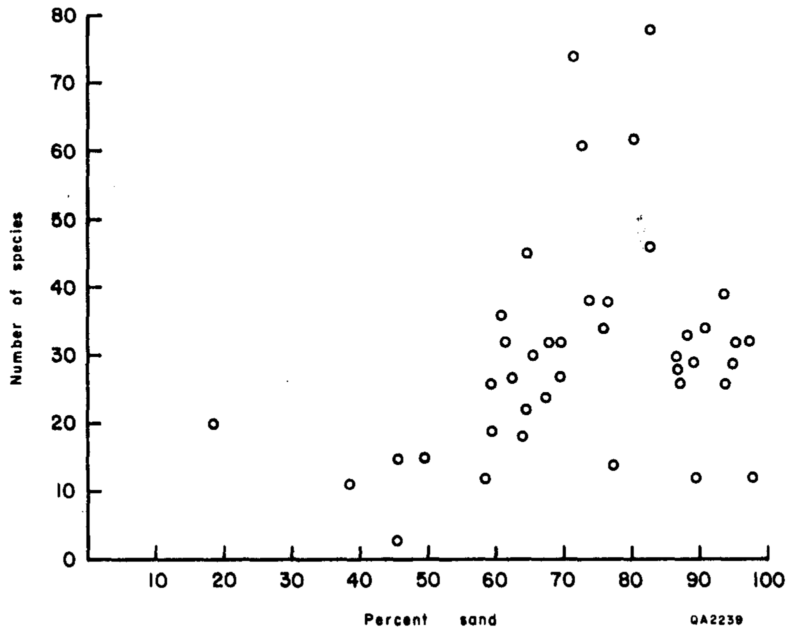


Figure 29. Scattergram of total species and sand on the inner shelf. correlation coefficient (r) = 0.291

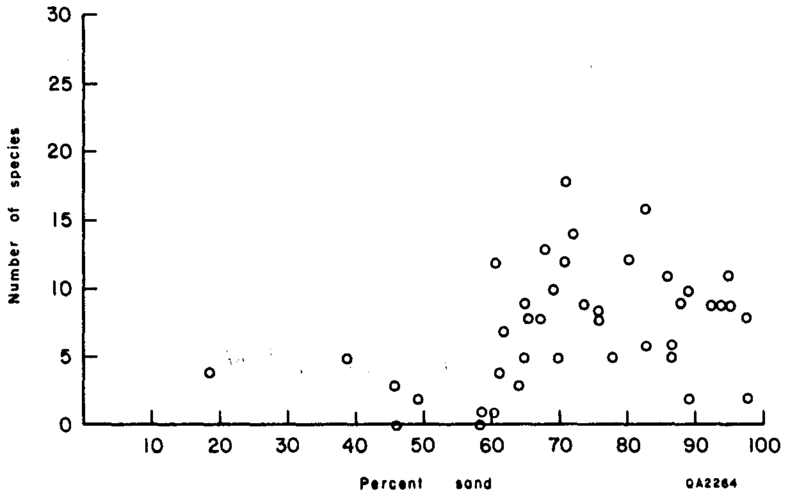


Figure 30. Scattergram of mollusks and sand on the inner shelf. r = 0.363

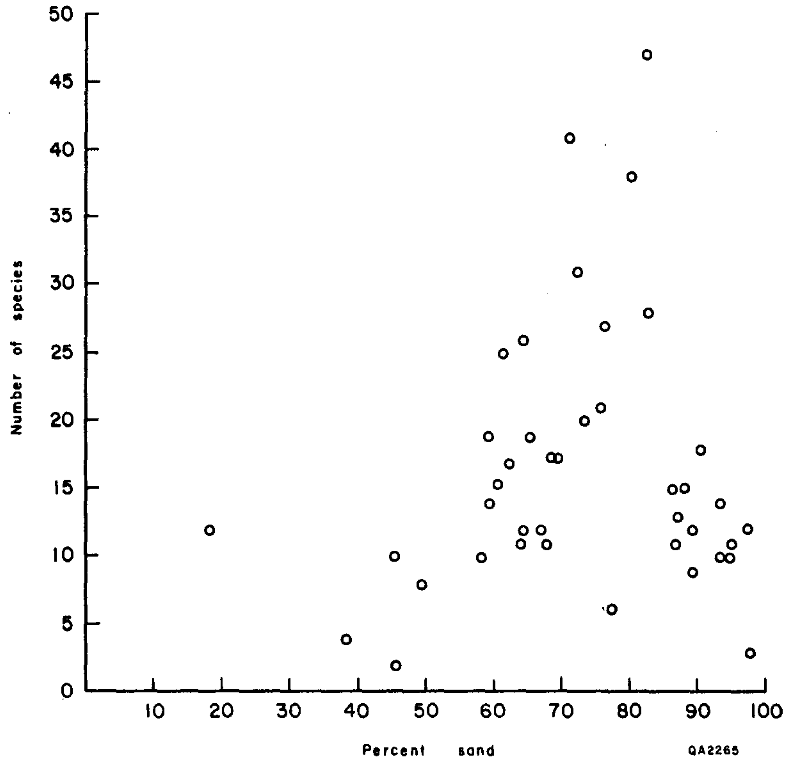


Figure 31. Scattergram of polychaetes and sand on the inner shelf.
r = 0.106

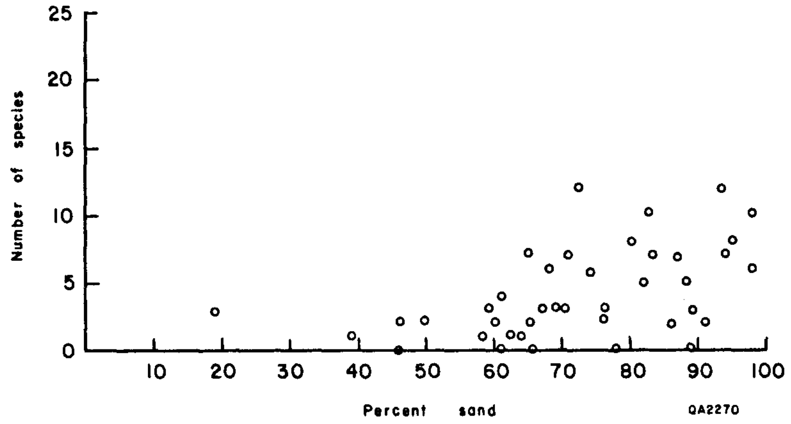


Figure 32. Scattergram of crustacea and sand on the inner shelf.
r = 0.492

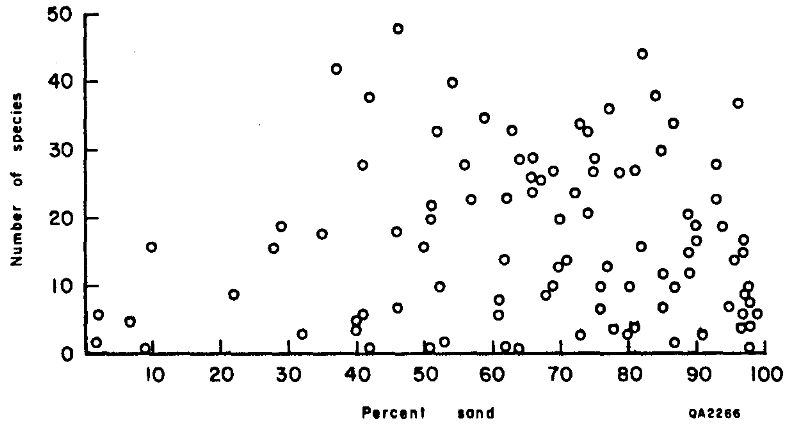


Figure 33. Scattergram of total species and sand in the bays.
correlation coefficient (r) = 0.083

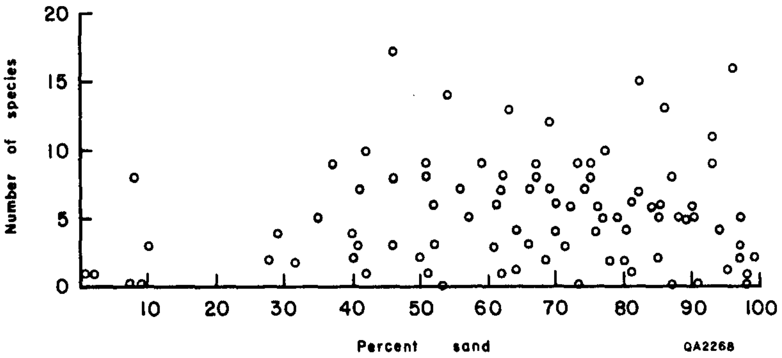


Figure 34. Scattergram of mollusks and sand in the bays.
r = 0.116

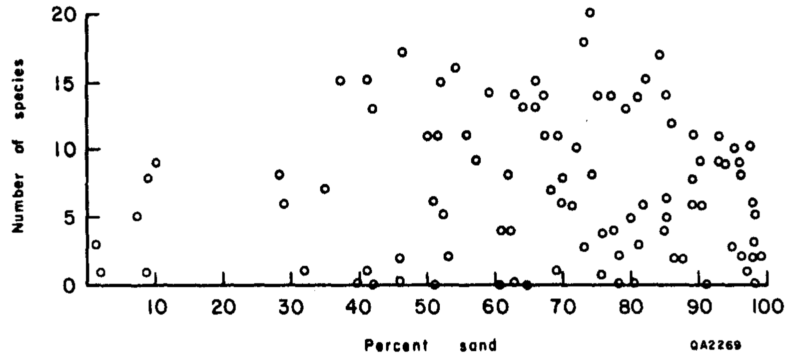


Figure 35. Scattergram of polychaetes and sand in the bays.
r = 0.076

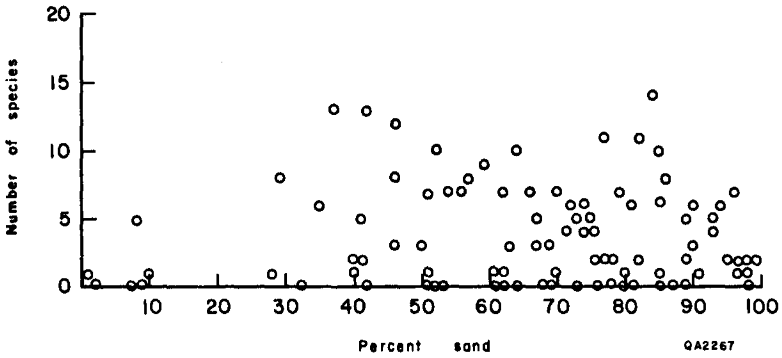


Figure 36. Scattergram of crustacea and sand in the bay.
r = -0.001

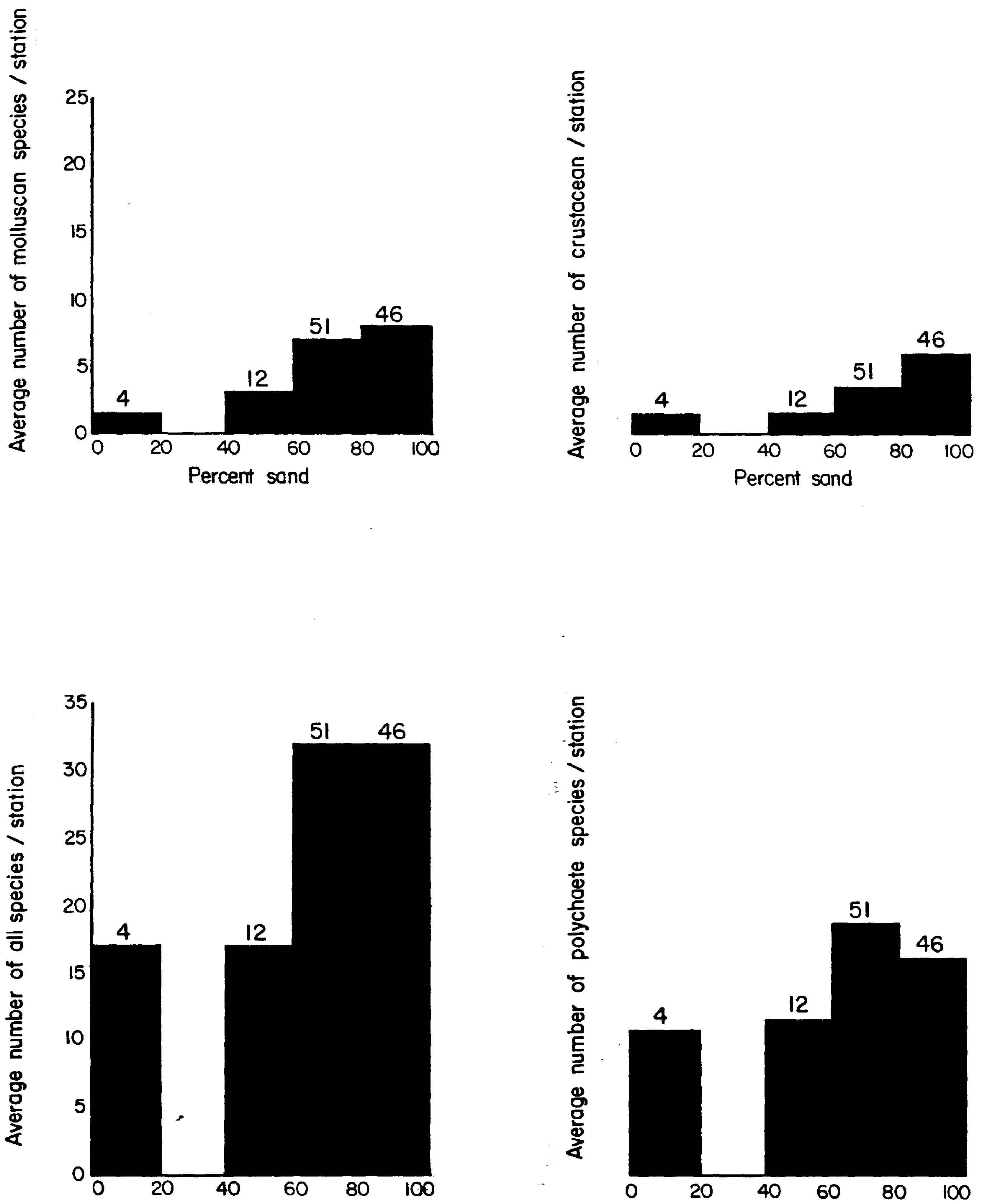


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Figure 37. Molluscan, crustacean, polychaete, and all species and percent sand on the inner shelf. Numbers above bars equal number of stations within that sediment type.

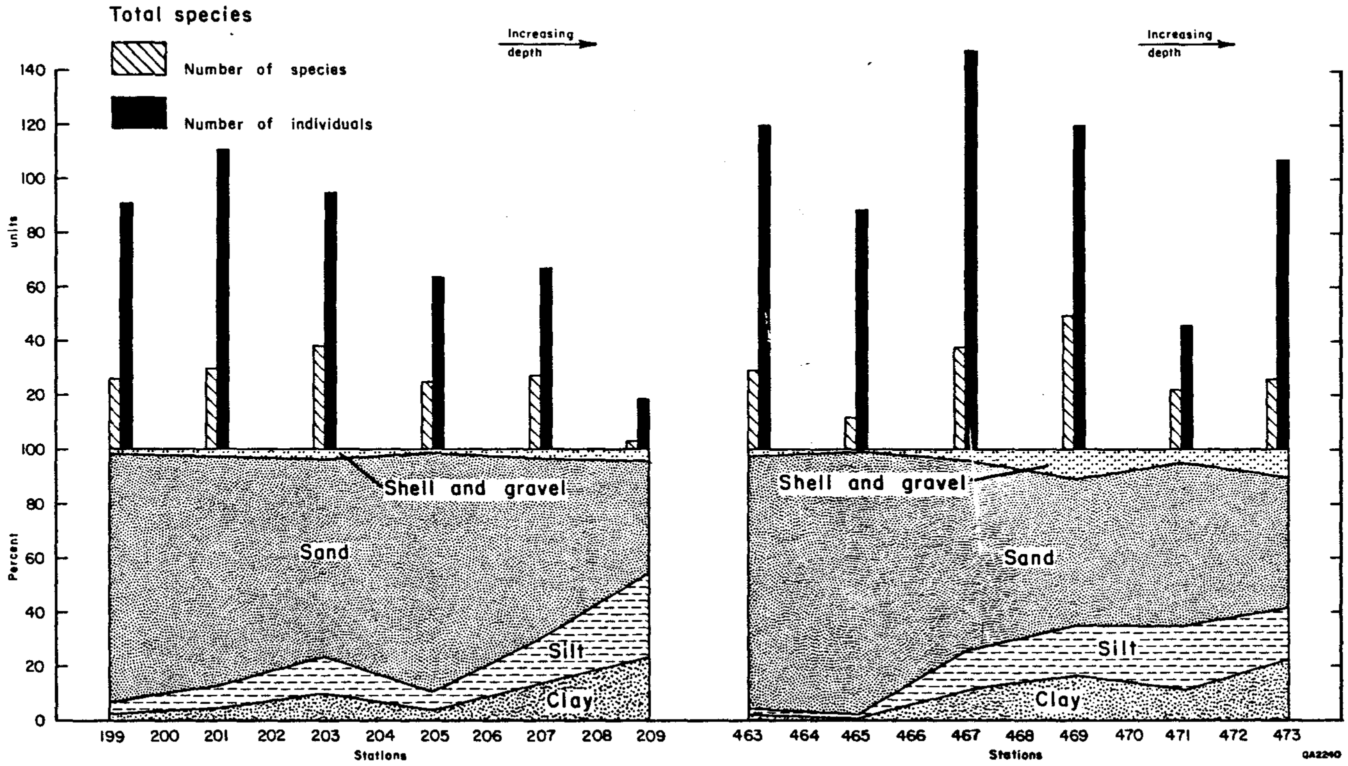


Figure 38. Total species distribution along two inner shelf transects.

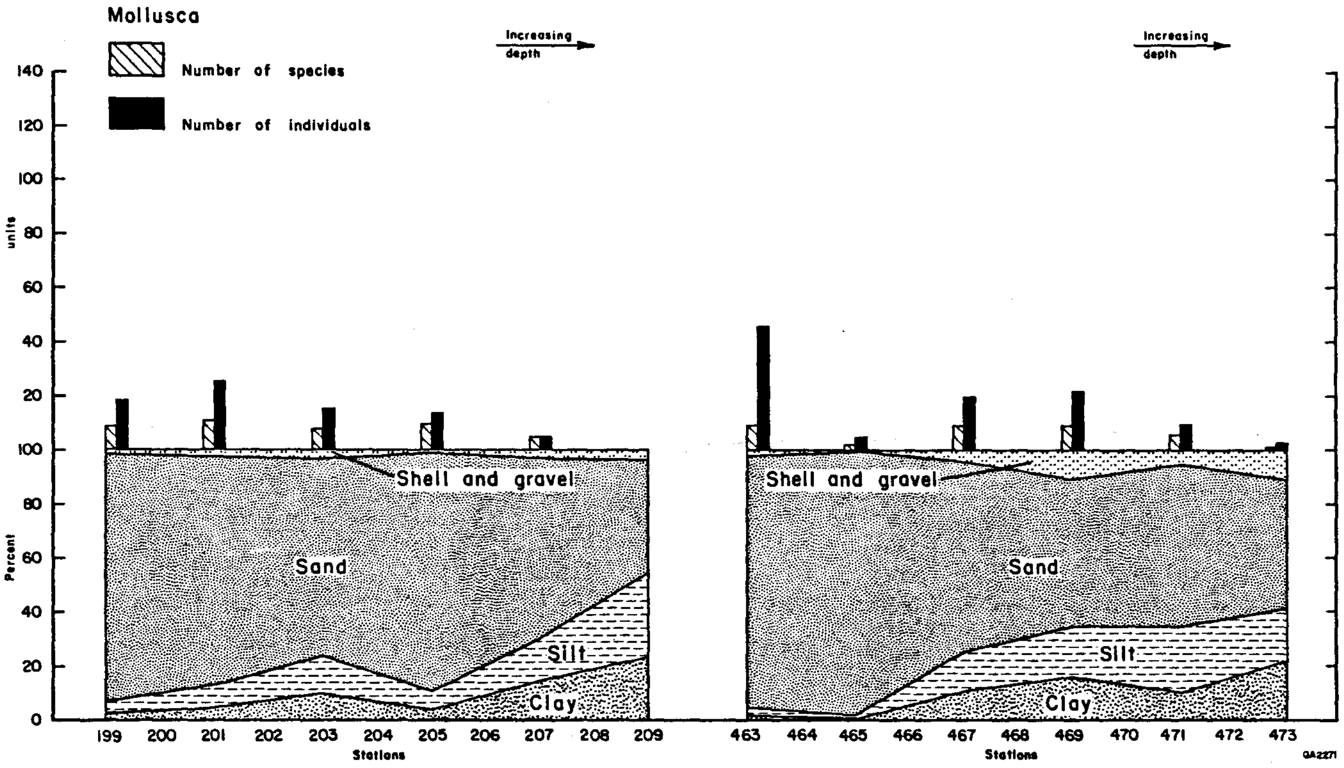


Figure 39. Molluscan distribution along two inner shelf transects. No mollusks were present at station 209.

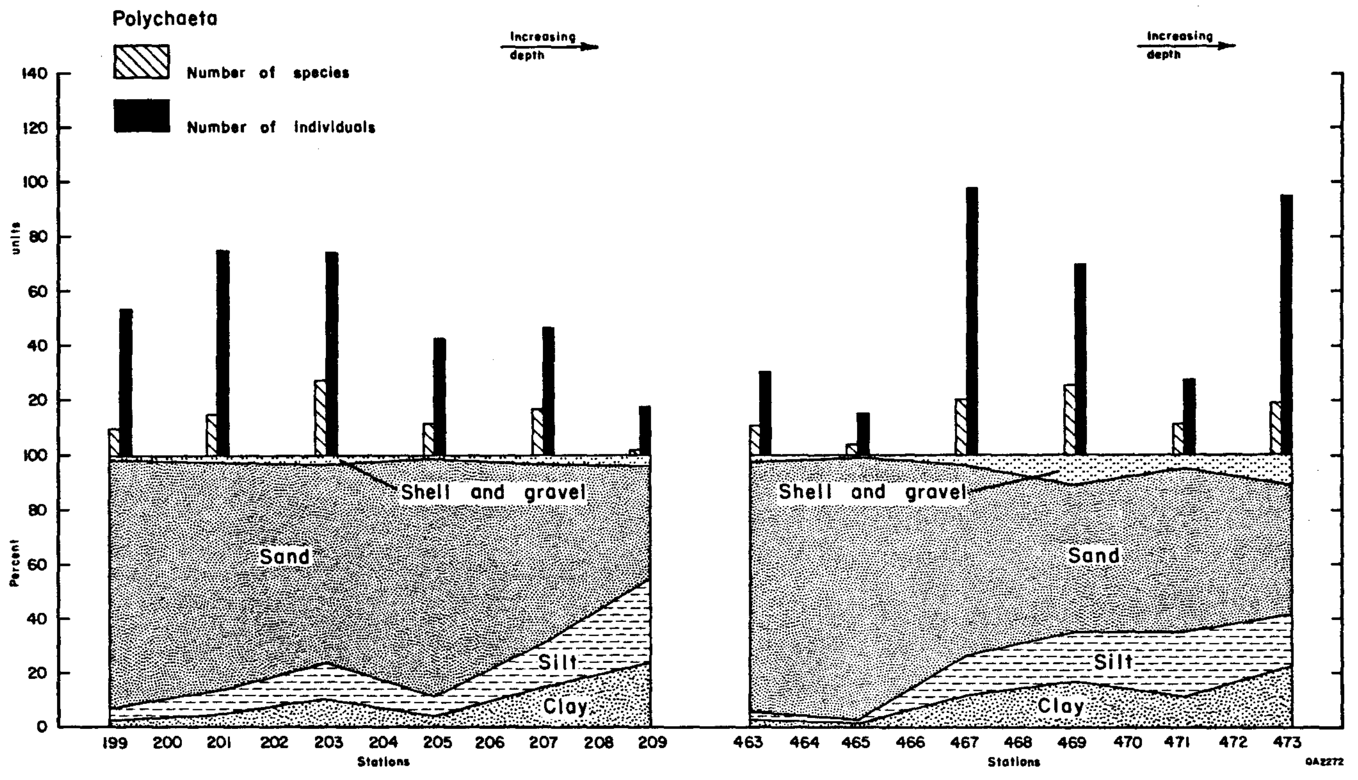


Figure 40. Polychaete distribution along two inner shelf transects.

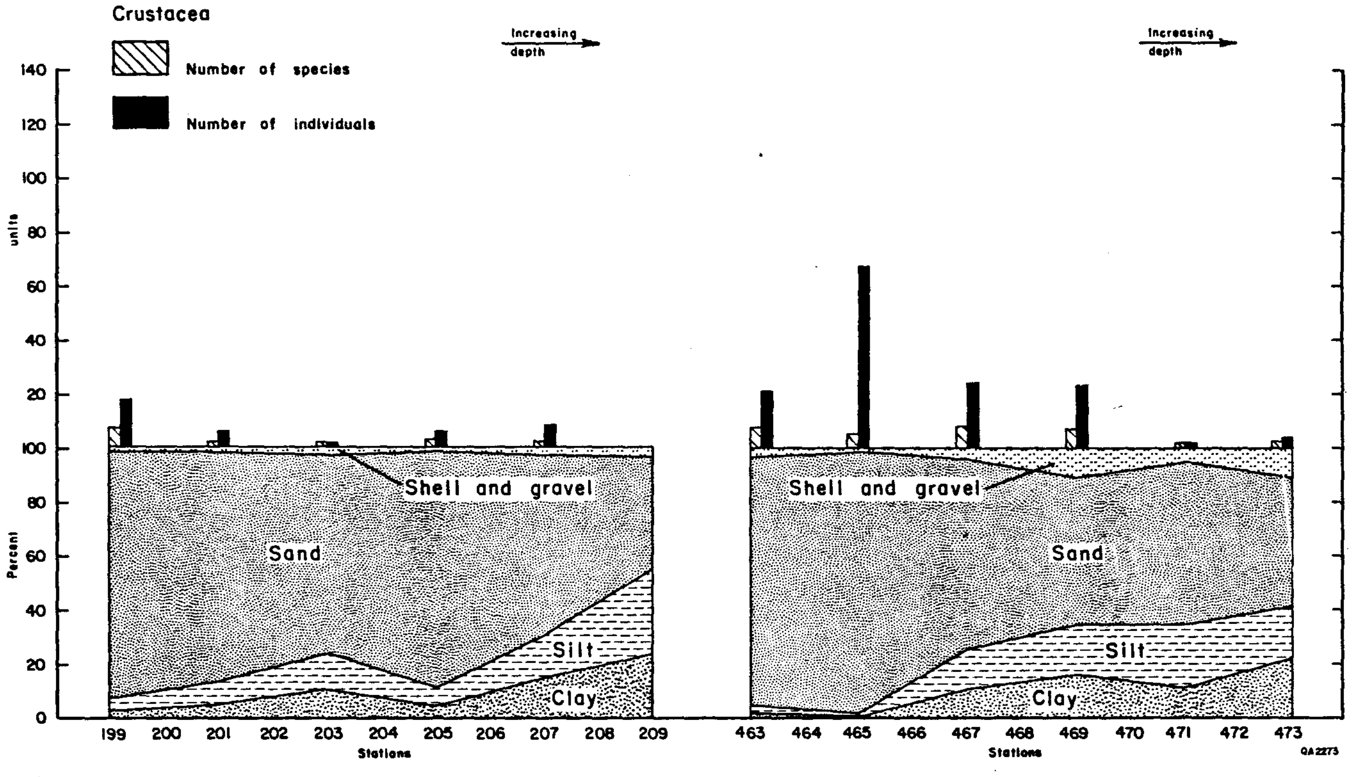
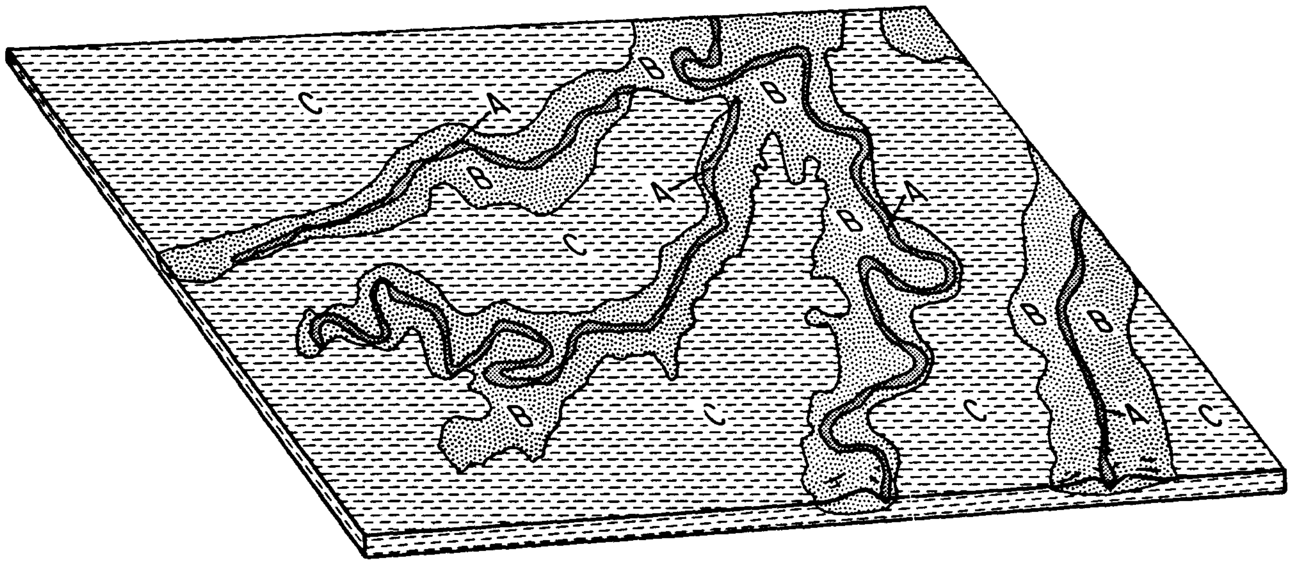


Figure 41. Crustacean distribution along two inner shelf transects. No crustaceans were found at station 209.



Depositional Unit	Typical Map Unit
A. Abandoned distributary channel	Brackish-water marshes Transitional areas Woodlands
B. Levee and crevasse splay deposit	Uplands Transitional areas
C. Interdistributary basins	Salt-water and brackish-water marshes Vegetated saline flats and transitional areas Sand or mud flats

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Figure 52. Typical units mapped in the Modern-Holocene deltaic system. Note the repetitive pattern of units across the figure. (Depositional units modified from Brown and others, 1980.)