BUREAU OF ECONOMIC GEOLOGY

DRAFT

THE UNIVERSITY OF TEXAS
AT AUSTIN
W. L. FISHER, DIRECTOR

SUBMERGED LANDS OF TEXAS, GALVESTON-HOUSTON AREA: SEDIMENTS, GEOCHEMISTRY, BENTHIC MACRO-INVERTEBRATES, AND ASSOCIATED WETLANDS

by

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

Preface by W. L. Fisher

DRAFT

1984

Bureau of Economic Geology
W. L. Fisher, Director
The University of Texas at Austin
Austin, Texas 78712

DRAFT

SUBMERGED LANDS OF TEXAS, GALVESTON-HOUSTON AREA: SEDIMENTS, GEOCHEMISTRY, BENTHIC MACROINVERTEBRATES, AND ASSOCIATED WETLANDS

by

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

Preface by W. L. Fisher

Special Contributions

Biology and Geology
W. A. Ambrose, J. A. DiGiulio, J. P. Herber, D. H. LeComte, J. G. Paine,
S. M. Robertson, J. L. Smith, G. J. Steck, 3. E. Sullivan,
L. R. Wilk, 3. H. Wilkins, and P. A. Yates

Cartography
Barbara Hartmann and R. L. Dillon

DRAFT

1984

Bureau of Economic Geology
W. L. Fisher, Director
The University of Texas at Austin
Austin, Texas 78712

Financial assistance was provided in part by (1) the General Land Office of Texas with funds in accordance with section 305 of the Coastal Zone Management Act for Coastal Zone Management Program (CZM P), (2) the Governor% Budget and Planning Office with grants in accordance with section 308 of the same act for the Coastal Energy Impact Program (CEIP), CZMP and CEIP funding are administered by the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce, and (3) the Minerals Management Service of the U.S. Department of the Interior; parts of the study were conducted in cooperation with the U.S. Geological Survey.

CONTENTS

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, transportation, 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 improtant 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

DRAFT

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 addition, the distribution of wetlands in adjacent areas was mapped using color infrared photographs taken in 1979.

Textural maps of the Galveston-Houston area show that mud and sandy mud, having a mean grain size of between 5ϕ and 8ϕ, are the dominant sediment types in bay-estuary-lagoon and inner-shelf areas. Generally, muds occupy the deeper, central-bay areas of Trinity and Galveston Bays, whereas sandier sediments occur along the bay margins. Sediment distribution patterns in East and West Bays, and the southern part of Galveston Bay are more complex. Sandy sediments are associated with flood-tidal deltas at Bolivar Roads and San Luis Pass, and with the modern barrier islands. Shelly sediments are locally abundant, primarily in association with oyster reefs. On the inner shelf, sand occupies the nearshore zone along the beach and shoreface. This zone, which is extremely narrow, along Bolivar Peninsula, broadens offshore from Galveston Island. Gulf ward, mud and sandy mud are widely distributed. Sandy mud occurs along much of the seaward perimeter of the study area and projects landward as "background" reentrant among the other sediment types. Arcuate trends of muddy sand and smaller patches of sand most likely delineate ancestral strandlines on the inner shelf. Shell represents only a minor fraction of shelf sediments. The distribution patterns of sediment types in many areas of the bays and in some areas on the inner shelf reflect different levels of wave and current energy controlled mostly by water depth.

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. In sediments composed predominantly of mud (>75% mud), the mean concentrations of barium, iron, manganese, and nickel are higher in shelf sediments than in bay sediments. The opposite is true for boron, chromium, copper, lead, and zinc, which have higher mean concentrations in bay muds than in shelf muds. Scatter grams 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 these sediments are primarily polychaetes, bivalves, gastropod, and crustaceans. Polychaetes were dominant in the bays and on the inner shelf. In general, on the inner shelf, stations with higher percentages of sand generally had more benthic species. In the bays, the positive correlation between percent sand and species number is lower than on the inner shelf. Most bay stations exhibited low to moderate diversity values. Diversity indices on the inner shelf were generally high to very high. 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 Galveston-Houston area, 19 map units, including 3 marsh categories, were used to delineate wetlands. Major marsh units include salt-, fresh- to brackish-, and fresh-water marshes, each subdivided into “high!' and "low" categories according to moisture conditions and vegetation reflected in 1979 photographs. Photographic analysis was confirmed by representative field observations, and augmented by other available data. Wetlands mapped for this project were compared with those of the Environmental Geologic Atlas of the Texas Coastal Zone (mapped

DRAFT

on 1956 photographs). The comparison suggests that some changes, such as the submergence of marshes and woodlands in many areas, are in part related to compactional subsidence, both natural and man-induced, and relative sea-level rise. In addition faulting has apparently had a role in some wetland changes.

DRAFT

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

DRAFT

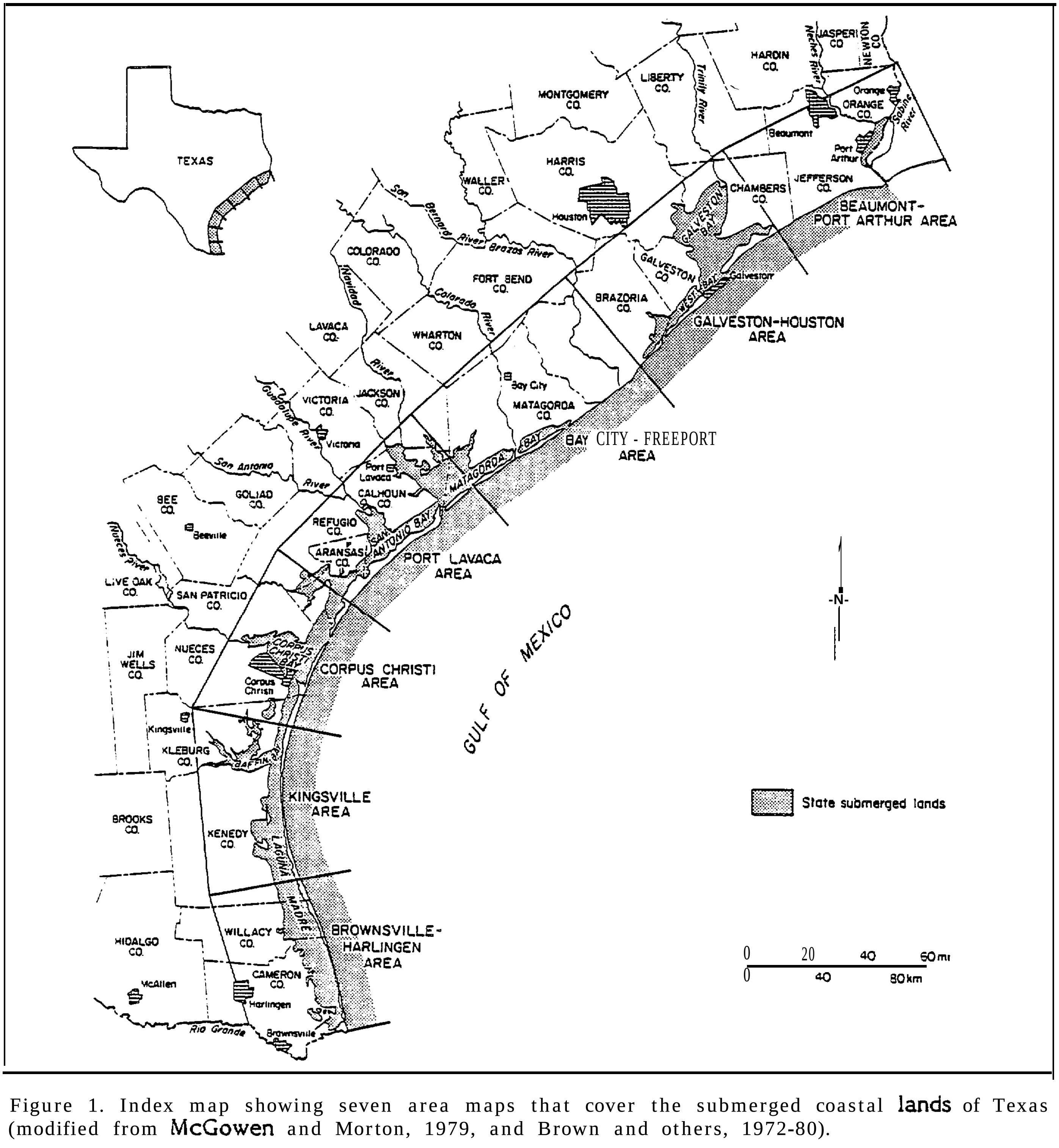


Figure 1. Index map showing seven area maps that cover the submerged coastal lands of Texas (modified from McGowen and Morton, 1979, and Brown and others, 1972-80).

as a series of seven atlases of the Texas coast, divided into areas (fig. 1) similar to those defined in the Bureau's Environmental Geologic 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; this atlas of the Galveston-Houston area is the second.

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 (.001.3 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.

DRAFT

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 Galveston-Houston 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

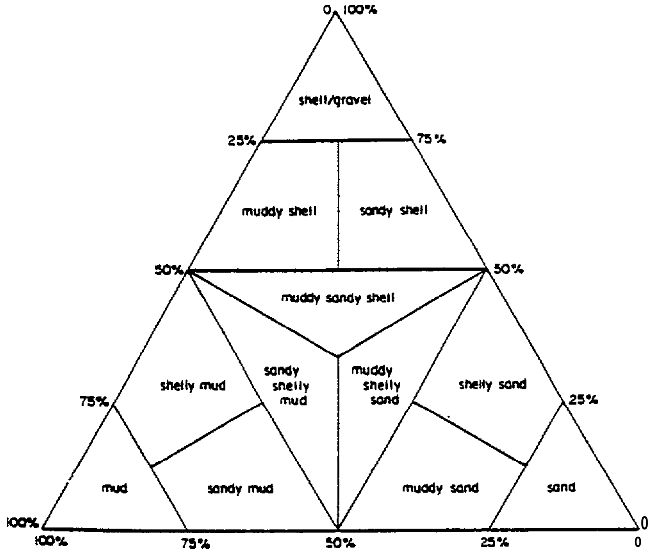


Figure 2. Classification of sediment types: shell (gravel)-sand-mud, submerged lands of Texas (from McGowen and Morton, 1979).

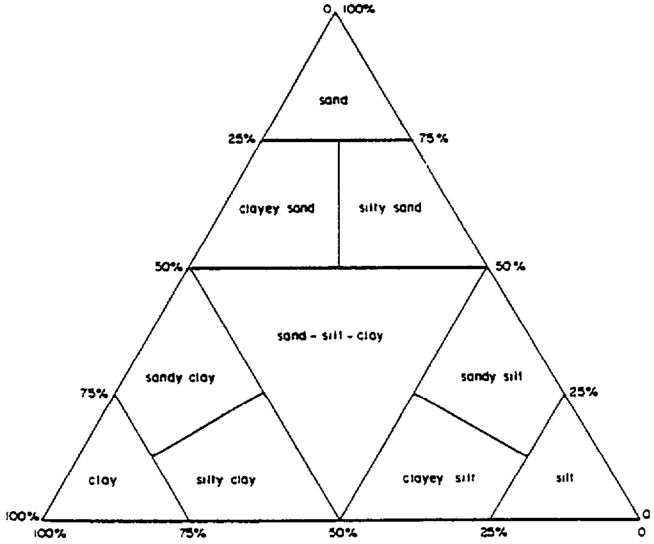


Figure 3. Classification of sediment types: sand-silt-clay, submerged lands of Texas (modified from Shepard and Moore, 1955).

distribution of mean grain sizes within the sand and mud fractions, complete the suite of textural maps (pi. 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, 111, 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 count y 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.

GALVESTON-HOUSTON AREA

The Galveston-Houston map area, as defined in figure 1 and plates I through VI, includes a relatively large bay-estuary-lagoon system--Trinity, Galveston, East, and West Bays--separated from the Gulf of Mexico and the inner shelf by a modern barrier-island and peninsula complex composed of Galveston and Follets Islands, and Bolivar Peninsula. Tidal exchange between marine and estuarine systems occurs at (1) Bolivar Roads, a tidal inlet between Galveston Island and Bolivar Peninsula, (2) San Luis Pass, a tidal inlet between Galveston Island and Follets Island, and (3) Rollover Pass, a man-made inlet through Bolivar Peninsula that connects Gulf waters to Rollover Bay and East Bay (fig. 4). Smaller embayments connected to this extensive bay-estuary-lagoon system include Tabbs Bay, Clear Lake, Dickinson Bay, Moses Lake, Dollar Bay, Chocolate Bay, Bastrop Bay, and Christmas Bay. Two major rivers discharge into estuarine areas. They are the Trinity and San Jacinto Rivers. Other smaller streams discharging into the bays (listed in a counterclockwise direction around the bay-estuary-lagoon system) are Double Bayou, Cedar Bayou, Buffalo Bayou, Clear Creek, Dickinson Bayou, Halls Bayou, Chocolate Bayou, and Bastrop Bayou (fig. 4). The Brazes River crosses the western corner of the atlas sheet but does not discharge in the map area.

Major cities in the map area include Houston, Galveston, Baytown, and Texas City. Several navigation channels cross the bay-estuary-lagoon system serving ports at the major cities. Channels include (1) the Houston Ship Channel, which connects to and extends up Buffalo Bayou, (2) the Texas City Ship Channel, (3) Galveston Ship Channel, and (4) the

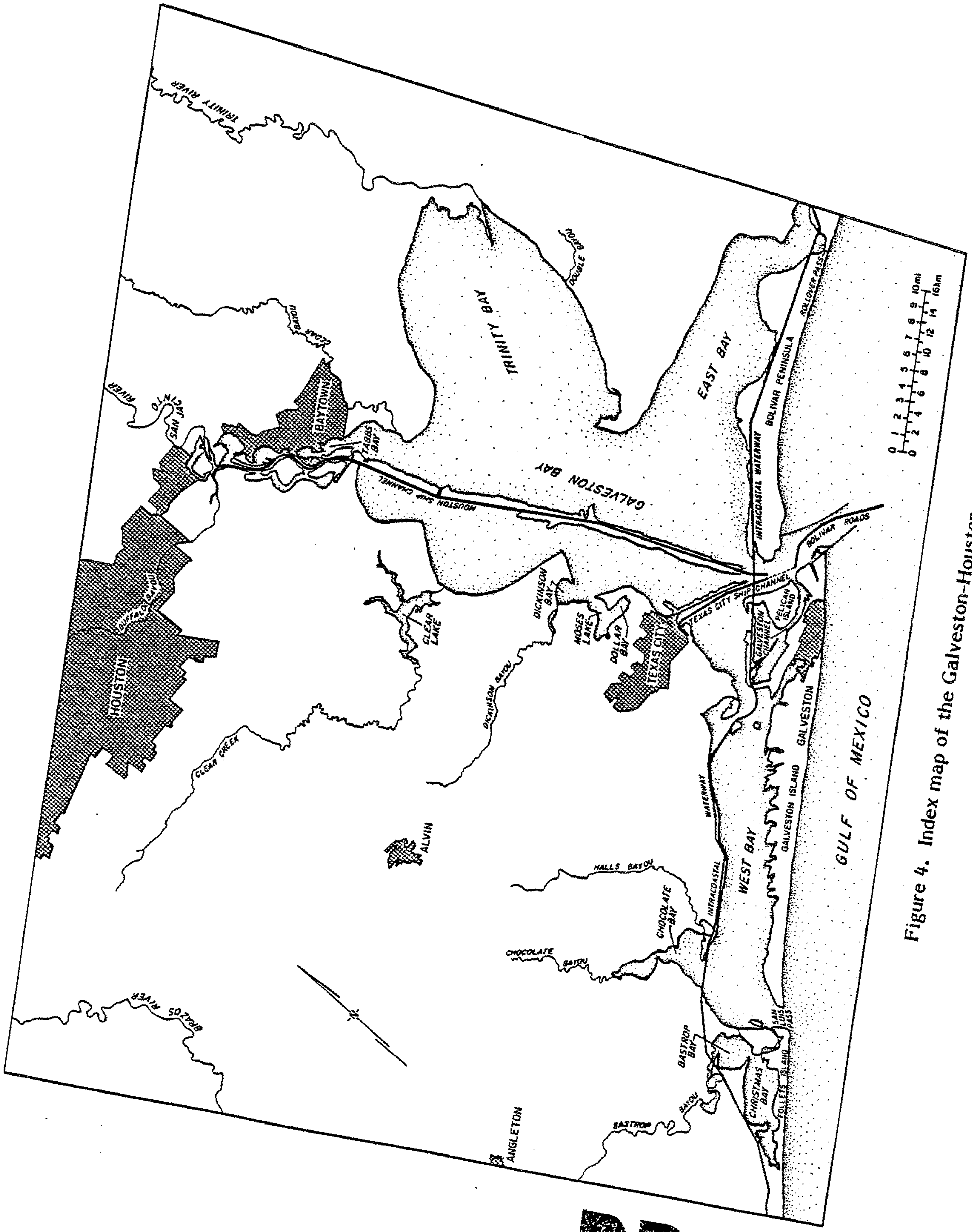


Figure 4. Index map of the Galveston-Houston area.

DRAFT

Intracoastal Waterway. Dredged spoil has been placed along most of the channels (Fisher and others, 1972). Extensive industrial complexes are located in the Houston area along Buffalo Bayou and the Houston Ship Channel, and at Texas City.

Climate

Climate in the Galveston-Houston area is humid (Thornthwaite, 1948). Average annual rainfall in the area ranges from 51.5 inches (130.8 cm) per year in Chambers County to 41.8 inches (106.2 cm) per year in Galveston County (Fisher and others, 1972). Between 1931 and 1960 the Galveston-Houston area had from 5 to 8 inches (12.7 to 20.3 cm) excess moisture from precipitation after evapotranspiration (fig. 5). Precipitation levels in the Galveston-Houston area during recent years are shown in figures 6 and 7. Although this area has occasional droughts, it is also affected by higher than normal precipitation levels, for example, from torrential rains accompanying hurricanes and tropical storms as from tropical storm Claudette in July, 1979 (fig. 8). Temperatures vary across the map area but generally range from average winter lows in the mid 40's (°F) (7° to 9°C) to summer-average maximum highs in the low to mid 90's (33° to 35°C). Between 1931 and 1960, the average annual mean free-air temperature in the Galveston-Houston area was about 70°F (21°C) (Fisher and others, 1972). Two principal wind regimes dominate the Galveston-Houston area -- persistent, southeasterly winds from March through November and short-lived but strong northerly winds from December through February (Fisher and others, 1972). 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

DRAFT

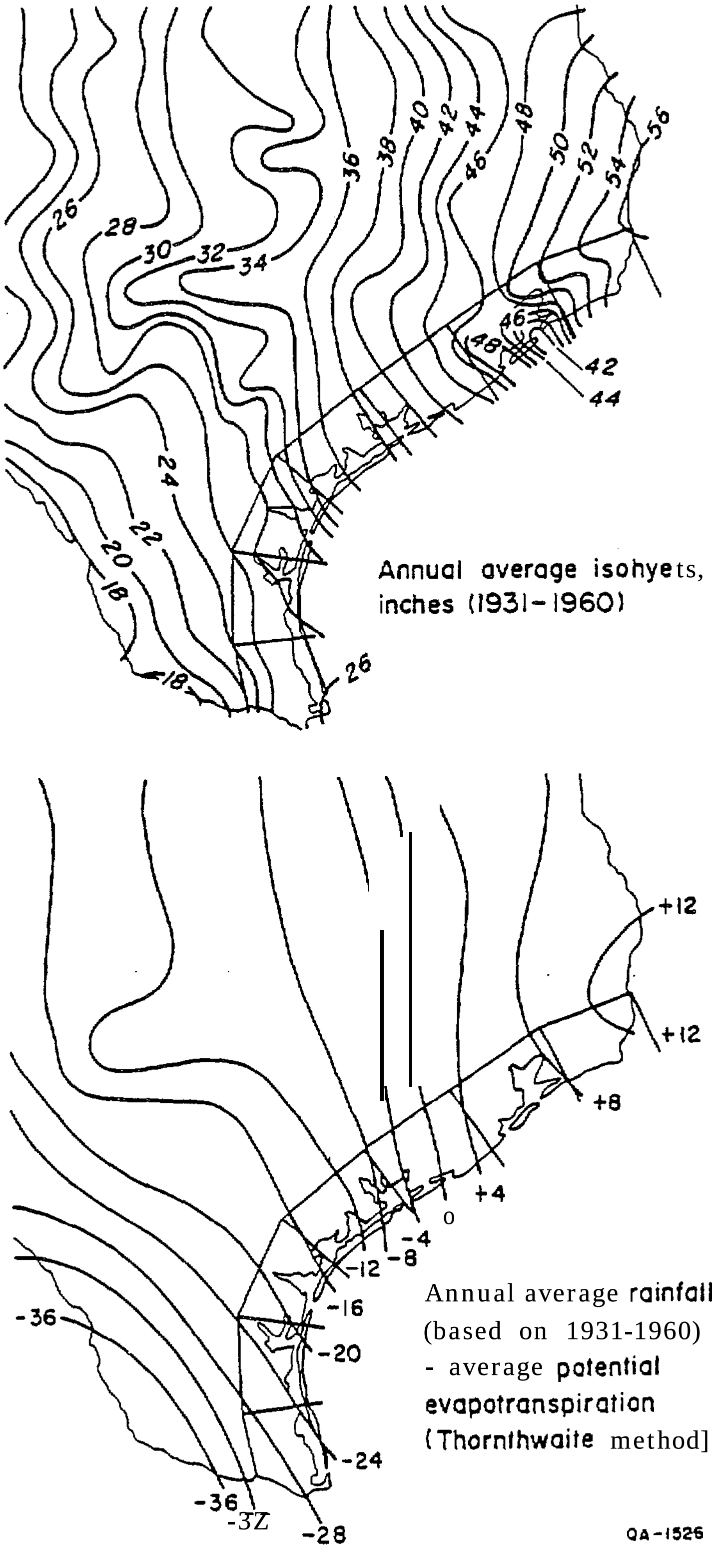


Figure 5. Regional climatic data, Texas Coastal Zone (after Brown and others, 1976). Calculation of average potential evapotranspiration from Thornthwaite and Mather, 1959.

DRAFT

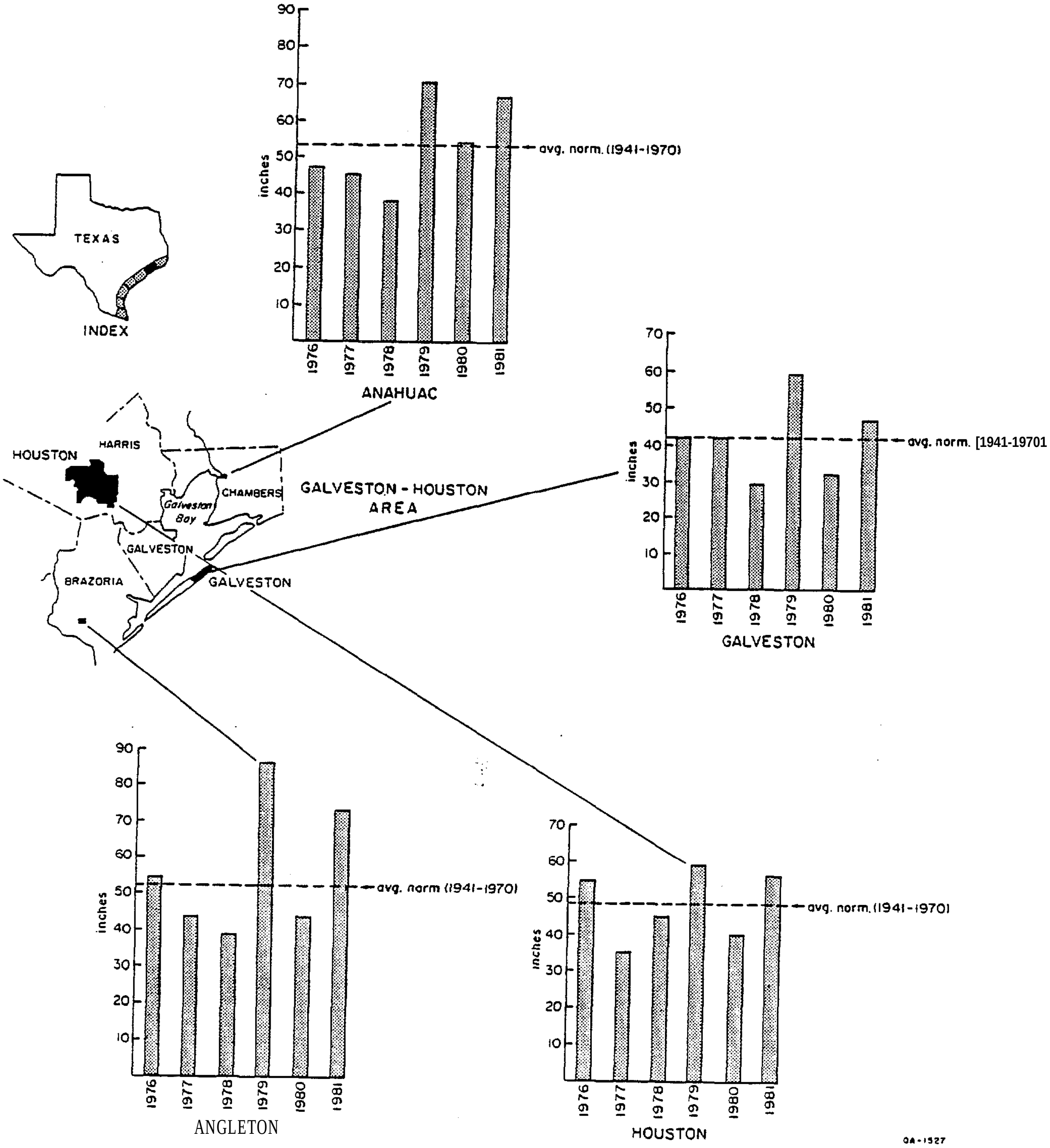


Figure 6. Annual precipitation of Anahuac, Angleton, Galveston, and Houston, Texas, 1976-1981. Compiled from records of the National Weather Service, U.S. Department of Commerce.

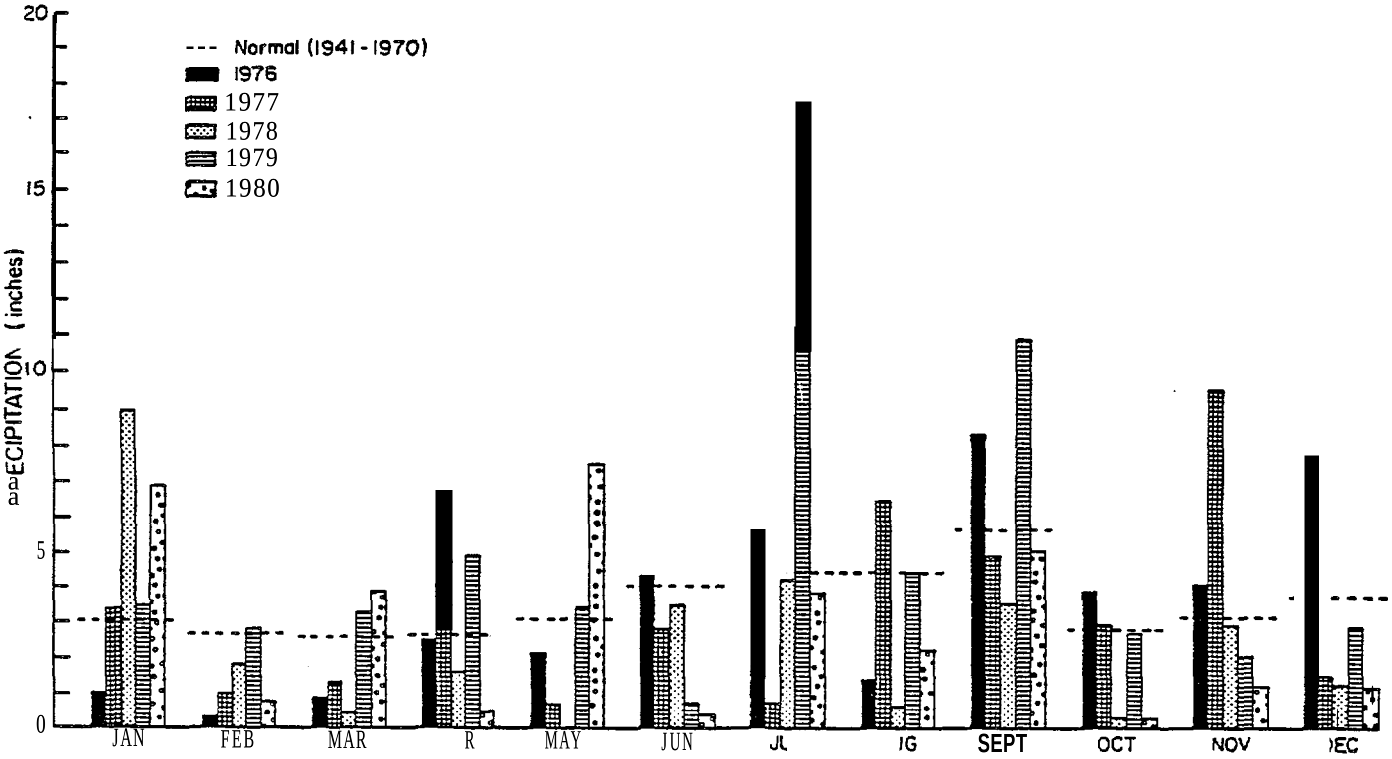


Figure 7. Monthly precipitation for Galveston, Texas, 1976-1980. Compiled from records of the National West-her Service, U.S. Department “of Commerce.

DRAFT

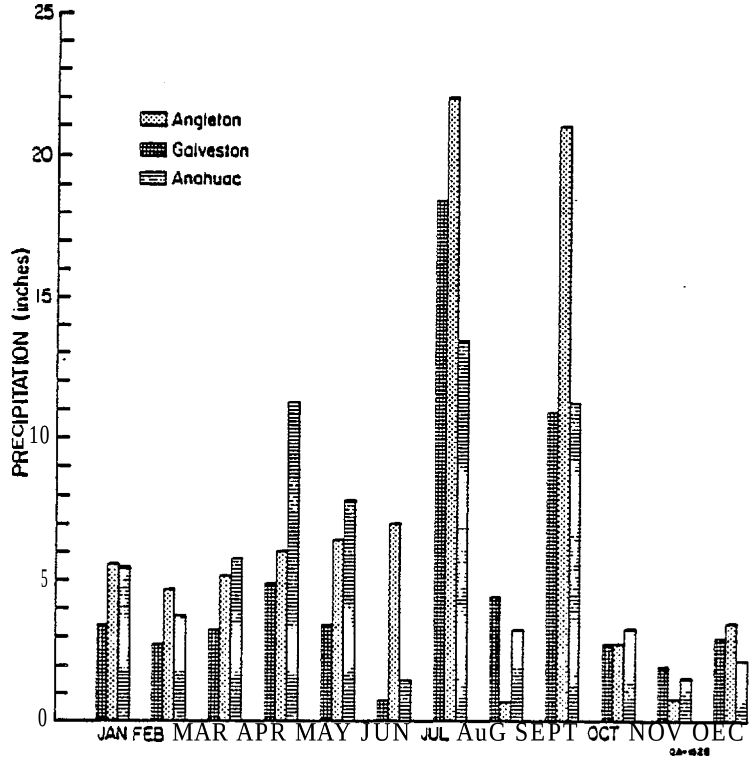


Figure 8. Monthly precipitation for Galveston, Angleton, and Anahuac, Texas, 1979. Compiled from records of the National Weather Service, U.S. Department of Commerce.

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 flows, and direct precipitation. From 1941 through 1976, annual average gaged fresh-water inflows (excludes ungaged inflows, diversions, and direct precipitation) were about 5,381,000 acre-ft (6,608 million m3) for the Trinity River Basin, 1,597,000 acre-ft (1,970 million m3) for the San Jacinto River Basin, and 109,000 acre-ft (130 million m3) for the San Jacinto - Brazes Coastal Basin (includes Clear Creek and Chocolate Bayou as well as several others bayous) (Texas Department of Water Resources, 1981). These gaged inflows compose about 60 percent of the total fresh-water inflows to the Trinity - San Jacinto Estuary. 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 wind-tidal flats and 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 Fisher and others (1972), reflect natural and genetic associations and include: (1) the off shore system, consisting of the inner continental shelf and barrier-island shoreface located seaward of the Gulf beaches, (2) the barrier-strandplain system, consisting of the modern barrier islands and the Pleistocene barrier-strandplains, (3) the bay-estuary-lagoon system, consisting of submerged estuarine environments, (4) the fluvial-deltaic system, consisting of the relict and modern environments formed by ancient (Pleistocene) and modern rivers and deltas, and (5) the marsh-swamp 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 Galveston-Houston area are discussed in a later section of this report in conjunction with wetlands, and a more in-depth discussion is presented by Fisher and others (1972).

Table 1. Generalized characteristics of active coastal processes and conditions in the Galveston-Houston area.

Climatic zone: Humid (Thornthwaite, 1948)

Average annual precipitation--41.8-51.5 inches/yr (106.2-130.8 cm/yr) (Fisher and others, 1972)

Dominant wind directions--southeasterly, northerly (Fisher and others, 1972)

Average wind speed (in 1978 at Texas City): 6.8 knots (12.6 km/hr) (Shew and others, 1981)

Astronomical tidal range

Gulf shoreline

Diurnal range: 2.1 ft (0.6 m) (U.S. Dept. of Commerce, 1978)
Mean: 1.1 ft (0.3 m) (U.S. Dept. of Commerce, 1978)

Bay shoreline: 0.9 to 1.4 ft (0.3 to 0.4 m) (Diener, 1975)

Tidal current velocities

Bolivar Roads

Average max. flood: 3.3 knots (6.1 km/hr) (Bernard and others, 1959)
Average max. ebb: 4.3 knots (8.0 km/hr) (Bernard and others, 1959)

Wave height

Gulf off Caplan, Texas

About 65 percent of the time onshore wave height is between 2.5 and 3.5 ft (0.8 and 1.1 m) (U.S. Army Corps of Engineers, 1956)

Direction of net longshore sediment transport--southwesterly (Fisher and others, 1972)

Max. hurricane surge height on open coast--12.7 ft (3.9 m) MSL (Bodine, 1969)

Hurricane frequency: 12% in any one year (Simpson and Lawrence, 1971)

Shoreline change Bolivar Roads to San Luis Pass from 1850-52 to 1973-74: Total gain from accretion of 1074 acres and total loss from erosion of 1183 acres for net loss of 109 acres (Morton, 1977)

DRAFT

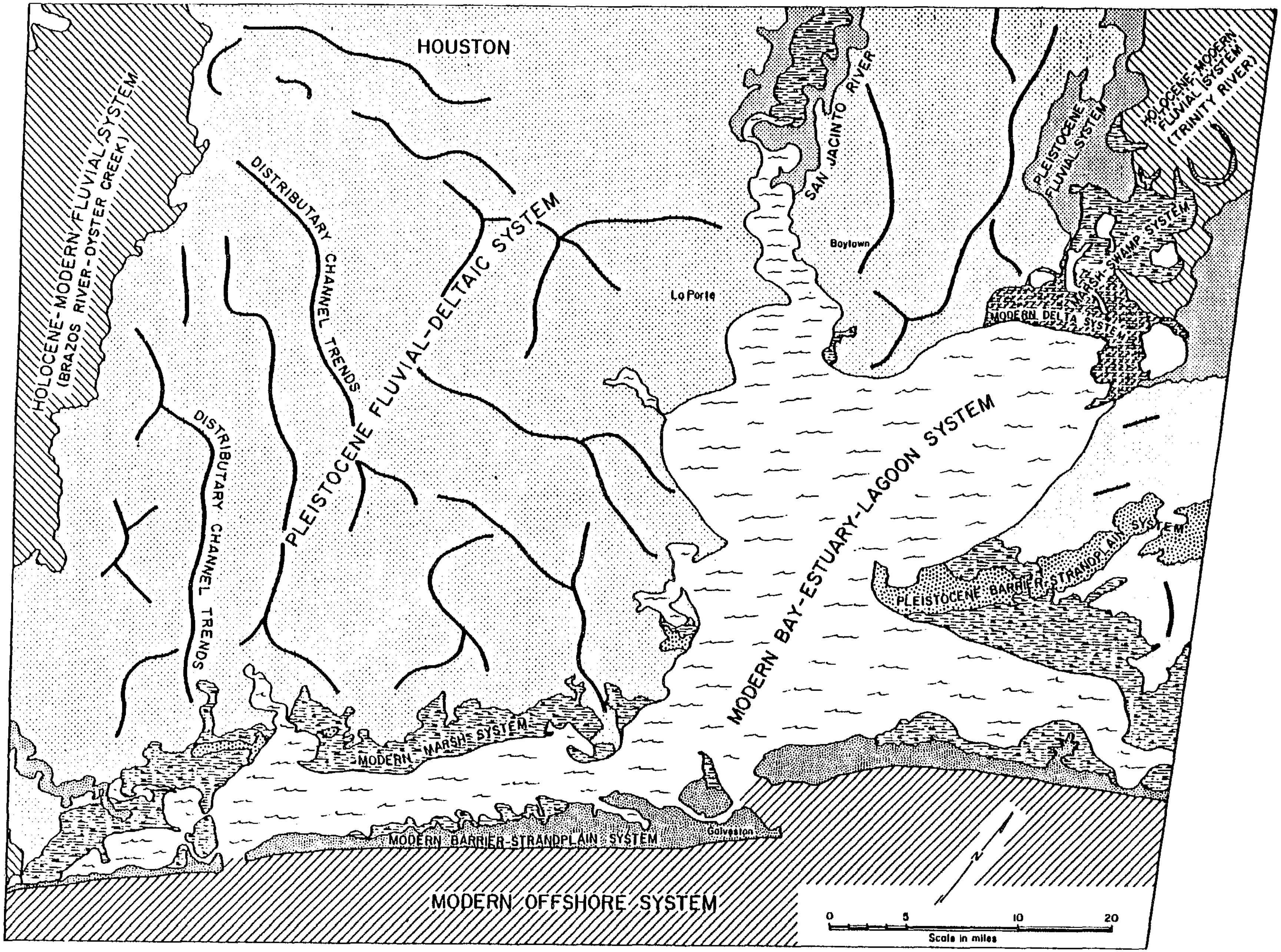


Figure 9. Natural systems of the Galveston-Houston area (from Fisher and others, 1972).

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).

Galveston Bay--the deepest bay in the system--is 10 to 12 ft (3 to 3.7 m) deep over most of the bay area. Depths in Trinity, East, and West Bays are less than in Galveston Bay; bay centers are approximately 8 ft (2.4 m), 4 to 8 ft (1.2 to 2.4 m), and 4 to 6 ft (1.2 to 1.8 m) deep, respectively. Depths in parts of East Bay and mid-Galveston Bay are variable because of the presence of oyster reefs over which the “resulting shallower water occurs.

Shallow bays, those with depths of generally less than 4 ft (1.2 m), include Chocolate, Christmas, Bastrop, Jones, Dickinson, Dollar, and Tabbs Bays and Clear Lake and. Moses Lake. The deepest areas in the bay-estuary-lagoon system occur in the dredged ship channels where dredged depths are near 45 ft (13.6 m). The Houston Ship Channel, which is 41 ft (12.8 m) deep, passes across lower and upper Galveston Bays, with branches to the city of Galveston and Texas City. The intracoastal canal is approximately 12 ft (3.7 m) deep, and passes across lower Galveston Bay.

Shelf bathymetry near the Gulf shoreline is characterized by a relatively steep slope (approximately 24 ft/mi or 4.8 m/km) across the shoreface 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 1 to 2 ft/mi (0.5 to 1 m/km) and depths along the southern edge of the map sheet exceed 60 ft (18.3 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 Galveston-Houston 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 (San Luis Pass, Bolivar Roads, and Rollover Pass). 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 the Galveston Bay system (including Trinity, East, and West Bay) provide some salinity data during the 1970's. Sediment samples were collected in the Galveston-Houston area in 1976 and 1977.

Salinities are generally highest in West Bay, followed, in order of decreasing average salinity, by Galveston, East, and Trinity Bays (fig. 10). Average salinities in West Bay are generally above 15 parts per thousand (ppt) and range into the 30's, which is in marked contrast to Trinity Bay, where average salinities range from below 5 to about 10 ppt. Salinities in Trinity Bay can drop to O ppt or exceed 25 ppt (fig. 10). Monthly ranges in salinities in Galveston Bay can vary considerably, as demonstrated by a range in measurements in July, 1973 of 0.6 to 33 ppt (fig. 10). Salinities in Galveston and East Bays generally increase toward Bolivar Roads demonstrating the effect of marine waters in this tidally influenced area. Also, salinities in West Bay generally increase toward San Luis pass and Bolivar Roads (Texas Department of Water Resources, 1981).

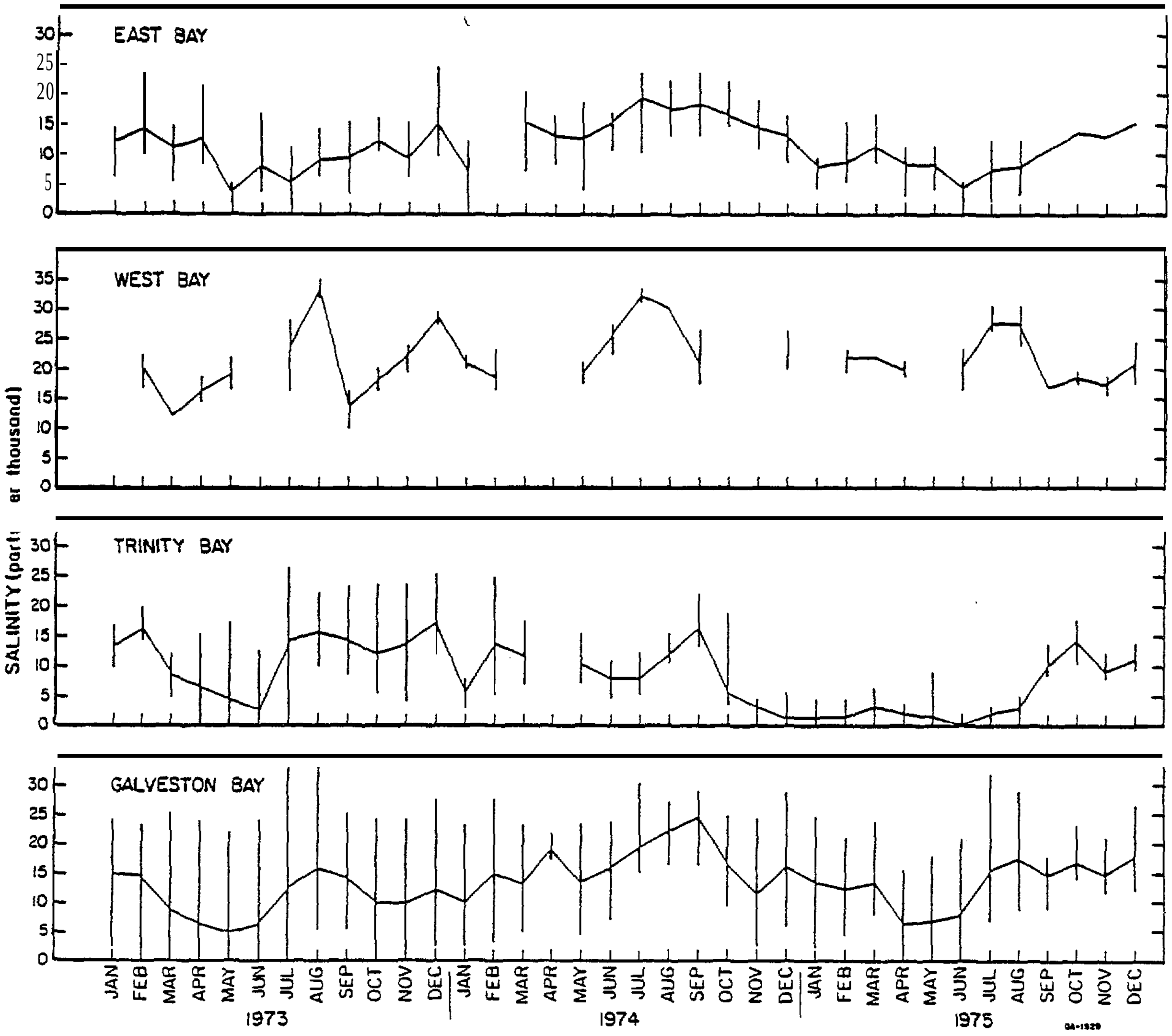


Figure 10. Monthly means and ranges in salinities in four bay systems in the Galveston-Houston area. (Compiled from Martinez, 1973, 1974, 1975).

Sample Collection and Analysis

A total of 1,366 sediment samples were collected from State-owned submerged lands in the Galveston-Houston area (pi. VI). Of those collected and stored almost all of them (1,360) were analyzed for total organic carbon; 525 were analyzed for textural properties; 263 for benthic macroinvertebrates; and 395 for selected trace and major elements (table 2). 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.

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

		Number of samples analyzed			
Location	Number of samples collected	Texture	TOC	Chemical elements	Benthic macroinvertebrates
Galveston-Trinity-East Bay	463	231	462	133	134
West Bay (including Chocolate, Christmas, Bastrop, and Jones Bays)	132	57	132	33	42
San Jacinto River	8	6	8	4	1
Buffalo Bayou (Houston Ship Channel)	36	21	36	36	3
Clear Lake	12	4	11	4	3
Offatt Bayou	3	1	3	1	0
Moses Lake	3	2	3	2	0
Dollar Bay	1	1	1	1	0
Dickinson Bayou	5	3	5	2	0
Galveston Channel	4	2	4	1	0
Intracoastal Waterway	23	11	23	10	0
Cedar Bayou	8	4	8	2	0
Bay-Estuary-Lagoon Totals	698	343	696	229	183
Inner-Shelf Totals	668	182	664	166	80
Submerged Lands Totals	1366	525	1360	395	263

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

Location	Sample Collection Dates
Galveston-Trinity-East Bays	July 15 to July 22, 1976; July 29 to August 9, 1976; August 19-August 25, 1976; September 18 to October 3, 1976
West Bay (including Chocolate, Christmas, Bastrop, and Jones Bays)	January 7 to January 15, 1977 (West Bay 1 to 62) July 18 to July 21, 1976 (West Bay 63 to 132)
San Jacinto River	September 12, 1976
Buffalo Bayou (Houston Ship Channel)	August 20 and September 11, 1976
Clear Lake	September 10, 1976
Inner Shelf	October 20 to October 26, 1976 (Stations 2851 to 3458) September 15, 1977 (Stations 3459 to 3521)

SEDIMENTS AND GEOCHEMISTRY

by Robert A. Morton, William A. White, 3. H. McGowen,
and H. Seay Nance

Assisted by William A. Ambrose, Janice L. Smith, Patricia A. Yates,
Jon P. Herber, Jeffrey G. Paine, and David H. LeComte

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 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, (5) nonterrestrial biogenic materials, composed primarily of oyster shells but including tests of other benthic invertebrates, and (6) spoil placed on submerged lands along dredged channels and in areas of shell-dredging. 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 Galveston. The influence of rivers on shelf sedimentation in this area has been largely indirect because the nearest river (Brazes) is more than 15 mi (24 km) southwestward, a direction opposite to the net movement of littoral drift. Despite this distance and direction the Brazes River was responsible for some of the coarse-grained sediment found near the surface and some of the fine-grained sediment buried beneath the most recent shelf deposits.

Although it seems incongruous, the areas of greatest erosion of the Texas Gulf shoreline and shoreface are near the mouths of the Rio Grande and Brazes and Colorado Rivers. Erosion and redistribution of fluvial-deltaic deposits of ancestral Brazes (Holocene) and Trinity (Pleistocene) Rivers were significant sources of shelf sediment for the Galveston-Houston area shortly after sea level reached its present position about 5,000 years ago. However, the volume of sediment supplied 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 Galveston today are (1) suspension and redistribution of preexisting shelf and shoreface sediments during storms and (2) transportation of suspended sediment from the adjacent bay-lagoon system. The latter group of sediments is transported onto the shelf through tidal inlets at Bolivar Roads and San Luis Pass. The “new” sediment introduced from the bay-lagoon system may include suspended fluvial sediment passing through the bay 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 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.

Rock fragments are common in shelf sediments off Bolivar Peninsula, along a short linear trend between stations 3072 and 3139, and along a narrow arcuate trend extending from stations 2854 to 2984 and 3129 (PL IA). Morton and Winker (1979) interpreted the latter trend as a relict beach deposit of the ancestral Brazes delta. Shell concentrations are generally greatest along these same trends where rock fragments are present. Together the shells and rock fragments constitute from 2 to 8 percent of the sediment volumes at the stations where the coarse fraction is abnormally high.

The size and volume of sand increases offshore where relict sands are abundant within the Galveston-Houston area; however, composition of the sand fraction does not vary substantially either alongshore or offshore. Major components of the sand fraction and their average percentages are quartz (91 percent), feldspar (3 percent), rock fragments (2 percent), and accessory minerals, including glauconite (3 percent). Black opaques account for nearly half of the heavy mineral population; other heavy minerals in decreasing order of abundance are: basaltic hornblende (10 to 15 percent), tourmaline (10 to 15 percent), rutile (3 to 7 percent), zircon (1 to 8 percent), and pyroxenes (1 percent). Chlorite and the micas (muscovite and biotite) account for about 6 and 5 percent, respectively. The heavy mineral assemblage and the relative proportions of the minerals are not markedly different from compositions and values reported by Bullard (1942) for beach and river sands of the central Texas coast.

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 oyster 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.

(4) Errors may have occurred during the processing of such a large quantity of data.

Bay-Estuary-Lagoon System

Shell(Gravel)-Sand- Mud.--The dominant sediment types in the Galveston-Houston bay-estuary-lagoon complex are mud, muddy sand, and sandy mud. The latter two are approximately equal in areal extent (pl. IA). Mud, composed of silt and clay, is widely distributed in the central areas of Trinity and northwestern Galveston Bays, and in the northern and southwest regions of East Bay (pl. 1A). Muddy sands and sandy muds flank bay-margin sands in most areas. The relatively high energy environments of (1) the Trinity River bay-head - delta-front area, and (2) the flood-tidal inlet area of Bolivar Roads are characterized by sandy sediments. Sands and muddy sands extend west and northwest from the human-modified flood-tidal delta, Pelican Island. Sand and muddy sand border the bayward side of Bolivar Peninsula and Galveston Island. Narrow West Bay is floored by relatively sandy sediments; sand occurs along the bay margins! muddy sand is extensive in the eastern and western parts of the bay, and sandy mud covers much of the west central part of the bay. Shell debris from oyster reefs apparently accounts for much of the sand fraction in the east-central half of West Bay.

The complex distribution of sand, muddy sand, and sandy mud in the gulf ward half (southern part) of Galveston Bay is apparently related to (1) the tidal and hydrodynamic conditions in this area (this is a high energy environment particularly during storms),(2) the presence of oyster reefs, (3) the sandy barriers of Galveston Island and Bolivar Peninsula, (4) the flood-tidal delta of Pelican Island, (5) upland Pleistocene fluvial-deltaic sands and barrier-strandplain sands (Fisher and others, 1972) found along the western shoreline (fig. 9), and (6) disposal of spoil along the Houston Ship Channel and associated navigation channels. The sand around the margin of Smith Point indicates it is derived from erosion of Pleistocene barrier-strandplain sands that make up the adjacent uplands.

The distribution of sandy shell and other mixtures of shell with sand and mud is associated in most cases with oyster reef flank deposits in various areas of Galveston Bay.

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 greater abundance of sand on the sand-silt-clay map (pi. IB) when compared to the shell- (gravel-) sand-mud map (pi. 1A). This difference can be seen by comparing the two maps between Hanna Reef and San Leon in Galveston and East Bays.

DRAFT

In the mud fraction, silt is generally more abundant than clay. This relationship is shown by the wide distribution of clayey silt over most of Trinity Bay as well as over the northern and northwestern parts of Galveston and East Bays. The predominance of silt over clay in deep bay-center muds, as well as in muds in deeper areas of the inner shelf is partly an artifact of the textural analysis used (see appendix A). Clay is more abundant than silt in only a few stations, for example, in Scott Bay (pi. IB) where sediments analyzed indicate a silty-clay substrate.

Mixtures of sand, silt, and clay, where no single sediment fraction exceeds 50 percent, are found near bay margins fringing sediments with higher sand content, such as in Trinity and East Bays. This mixed sand-silt-clay map unit has a relatively broad distribution in the lower (southeastern) half of Galveston Bay, and in West, Chocolate and Christmas Bays.

Most bay-margin sands grade bayward into silty sand. Silty sand also occurs along the flanks of oyster reefs in Galveston, East, and West Bays. Relatively widespread occurrences of sand and silty sand in the southeastern part of Galveston Bay between San Leon and Pelican Island are probably a result of (1) the high energy hydrodynamic conditions prevalent in this tidally influenced area near Bolivar Roads, a tidal inlet, (2) the presence of oyster reefs and dredged-spoil deposits that can contribute sand-size material, and (3) the presence of other nearby sources of sand such as Galveston Island, Pelican Island, Bolivar Roads and the mainland. The broad distribution of sand and silty sand in West Bay appears to be the result of similar conditions including (1) the tidally dynamic area of San Luis Pass in the western part of the bay, (2) the presence of extensive reefs in the eastern part of the bay, (3) the presence of extensive spoil islands that line the Intracoastal Waterway especially along the northwestern side of the bay and (4) the presence of the sand-rich barrier--Galveston Island. Sandy bay sediments bayward of Galveston Island are apparently, in part, the result of storm washover processes.

Percent Sand. --The sand percent map (pi. IC) can be used with other sediment maps to provide a more complete picture of the textural variations in the bay-estuary-lagoon system. Samples containing between 60 and 100 percent sand are common throughout much of West Bay, southwestern Galveston Bay, and along most bay margins. The distribution of sand follows a relatively systematic pattern in the largest bays (Trinity Bay and upper Galveston Bay), wher bay margins contain high sand percentages that grade to less than 20 percent sand toward ba centers. A broad belt of sand--the result of fluvial-deltaic deposition--occurs at the head o Trinity Bay. Surface sediments over most of the central bay areas in Trinity Bay and Uppe Galveston Bay contain less than 5 percent sand. In East Bay, the distribution pattern of sand sediments along bay-margins is as ym metrical; the southern margin of the bay along Boliva Peninsula is characterized by a broad band of sandy sediments, whereas along the opposite (mainland) shore, the band of sandy sediments is relatively narrow (near Smith Point) an pinches out along shore to the east.

High (60- 100 percent) to intermediate (40-60 percent) concentrations of sand cover broa areas of southern Galveston Bay between San Leon and Pelican Island, and in West Bay Probable sources of sand for these sand-rich bay sediments are listed in the preceding sectio on sand-silt-clay.

Mean Grain Size---Mean grain size of the sand, silt, and clay fractions is expressed an mapped (pi. ID) in phi (ϕ) units. Phi units are logarithmic transformations of the Wentwort (1922) grade scale and are equivalent to the negative logarithm to the base 2 of particle diameter (Krumbein, 1934). (In the Phi scale, larger numbers represent finer grain sizes., Because gravel was excluded in the mean-grain-size determinations (app. A) some sampl stations mapped as predominantly shell (gravel) on the shell-sand-mud map (PI. IA) may have a mean grain size in the fine sand range on pl. ID (for example, Station 16 in West Bay).

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 detaile subdivision of sediments. The coarser sediments, ranging from very fine to medium sand (4ϕ t 1.9ϕ), occur (1) in tidally-influenced areas of Bolivar Roads and San Luis Pass, (2) along the Trinity bay-head delta, (3) on the flanks of oyster reefs and spoil islands and (4) along most bay margins. Mean grain size generally is more than 7ϕ in the central areas of Trinity Bay and locally in upper Galveston Bay and East Bay. A relatively large tongue of fine sand (<3ϕ--the coarsest sediment mapped) projects bayward from the mouth of Bolivar Roads at the tip of Bolivar Peninsula. This coarser sediment reflects the strong currents that typically occur near tidal inlets, but it may also reflect spoil-disposal operations along the Houston Ship Channel. Shell- and channel-dredging and spoil-disposal operations have altered natural sediment trends and patterns in many areas, for example, along the Houston Ship Channel and Intracoastal Waterway. Also, mean grain size is increased by detrital shell material along the flanks of oyster reefs such as those found in East, West, and Galveston Bays.

Inner-Shelf System

Shell (Gravel)-Sand-Mud.--Only one half of the 12 possible sediment types are represented on the shelf portion of plate IA because of extremely low percentages of shell in the sediments. Even though shelf sediments are composed 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. For example, the offshore increase in sand near the three-league line is accentuated and the distinction between sand and mud is quantitatively defined. However, sand and mud can also be delineated on other maps because biogenic detritus is unimportant in the Galveston-Houston area.

Shell content of shelf sediments is so low that its use in the classification scheme mainly influences the sand/mud ratio. Only three “stations (3014, 3122, and 3484) have sufficient quantities of the three sediment types to plot “within the fields of muddy, shelly sand, or sandy, shelly mud. 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).

Dominantly sand-sized sediments occupy the nearshore zone along the beach and shore face. This zone, which is extremely narrow along Bolivar Peninsula, broadens to about 2 mi (3.2 km) offshore from Galveston Island. Water depths average about 25 ft (7.5 m) at the outer limits of this sand-rich area. The greatest extent of sand is associated with the ebb-tidal deltas at Bolivar Roads and San Luis Pass. Preliminary mapping of surface sediments (McGowen and Morton, 1979) suggested that the most likely deposits of shelf sand suitable for beach nourishment material were associated with these ebb-tidal deltas. This was confirmed by Williams and others (1979). Overall, the highest concentration of sand parallels the coastline.

Patches of muddy fine sand lie seaward of the nearshore sand zone and extend to the seaward limits of the study area off Bolivar Roads and the western end of Galveston Island. Two large deposits of muddy sand are found in water depths ranging from 36 to 54 ft (12 to 18 m). Muddy sands off shore and detached from Bolivar Peninsula (stations 3416 to 3516) represent the western flank of an arcuate trend of sediment that extends onshore near High Island. The patchy trend of muddy sand that extends offshore from central Galveston Island parallels the eastern flank of another arcuate trend of coarse sediment that most likely delineates a strandline of the ancestral Brazes delta (Morton and Winker, 1979). Superimposed on this regional trend are local concentrations of sand off Galveston Island (stations 3056 to 3078) related to topographic highs that have low relief above the sea floor.

Sandy mud occurs along much of the seaward perimeter of the study area and projects landward as “background” reentrant among the other sediment types. The most continuous area of sandy mud is located offshore from Bolivar Peninsula in water depths of 18 ft (6 m) or greater. West of Bolivar Roads sandy mud deposits are consistently found in water depths of 30 ft or more.

Mud deposits closely correspond to the areas previously mapped (McGowen and Morton, 1979) as loci of fine-grained deposition. Two deposits of mud lie immediately offshore from Bolivar Peninsula and seaward of the shoreface sands. This mud delineates the depositional area of fine grained sediments sorted from the beach and upper shoreface by wave action and associated littoral currents. The area of mud north of Bolivar Roads represents a shadow zone protected from high wave energy by the jetty. Off the eastern half of Galveston Island, mud is

DRAFT

also found seaward of the shoreface sands and muddy sands but in slightly deeper water since the shoreface sands occur in water up to 30ft (9 m) deep. A similar setting exists off Follets Island where mud deposits are separated from the shoreface sands and extend offshore from near the 36ft (12 m) bathymetric contour.

Sand-Silt-Clay.--Subdivision of the shelf mud fraction into silt and clay provides a greater definition of sediment size; however, a patchy pattern emerges (plate 1$). This pattern is complicated by the presence of both modern and relict sediments. Anomalous patches of coarser sediment near the seaward limit of the study area are attributed to relict sediments. Where grain-size changes are more uniform, for example off eastern Galveston Island and Follets Island, sand passes gradationally into silty sand, sandy silt, and silt, and finally into clayey silt. The finest grained sediments on the inner shelf are composed of clayey silt.

Nearly equal amounts of sand and mud constitute sediments in the normal transition zone along the shoreface. These sediments, which are slightly coarser than adjacent muds, owe their distinctive characteristics to physical and biological processes that together have created a mixture of sand and mud. Burrowing organisms have been particularly effective in producing the more homogeneous sediments by reworking shoreface sand transported offshore during storms. Some of the storm deposits are incorporated into the underlying mud as 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).

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 1 to 97 percent of the inner-shelf sediments (pi. IC), depending partly on water depth and concomitant distance from the shoreline. Areas containing the highest proportions of sand are adjacent to the beaches of Galveston and Follets Island. In these areas concentrations of sand greater than 80 percent are generally limited to within one mile of the shoreline, except near the former ebb-tidal delta at Bolivar Roads where relatively clean sand extends up to 3 miles offshore.

Thickness and lateral extent of the nearshore sand trends along Galveston Island and Follets Island are related to the configuration of the Holocene sediment wedge that was deposited following sea-level stillstand (see Fisher and others, 1972, for discussion of sea-level changes). For example, the reentrant of fine grained sediments on west Galveston Island (stations 3106- 3129) coincides with an area where sandy Holocene sediments on the inner shelf are thin (fig. 11) and less abundant than in adjacent areas. Numerous borings indicate that Holocene sediments along Galveston Island and Bolivar Peninsula thicken towards Bolivar Roads (fig. 11) which overlies the former entrenched valley cut by the Trinity River system when sea level was lowered during Wisconsin glaciation (Rehkemper, 1969). Maximum thickness of Holocene sediments near Bolivar Roads 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. 11) over much of the inner shelf.

As shown previously by the surface sediment map (McGowen and Morton, 1979), mud is the predominant sediment type of the inner shelf in the Galveston-Houston area. Mud sinks are contrasted against the background of sediment composed of nearly equal portions of sand and mud (40-60 percent sand). The three major areas of mud deposition are located (1) just offshore from Bolivar Peninsula in 18 to 30 ft (6 to 9 m) of water (stations 3347 to 3521), (2) 3 to 11 mi off shore from the eastern half of Galveston Island in 36 to 60 ft of water (stations 3102 to 3394), and (3) along the central part of the inner shelf west of San Luis Pass in 36 to 60 ft of water (stations 2862 to 3016). The sources of mud may vary from one area to another. For example, fine-grained sediments deposited off Bolivar Peninsula appear to be winnowed from beach deposits and reworked relict sediments. In contrast, the broad area of mud off Galveston Island is probably an accumulation of sediment transported from the Galveston-Trinity Bay System through Bolivar Roads, the adjacent tidal inlet, and deposited downdrift from the

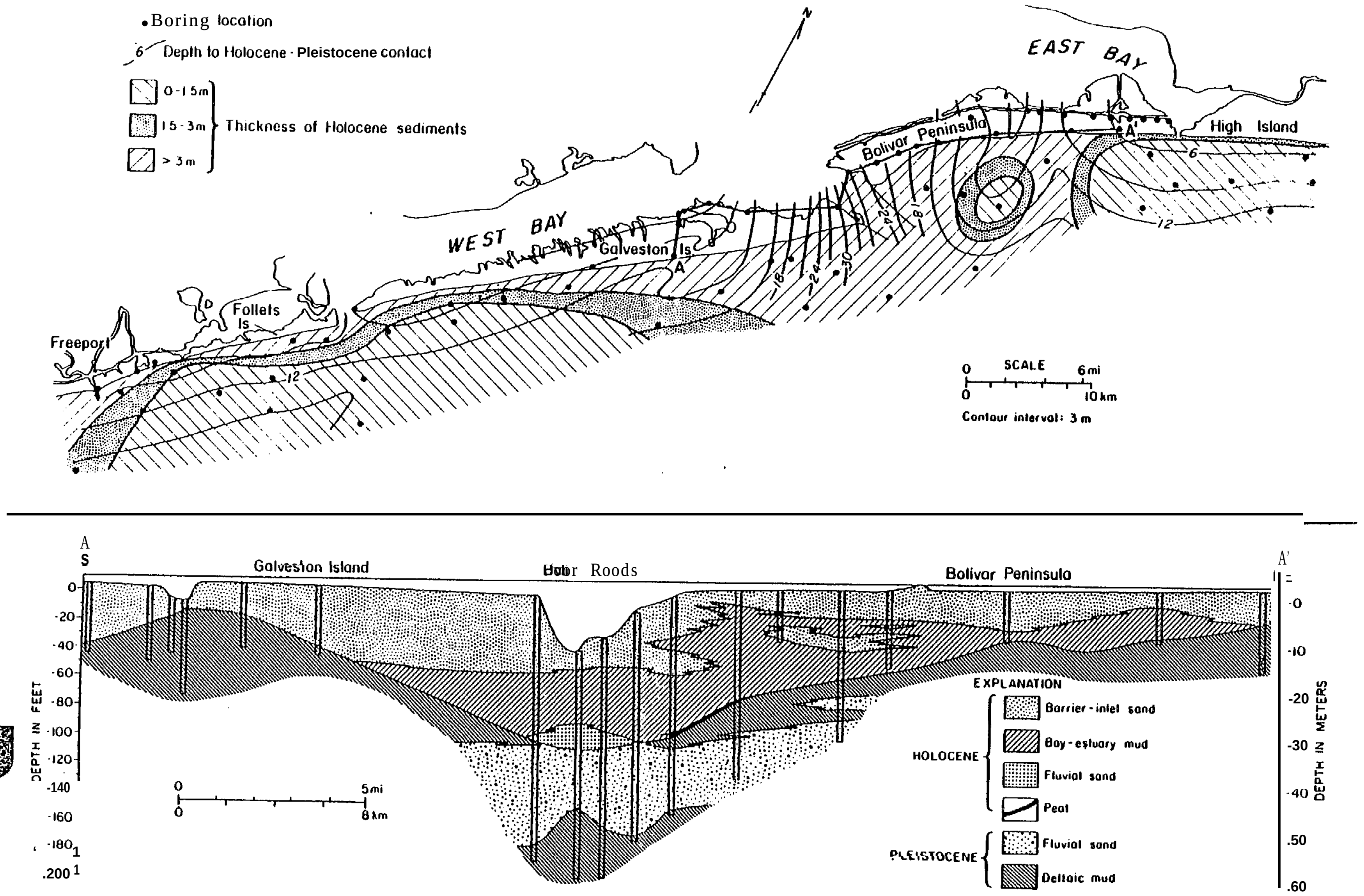


Figure 11. Isopach map and strike section of Holocene sediments and sub-sea depth to the Holocene-Pleistocene unconformity, upper Texas Coast. Contour interval 3 m. (From Morton and Nummedal, 1982. Original data from Bernard and others, 1970, Williams and others, 1979, and U.S. Army Corps of Engineers, 1972).

former ebb-tidal delta. A riverine source is envisaged for the mud off Follets Island. This deposit encompasses the eastern flank of alobate trend centeredon the ancestral Brazes River. The shape, continuity, and orientationof this mud trend point toward a Brazes River source; in this case the mud would represent prodelta deposits related partly to extant deposition by the Brazos River, but more substantially related to landward retreat of the Brazes delta during the past few thousand years. The offshore mud lobe of the Modern Brazos delta is outlined along its seaward margin by an arcuate trend of coarser sediments that includes the inliers of sand (60-80 percent) at stations 2922-2963,3052, 3056-3078, and3 136.

Mean Grain Size.--inner shelf sediments are characterized by average textures that range from 3.1ϕ to 7.5ϕ, or very fine sand to fine silt (pi. ID). As with other sedimentological properties, mean-grain sizes either decrease offshore with trends roughly parallel to the shoreline or are irregular and patchy. Sediments with medium silt textures are areally more extensive than the other grain sizes. Fine silt is also abundant, whereas very fine sand and coarse silt are least abundant. The inner-shelf sediments with the finest textures have mean grain sizes between 6ϕ and 7ϕ (medium to fine silt). These sediments are coarser than the finest bay sediments, which have textures of fine silt and clay.

The complexity of the textural patterns suggests a recent geologic history and a set of physical processes that are diverse. The inner shelf off Bolivar Peninsula, Galveston Island and Follets Island is removed from riverine discharge. Consequently sedimentation rates in this interdeltaic setting have not been great enough to completely bury relict sediments that were deposited by Holocene or Pleistocene fluvial-deltaic systems or as strandlines (beaches and barriers) when the deltas were transgressed. The relict sediments are out of equilibrium with modern shelf processes. Some are mixed with modern sediments and others remain exposed on the seafloor. Both conditions contribute to the irregular distribution of grain sizes and sediment types.

Gross Changes in Sediment Distribution (1867-1976), Galveston Harbor Entrance

Jetty construction and frequent channel dredging over the past century have contributed greatly to changes in sediment textures at the Gulf entrance to Galveston Harbor. These sediment changes were primarily associated with modification of the ebb-tidal delta at Bolivar Roads. Comparison of sediment maps for 1867 and 1976 (fig. 12) show that some mud is now found where sand formerly existed just north of the north jetty. The converse is true for an area adjacent to the south jetty where mud has been replaced by sand. Sediments presently within the deep-draft channel contain more mud than was reported before dredging when the channel was in a natural state.

Apparently the north jetty acts as a trap for fine-grained sediment transported downdrift (southwest) along Bolivar Peninsula. This would cause encroachment of mud over the ebb-delta sands and shoaling adjacent to and updrift from the impermeable barrier. The variation from mud to sand is more difficult to explain. This change is possibly related, in part, to shoreface erosion and shoreline deposition that followed construction of the south jetty (Morton, 1977) but it may also be caused by reworking of spoil material deposited by hopper dredges. Periodically the channel is deepened or project depths are maintained by dredging; the spoil from these activities is transported to the disposal sites which are adj scent to the area of sand accumulation (fig. 12).

A different mechanism is probably responsible for mud deposition in the channel. Here abnormally deep water serves as a sink for fine-grained sediment transported into the dredged channel from adjacent bays or the Gulf. Siltation is common because slopes and depths of the dredged channel are in disequilibrium with the surrounding environs.

Bathymetry and Sediment Distribution

The distribution of sediment textures in the bay-estuary-lagoon system is controlled largely by wave and current energy levels that in turn are related to water depth. The sandy bay margins in the larger bays reflect not only sand sources, but also the relatively high energy

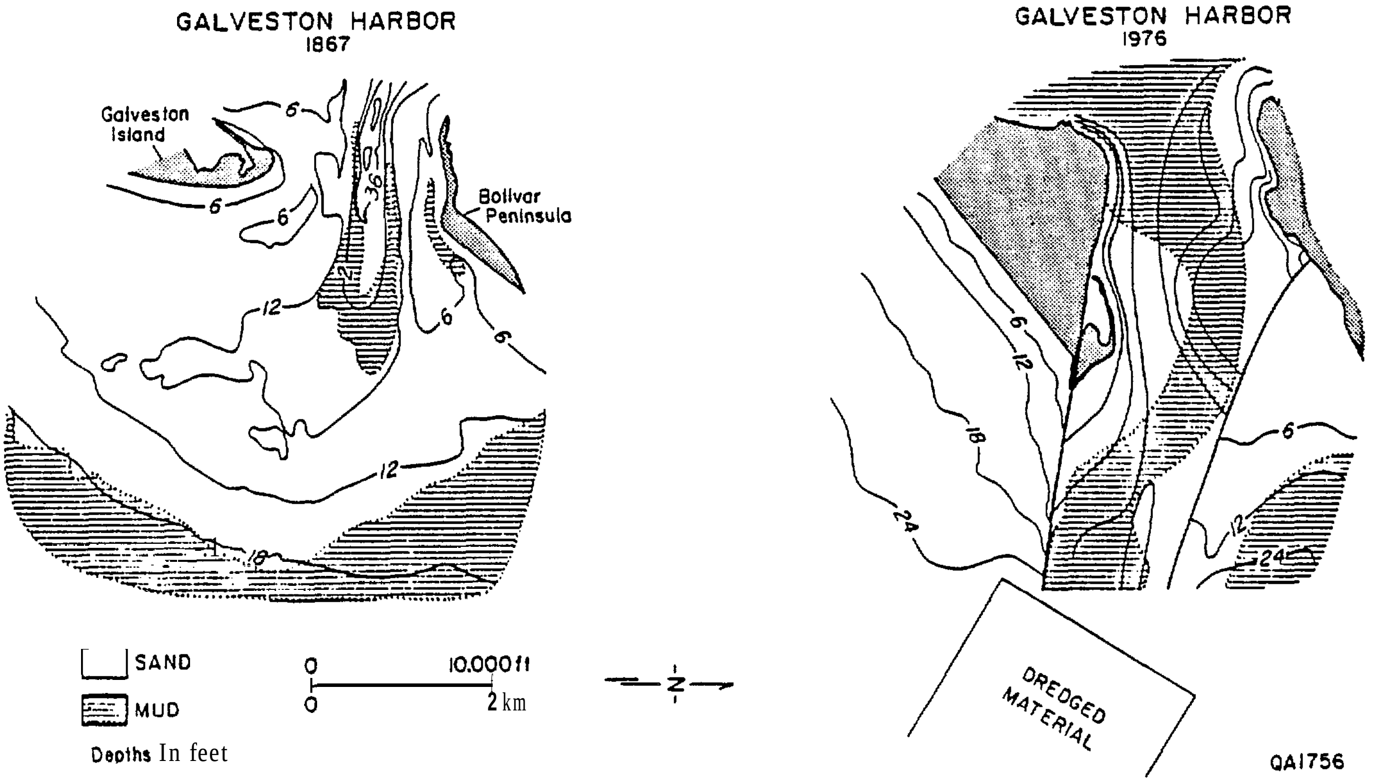


Figure 12. Changes in bathymetry and sediment distribution at Bolivar Roads associated with channel modifications.

of these shallow environments, where breaking waves and littoral currents are common. Sand eroded from shorelines is dispersed along the bay margin by littoral currents. Sand remains in the shallow bay margins because current energy decreases in deeper water. The exception is in tidal inlets like Bolivar Roads where sand may be deposited in deeper inlet waters by strong tidal currents. The relation between bathymetry (pl. VI) and texture is apparent on all four textural maps particularly in larger water bodies such as Trinity, Galveston, and West Bays. In those areas, shallow bay margins are characterized by sand, and deeper bay centers by mud or silt and clay. Sand mapped in deeper water environments, for example, in Galveston Bay at sample stations 43, 50 and 51 (pi. VI), are related to the hydrodynamics of the tidal inlet (Bolivar Roads), and possibly to the disposal of dredged material along the Houston Ship Channel. Sand mapped at some other deep water stations in Galveston Bay may be composed of sand-sized shell fragments, indicating a biogenic source of the sand.

The sand-silt-clay map (pi. IB) depicts the relationship of finer textures and deeper waters, especially in Trinity and northern Galveston Bays, where the central areas of the bays are covered by clayey silt. The sediment distribution and depth of West and parts of East Bays are affected by oyster reefs and reef-flank detritus. In the eastern part of West Bay, which is relatively shallow around the oyster reefs, high sand concentrations extend from bay margins into bay centers. In many small shallow bays—Bastrop, Christmas, and Jones Bays--fine-grained sediments are very extensive and the relation between texture and water depth is not well defined. Exceptions to the general relation between coarse texture and shallow depth can be explained by (1) absence of sand sources, (2) presence of silt and clay sources, (3) low physical energy that allows settling of fine particles in shallow water, and (4) disposal of dredged materials, which alters natural sediment trends.

Unlike the bays, the distribution of terrigenous sediment on the inner shelf is only partly controlled by water depth and distance from the shoreline. Muddy sediments are slightly more abundant than sandy sediments, although sand covers the steepest slopes of the inner shelf. The transition zones between sand and mud, or zones of greatest sediment mixing are poorly defined and do not correspond to breaks in shelf gradient as they do in other areas. The shelf gradient decreases in a northeasterly direction and is considerably steeper off Follets Island than off Bolivar Peninsula. The flatter gradient off Bolivar Peninsula, which generally conforms to the underlying Holocene-Pleistocene unconformity (fig. 11) accounts for the higher sand content of modern shelf sediments in water depths greater than 36 ft (12 m).

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, HI, 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 re-emphasized 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 inductive y 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. H, 111, 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. Most of the samples analyzed by ICP-AES were collected from the smaller embayments, such as Chocolate Bay, Christmas Bay, and Clear Lake, whereas almost all of the sediment samples from the larger bays and Buffalo Bayou (Houston Ship Channel) were analyzed by the emission spectrograph. These geographic differences provide a measure of separation between the two sets of data.

Total Organic Carbon

Bay sediments--- Patterns of total organic carbon (TOC) concentrations in submerged land sediments (pi. II) are similar to those shown on textural maps (pi. I). Percentages of TOC have a positive correlation with percentages of mud (fig. 13). Highest concentrations of TOC occur in bay-center muds and lowest in bay-margin sands. Such a relationship has been reported in earlier studies, for example, Shimp and others (1970). Values of TOC range from a low of 0.1 percent to highs of 2.4 percent in Trinity Bay, 1.9 percent in Galveston Bay, 1.8 percent in East Bay, and 1.6 percent in West Bay. The highest concentrations of TOC, however, occur in channels such as Galveston Channel (5.7 percent, Station 1), Offatts Bayou (4.0 percent, Station 3), and Buffalo Bayou (3.9 percent, Station 34). These channels, which are characterized by deeper-water, wave-protected, and oxygen-deficient bottom sediments, locally serve as sinks for the accumulation of organic-rich muds.

Sediments with TOC concentrations above 1.5 percent are widely distributed in Trinity Bay, and several stations near the north central half of the bay have TOC concentrations of more than 2 percent (pi. 11A). The location of these sediments near the head of the bay suggests that the Trinity River and bay-head delta (approximately 3 miles (4.8 km) away) are probably

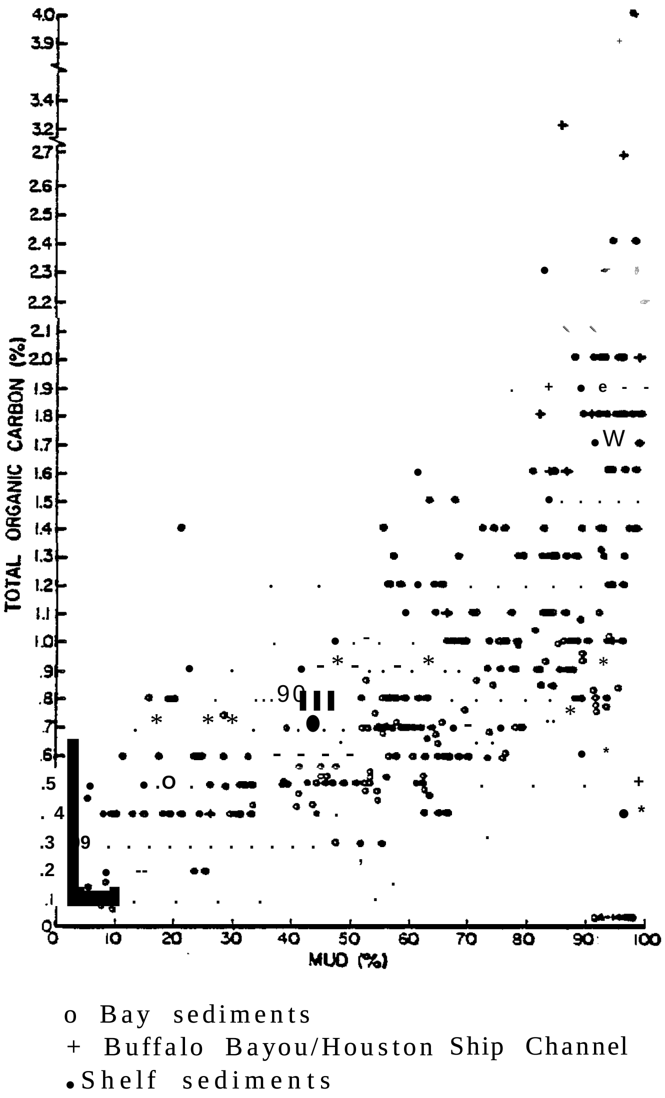


Figure 13. Scattergram of total organic carbon and mud, Galveston-Houston area. (Letters next to plotted points are sample station identifiers--see figure 24 for explanation.)

the primary sources of the organic carbon. Much of the Trinity River valley is characterized by marshes and swamps from which organic carbon is exported during floods.

Muds in upper (northwest) Galveston Bay and in East Bay typically have TOC concentrations of 1.2 to 1.5 percent with local highs of 1.6 to 1.9 percent. Concentrations of TOC in lower (southeast) Galveston Bay and in West Bay are not as high (typically less than 1 percent). These lower values correspond with the coarser sediments (pi. IA). Concentrations of TOC in bay-margin sands are generally less than 0.4 percent.

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 (pi. IIA, app. B). Accordingly, TOC concentrations exhibit patterns that are similar to the shelf sediment patterns (pi. I). Concentrations of TOC in shelf sediments from the Galveston-Houston area range from less than 0.1. to 2.0 percent; most samples, however, contain between 0.4 and 1.2 percent TOC. These concentrations (fig. 13) are less than half those measured in sediments from adjacent bays where biological productivity is substantially greater.

Highest values of TOC approximately coincide with mud sinks and lowest values of TOC correspond with shoreface sands and coarse elastics that occur in association with topographic highs off the west end of Galveston Island. There are, however, many exceptions to the rule. Other local areas with low TOC are near Rollover Pass (station 3499), along the muddy sand trend extending offshore from Bolivar Roads (stations 3332 to 3337), and a linear trend bounded by potentially active faults off Galveston Island (stations 3136 to 3180).

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 (station 3001) was from a sandy mud with 30 to 40 percent sand and 2 to 4 percent shell. These 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 west of Bolivar Roads is complex owing to the high variability of the sediment types. However, transects from the shoreline usually exhibit increases and then decreases in TOC in an offshore direction.

Barium

Bay sediments.--Concentrations of barium (Ba) in bay sediments range from less than 100 ppm to 1,600 ppm; average values are about 370 ppm (pi. HB). Barium concentrations have a positive correlation with mud. The highest concentrations of barium generally occur in sediments with the highest percentages of mud, although there are variations as shown in the scattergram in figure 14.

The highest measured concentration of barium (1,600 ppm) occurs near the mainland shore of East Bay (pi. IIB). This value is almost twice the concentration of the next highest value (820 ppm), which occurs in the center of Trinity Bay. Anomalous occurrences of barium are commonly related to oil and gas 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.

Highest concentrations of barium in Galveston Bay and East Bay are 680 ppm and 350 ppm, respectively. Values exceeding 600 ppm also occur in Clear Lake and Chocolate Bay (pi. IIB). In bay margin sands, barium concentrations are typically below 200 ppm.

Shelf sediments.--Surface sediments of the inner shelf contain barium in quantities ranging from 230 to 1,300 ppm (pi. IIB, app. C). The maximum concentrations of barium in most shelf sediments are higher than those for sediments in adjacent bays. Also, shelf sediments contain more barium than bay sediments having comparable amounts of mud (fig. 14). The lowest amounts of barium occur nearshore along Galveston and Follets Islands especially near San Luis Pass whereas highest amounts occur farther offshore but in irregularly shaped patches rather than in systematic trends. In general, barium concentrations increase from west to east. 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.

Most samples contain between 400 and 600 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 10 ppm to more than 100 ppm in the bay system. Higher concentrations of boron (more than 85 ppm) are usually associated with higher percentages of mud (sediments composed of more than 60% mud) (fig. 15). This relationship is particularly evident in Trinity Bay where relatively high concentrations of mud and boron characterize deeper bay-center areas (pls. IA and IIC).

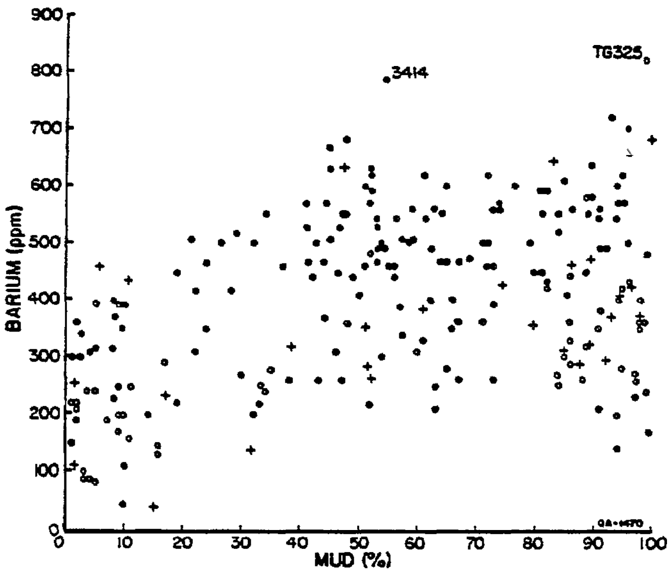
The highest concentration of boron (120 ppm) occurs near Morgan Point at Station 351 (app. B; pl. VI). Other values of more than 100 ppm occur in Trinity, Galveston, and East Bays_ The mean concentration of boron in bay muds is about 80 ppm, and in bay sands about 35 ppm.

Although there is a positive correlation between boron and total organic carbon in sediments of the Galveston Bay system (fig. 16; correlation coefficient, r, = approximately 0.55), the correlation is not as high as that for boron and TOC in sediments of the Corpus Christi Bay system (r = 0.74) reported by White and others (1983).

Shelf sediments.—Boron concentrations in shelf sediments (pi. IIC, app. B) range from 11 to 88 ppm, a range slightly less than that of nearby bay sediments. The correlation between boron and mud (fig. 15) is also similar for both areas. The relation of boron to mud in shelf sediments generally corresponds to the mid range of bay sediments (fig. 15) but shelf sediments have more uniform concentrations of boron for a given percent mud.

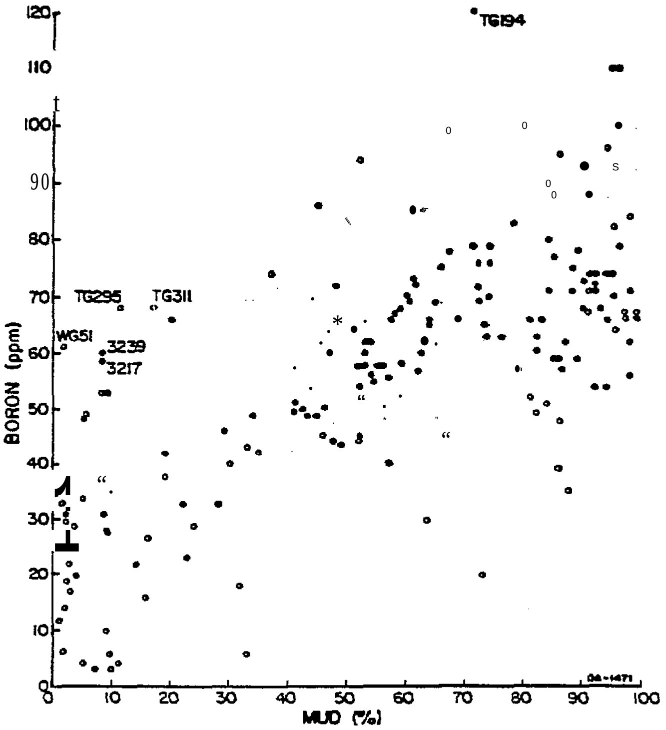
Boron generally increases offshore along Galveston and Follets Islands; however, the patterns are not systematic and they are not related to water depth (pl. I). Lowest boron concentrations occur where sand is abundant, especially along the shoreface. In contrast, highest concentrations of boron are normally limited to isolated sample sites. Most samples have boron concentrations ranging from 60 to 80 ppm (pl. IIC).

DRAFT



o Bay sediments; Ba analyses by USGS; r = 0.593
+ Bay sediments; Ba analyses by Bureau of Economic Geology
•Shelf sediments; Ba analyses by USGS; r = 0.363

Figure 14. Scattergram of barium and mud. (Letters and numbers shown next to plotted points are sample station numbers-see figure 24 for explanation; r = correlation coefficient.)



o Bay sediments; r = 0.699
•Shelf sediments; r = 0.754

Figure 15. Scattergram of boron and mud. (Letters and numbers shown next to plotted points are sample station numbers--see figure 24 for explanation; r = correlation coefficient.)

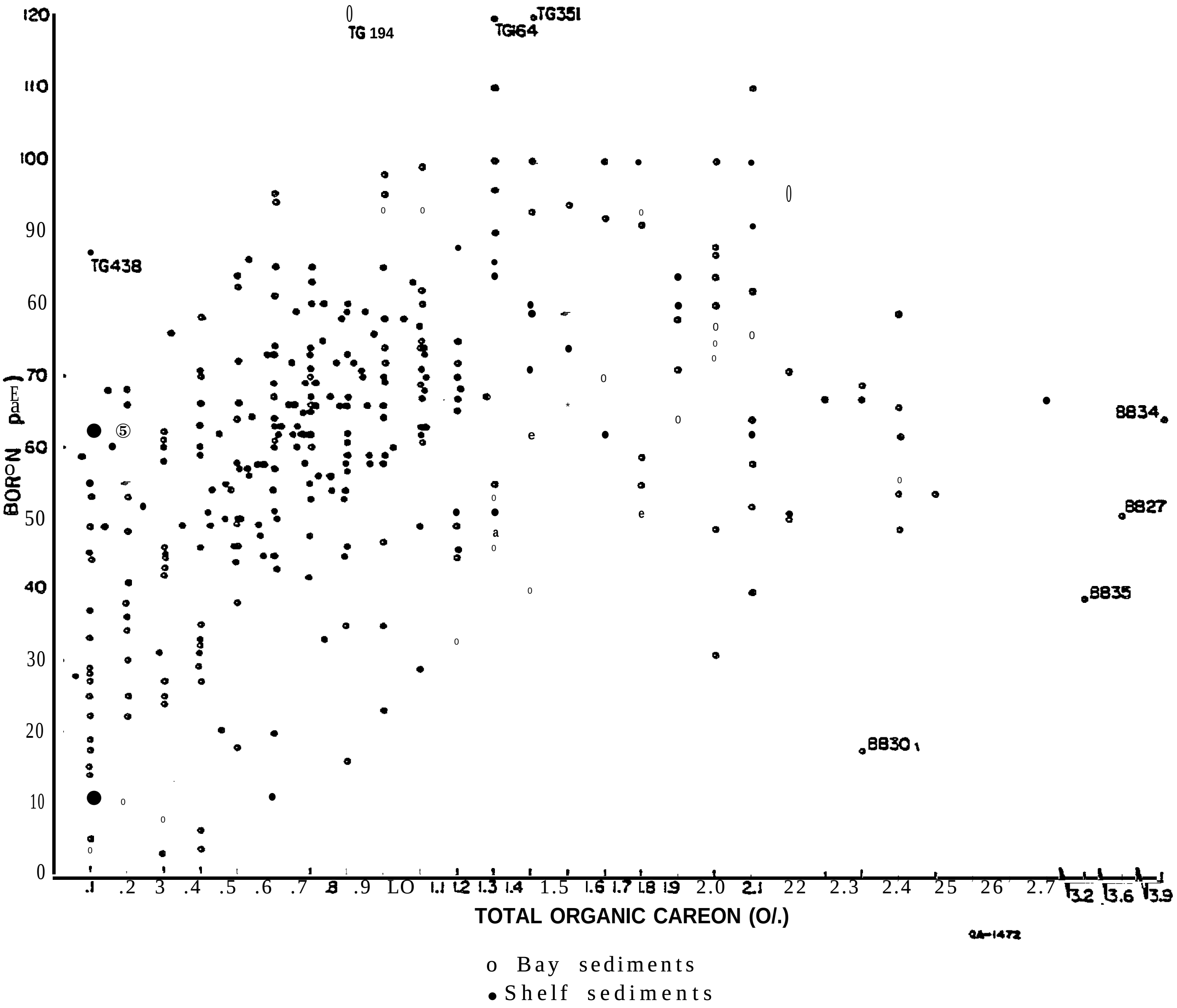


Figure 16. Scattergram of boron and total organic carbon. (Letters and numbers shown next to plotted points are sample station numbers—see figure 24 for explanation.)

Calcium

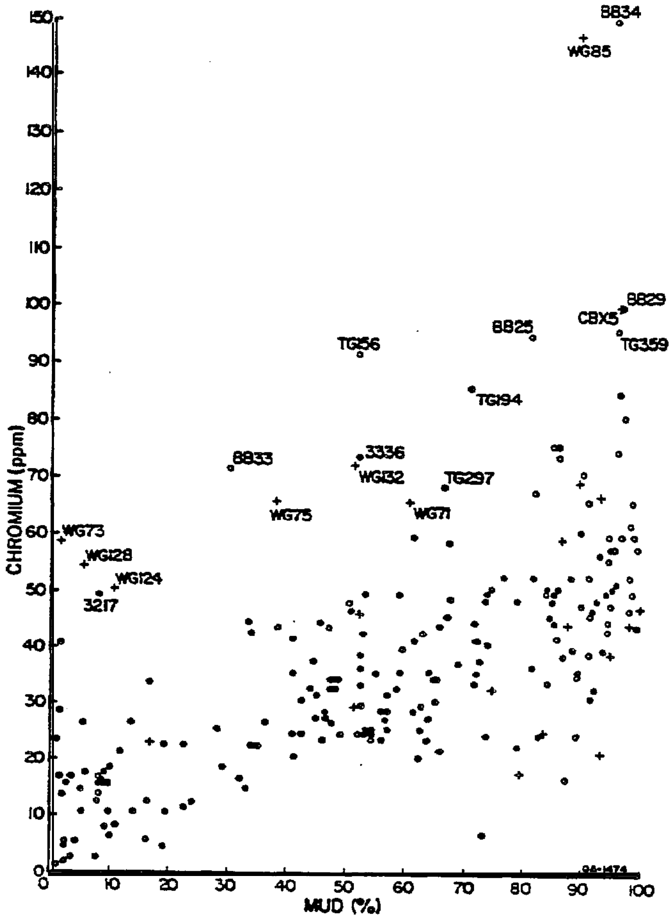
Bay sediments---Concentrations of calcium (Ca) in the bay-estuary-lagoon sediments typically are below 4 percent (40,000 ppm), but reach highs of near 30 percent (300,000 ppm) near Hanna Reef at the junction of Galveston and East Bays, and at one station in Bastrop Bay (pi. IID). Highest concentrations of calcium are associated with high shell (gravel) content in sediments typically found near oyster reefs. Of the thirteen sample stations that contained more than 11 % calcium the average shell percentage per sample was about 40%. A high of about 64% shell occurred at West Bay Station 122 (app. B), which also had the highest calcium concentration (36%) of any bay station.

Shelf sediments.--Although concentrations of calcium in shelf sediments range from 0.3 to 28 percent, most samples contain less than 2 percent (pi. IIC). Anomalously high concentrations are found near Rollover Pass and the Galveston Ship Channel (pl. VI). This dredged or reworked material contains abundant shell and caliche from relict Pleistocene sediments. Another area of high calcium concentrations (stations 3091 to 3135) corresponds to a trend of coarser sediment including shells and shell fragments. Calcium is less abundant on the shelf than in adjacent bays probably because modern shelf sediments generally contain less shell material than do bay sediments.

Chromium

Bay sediments.-- Chromium (Cr) ranges from less than 10 to 150 ppm (app. B) and averages about 40 ppm. The highest measured values of 150 and 148 ppm occur in samples from Buffalo Bayou and from a dredged channel along Chocolate Bayou, respectively. The highest value occurring in bay sediments (outside of dredged channels) is 120 ppm and is from a station in East Bay (pi. 111A).

Concentrations of chromium (pi. 111A) generally show a positive correlation (r= 0.724) "with mud (pi. IA). Accordingly, a scattergram of chromium and mud shows a linear relationship, but several samples plot above the normal distribution pattern established by most samples (fig. 17).



o Bay sediments; Cr analyses by USGS; r = 0.724
\+ Bay sediments; Cr analyses by Bureau of Economic Geology
• Shelf sediments; Cr analyses by USGS; r = 0.665

Figure 17. Scattergram of chromium and mud. (Letters and numbers shown next to plotted points are sample station numbers--see figure 24 for explanation; r = correlation coefficient.)

As expected, several of these anomalous values occur in sediments from Buffalo Bayou (Houston Ship Channel) where high levels of trace metals resulting from anthropogenic input have been previously reported (Warshaw, 1976, for example). Other anomalies differentiated in the scattergram are from stations in West Bay, Trinity Bay, and East Bay (fig. 17; pl. 111A). Sand-rich samples such as along bay margins, commonly contain less than 20 ppm chromium.

Shelf sediments.--Chromium concentrations in shelf sediments (pi. 111A, 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. 17) shows a correlation similar to that established by data from adjacent bays. Shelf sediments generally contain less chromium than do bay sediments, consequently, areas of lowest 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 3089, 3217, 3336). Although chromium concentrations range from 6 to 98 ppm, values between 20 and 50 ppm are most common. Values above 70 ppm only occur at a few individual sample sites. The poor correlation of chromium with sediment characteristics may be partly attributed to these low concentrations. The areas of greatest chromium concentration generally coincide with the finest grained sediments and are similar to high concentrations of other trace elements.

Copper

Bay sediments. --The average concentration of copper is between 15 and 20 ppm (pi. IIIB). Concentrations range from less than 5 to 160 ppm (app. B). Sediment from a sampling station in San Jacinto Bay, which is near Buffalo Bayou (Houston Ship Channel), contained the highest concentration (160 ppm) of copper. Other relatively high concentrations occur in sediments from Buffalo Bayou (Houston Ship Channel) and Clear Lake (pi. IIIB). In the larger bay areas the highest values (greater than 25 ppm) are generally associated with bay-center muds. The highest value recorded in Trinity Bay sediments was 130 ppm occurring at Station 265 (pl. IIIB; pl. VI). Abnormally high values (>50 ppm) also occur in northwest Galveston Bay.

Although there is positive correlation between copper and percent mud (fig. 18) many sediment samples, especially those from Buffalo Bayou (Houston Ship Channel) and Clear Lake as well as from some areas in Galveston and Trinity Bays (pi. IIIB), vary considerably from the established trend. The variations are probably the result of anthropogenic contributions of copper. Relatively high levels of copper have been previously reported in Clear Lake (Texas Dept. of Water Resources, 1981).

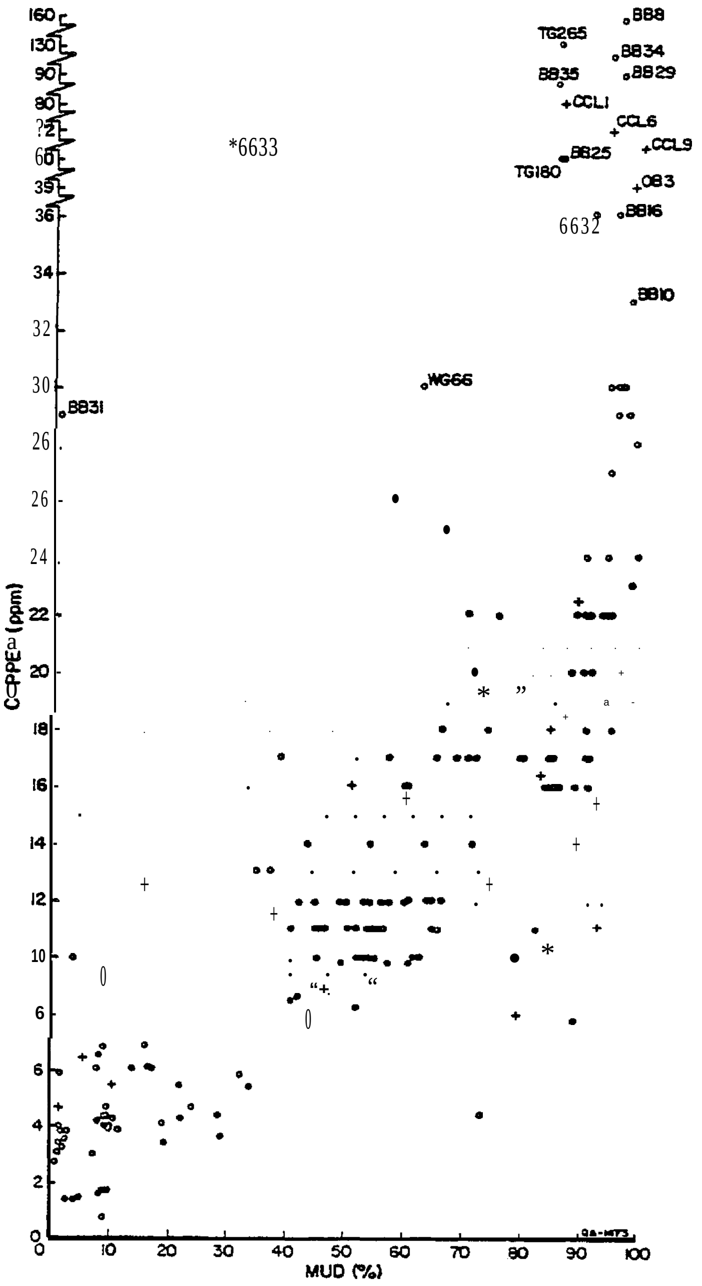
Shelf sediments.--Concentrations of copper in shelf sediments range from 1.5 to 34 ppm (pi. IIIB, app. B); however, most shelf sediments contain between 10 and 20 ppm. Copper values generally increase offshore; lowest concentrations occur nearshore where sand is abundant whereas highest concentrations are generally associated with fine-grained sediments and are commonly restricted to isolated sample sites such as stations 2891, 3095, and 3131 (pi. VI).

Copper concentrations in shelf sediments correlate well with percent mud (fig. 18). Concentrations of copper on the shelf are comparable to those in adjacent bays considering the abundance of mud.

Iron

Bay sediments.--Concentrations of iron (Fe) in bay sediments (pi. IIIC) range from less than 0.5 percent (500 ppm) to 6.2 percent (62,000 ppm), with the latter value occurring near the mouth of a tributary (Sims Bayou) of Buffalo Bayou. Highest measured concentrations of iron (greater than 4.0 percent) in bay sediments (excluding channels) occur in Trinity Bay, East Bay, and northern Galveston Bay. Three samples from Clear Lake contain iron concentrations of more than 3.0 percent. As with the trace metals chromium and copper, highest iron percentages are associated with fine-grained sediments. Rarely do samples composed of more than 90 percent mud contain less than 1.6 percent (16,000 ppm) iron (fig. 19). The scattergram relating percentages of iron and mud (fig. 19) isolates several anomalous concentrations of iron. Along bay margins and in other sand-rich environments, iron concentrations are generally less than 1.0 percent.

DRAFT



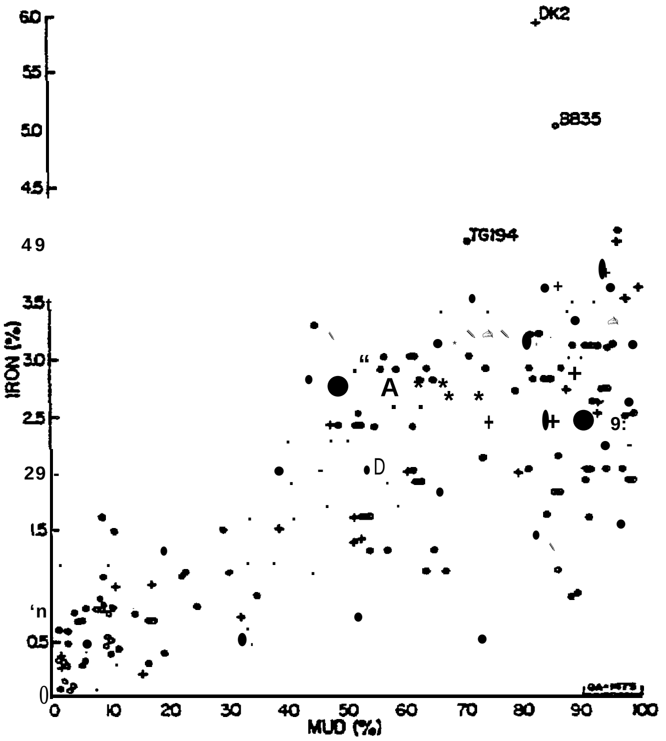
o Bay sediments; Cu analyses by USGS; r = 0.528

+ Bay sediments; Cu analyses by Bureau of Economic Geology

• Shelf sediments; Cu analyses by USGS; r = 0.853

Figure 18. Scattergram of copper and mud. (Letters and numbers shown next to plotted points are sample station numbers—see figure 24 for explanation; r = correlation coefficient.)

DRAFT



o Bay sediments; Fe analyses by USGS; r = 0.769
+ Bay sediments; Fe analyses by Bureau of Economic Geology
• Shelf sediments; Fe analyses by USGS; r = 0.813

Figure 19. Scattergram of iron and mud. (Letters and numbers shown next to plotted points are sample station numbers--see figure 24 for explanation; r = correlation coefficient.)

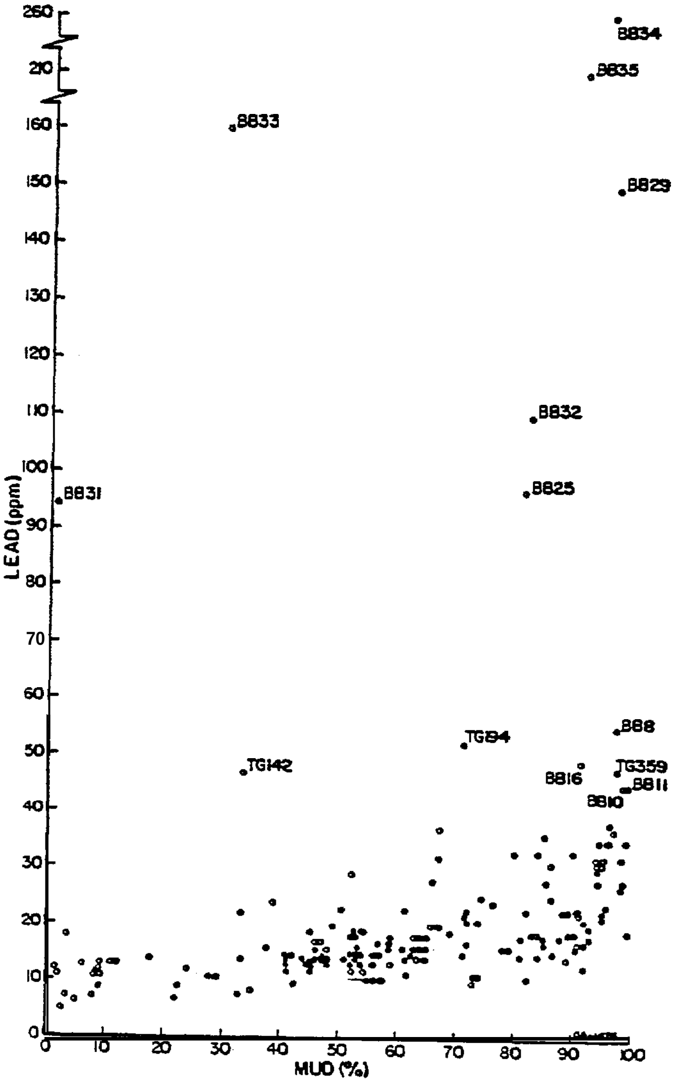
Shelf sediments.--The abundance of iron in shelf sediments (pl. IIIC) ranges from 0.3 to 3.7 percent and generally increases in an offshore direction. As in the bays maximum values coincide with fine-grained sediments (fig. 19); conversely, lowest values occur along the shoreface where sand is abundant as along Galveston and Follets Islands. Patterns of iron abundance are simple, and concentrations are normally between 2 and 4 percent. Shelf sediments generally contain more iron than do bay sediments having comparable amounts of mud.

Lead

Bay sediments.--Lead (Pb) concentrations range from less than 10 to 260 ppm. Lower values typically occur in sandy areas such as along bay margins of Trinity and Galveston Bay and in much of West Bay (pl. IIID). Higher concentrations generally occur in deeper muddy areas of Trinity, Galveston, and East Bays. The mean concentration of lead in sediments containing more than 75 percent mud is about 35 ppm, and in sediments with less than 25 percent mud, from 10 to 15 ppm. This positive relationship between lead and percent mud is shown in figure 20. The scattergram also shows that sediments containing more than 40 ppm lead plot significantly above the normal linear trend of the majority of the bay sediments. Of the 24 samples with concentrations above 40 ppm (app. B), 75 percent, including the highest value of 260 ppm, are from Buffalo Bayou (Houston Ship Channel), where high levels of lead have previously been reported (Warshaw, 1976).

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 15 and 20 ppm. Lead concentrations are commonly higher in bay sediments than in shelf sediments. Lowest concentrations generally occur nearshore, especially along Galveston and Follets Islands and along a linear trend between stations 3091 and 3113 where sand is abundant. Although lead distribution is patchy, abundance generally increases offshore. Lead concentrations greater than 20 ppm occur in small patches and as isolated samples associated with fine-grained sediments. Highest values of lead occur where the sediments are composed of at least 70 percent mud (fig. 20).

DRAFT



o Bay sediments; r = 0.454

● Shelf sediments; r . 0.669

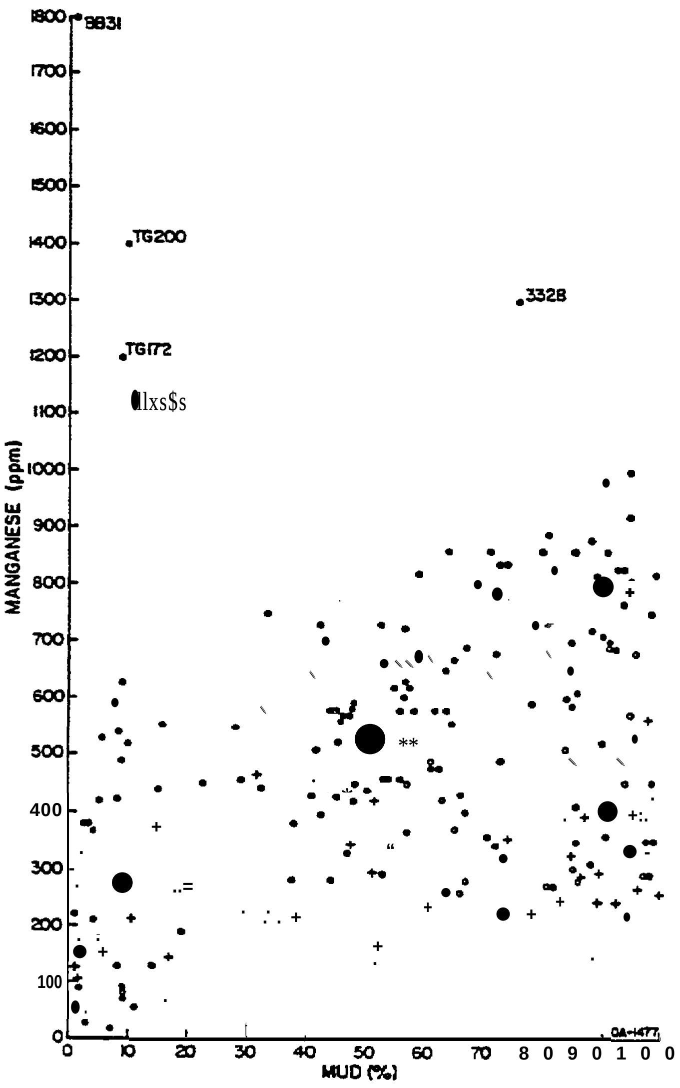
Figure 20. Scattergram of lead and mud. (Letters and numbers shown next to plotted points are sample station numbers--see figure 24 for explanation; r = correlation coefficient.)

DRAFT

Manganese

Bay sediments---Concentrations of manganese (Mn) in bay sediments range from less than 50 to a high of 1,400 ppm in East Bay (pl. IVA). The highest measured value (1,800 ppm), however, was in sediments collected near the mouth of a tributary of Buffalo Bayou (Houston Ship Channel). Although there is a slight correspondence between manganese concentrations (pl. IVA) and textural distribution (pl. IA), that is, high concentrations are commonly associated with muddy sediments and low concentrations with sandy sediments, the correlation coefficient between manganese and percent mud is very low (r=0.193, n or number of samples = 78). Still, this low, positive relationship with mud percent helps differentiate samples that contain anomalous concentrations of manganese with respect to mud content (fig. 21). Broad central areas of Trinity Bay where mud is predominant, commonly have manganese concentrations of between 400 and 500 ppm, with a high at one station of 680 ppm. Sandy sediments typically contain less than 300 ppm manganese. Concentrations in West Bay are relatively low with a high of 550 ppm.

In East Bay and near its junction with Galveston and Trinity Bays, manganese concentrations found in several sediment samples are above 600 ppm. Three samples containing greater than 1,000 ppm manganese each have a mud content of less than 15 percent, but each contains more than 55 percent shell gravel. Textural data is not available for a fourth sample (station 149) that has over 1,000 ppm manganese, but the proximity of the sampling station to an oyster reef suggests that it too, is high in shell content. This relationship of manganese with shell material possibly is the result of manganese substituting for calcium in calcite (Bryan and Ward, 1965). It should be noted, however, that at least seven other samples high in shell material (ranging from 22 to 64 percent) were not excessively high in manganese (ranging from 367 to 580 ppm). Thus, other factors besides the presence of shell material must account for the high levels of manganese in East Bay.



o Bay sediments; Mn analyses by USGS; r = 0.193
+ Bay sediments; Mn analyses by Bureau of Economic Geology
“ Shelf sediments; Mn analyses by USGS; r = 0.577

Figure 21. Scattergram of manganese and mud. (Letters and numbers shown next to plotted points are sample station numbers—see figure 24 for explanation; r = correlation coefficient.)

Shelf sediments.--Surface sediments on the inner shelf contain between 260 and 1,300 ppm manganese; these concentrations are generally higher than those in nearby bay sediments (pi. IVA; fig. 21). Within the shelf area, manganese tends to decrease from east to west. This alongshore trend is more prominent than the onshore-offshore trends that characterize most of the other elements. Manganese in surface sediments from central Galveston Island eastward typically exceed 500 ppm; whereas westward from that area, concentrations are usually less than 500 ppm but greater than 300ppm. Low concentrations of manganese are found nearshore from Bolivar Roads westward to Follets Island. Manganese is least abundant in the vicinity of San Luis Pass except for isolated occurrences at stations 2985 and 3003. In these areas, manganese concentrations are generally between 200and 300 ppm.

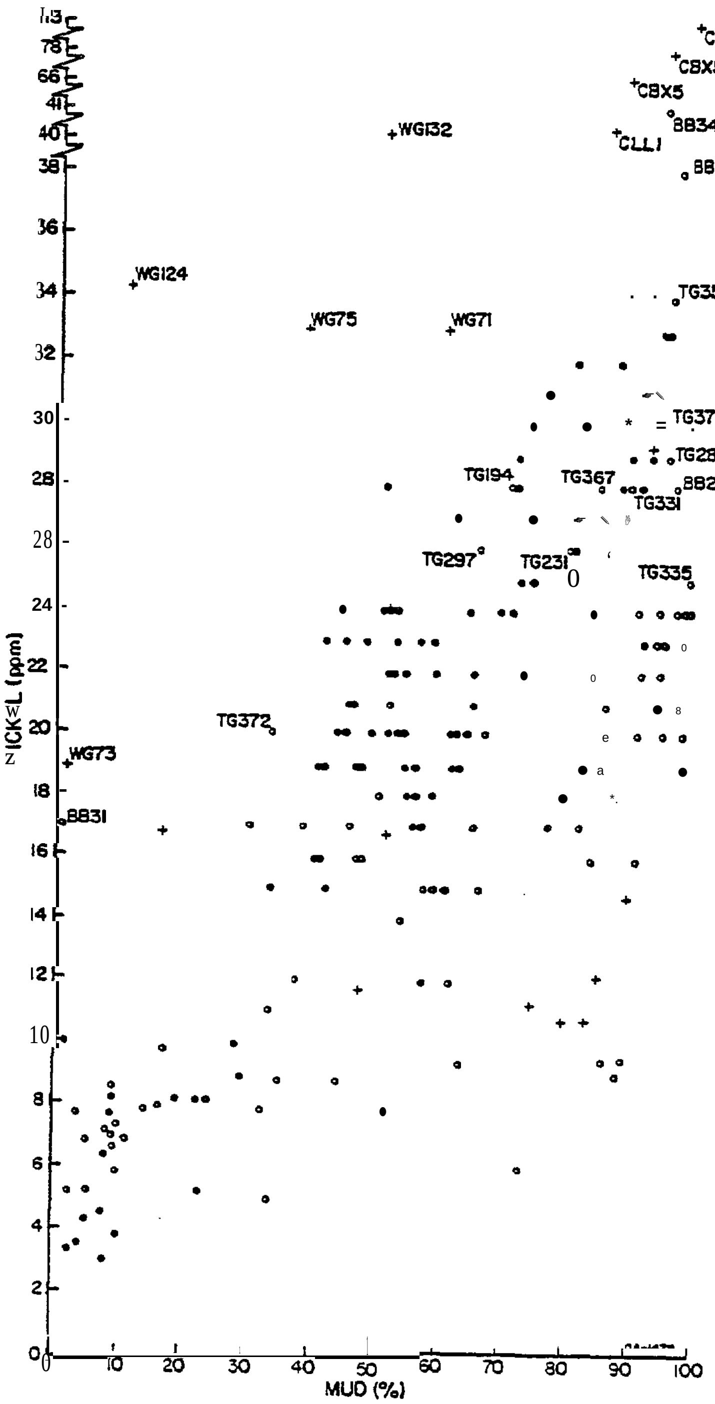
Nickel

Bay sediments---Concentrations of nickel (Ni) in bay sediments range from less than 5ppm to a high of 113 ppm* in sediments of Clear Lake. Typically, the highest concentrations, which correspond with bay center muds, are less than 30 ppm (pl. IVB). Most of the sediments with more than 80 percent mud contain nickel concentrations of 15 ppm or more. Areas with high sand concentrations, such as bay margins, contain less than 10 ppm nickel. As with other trace metals there is a relatively good positive correlation (r=0.751) between mud percent and nickel concentration. Such a relationship allows sediments with anomalous concentrations of nickel to be distinguished in a scattergram of nickel and mud (fig. 22). Among the sediment samples that appear as anomalies in the scattergram are several taken from Buffalo Bayou/Houston Ship Channel (BB), West Bay (WG), Cedar Bayou (CBX), and Clear Lake (CLL) (pi. IVB). While there is reason to suspect that many of these anomalies are the result of anthropogenic sources, it should be re-emphasized that two different laboratories employing different methods of analyses were used (see section on Geochemistry "under Data Acquisition

---

*This concentration of nickel is abnormally high and may have been contaminated during analysis.

DRAFT



○ Bay sediments; Ni analyses by USGS; r = 0.751

\+ Bay sediments; Ni analyses by Bureau of Economic Geology

● Shelf sediments; Ni analyses by USGS; r = 0.847

Figure 22. Scattergram of nickel and mud. (Letters and numbers shown next to plotted points are sample station numbers--see figure 24 for explanation; r = correlation coefficient.)

and Analysis). Accordingly, when the data are plotted together in a scattergram, there is a possibility that some values will appear as anomalies because of the different semiquantitative analytical methods used.

Shelf sediments.--Concentrations of nickel in shelf sediments only range from 2.7 to 34 ppm; nevertheless, distinct patterns emerge within this limited range (pi. IVB). The clearest pattern is an increase in an offshore direction associated with decreases in sediment size. Abundance of nickel also increases from west to east. Lowest concentrations are found nearshore along Galveston Island and Follets Island and within a linear trend that extends from stations 3069 to 3135. 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 3153 and 3311 and between stations 3353 and 3394. These maximum concentrations exceed those found in sediments of the adjacent bays. In fact, shelf sediments generally have higher concentrations of nickel than do bay sediments when the relationship with sediment texture is taken into consideration (fig. 22).

Strontium

Bay sediments---Strontium (Sr) concentrations in bay sediments range from less than 25 to 1,400 ppm (pi. IVC). The highest concentrations are in East Bay, and near the junction of East Bay and Galveston Bay where concentrations exceeding 1,000 ppm correspond with an extensive oyster reef (Hanna Reef, pl. VIC). In this particular area, the mapped distribution of strontium is based not only on the analyzed sample localities but it is also based on the location and distribution of the reef (pi. VIC). Comparisons of strontium (pl. IVC) and calcium (pi. IIC), which is a major component ($CaCO_3$) of the shell material in reefs, show a strong positive relationship in their distribution patterns. Of 11 samples containing more than 450 ppm strontium, 7 have a shell content of more than 40%, and all but one have a shell content of more than 20°A (table 4). There is a high statistical correlation between strontium and calcium as demonstrated both in other studies (for examples, Holmes, 1974, and W bite and others, 1983),

Table 4. Relationship between high concentrations of strontium (Sr) and shell gravel in sediment.

Sample Station Number		Strontium (ppm)	Shell (%)
G	117	730	59.5
	142	1,000	40.3
	149	1,000	not determined
	172	1,100	57*9
	200	1,200	60.5
	205	1,400	56.5
	265	460	3.4
	396	750	61.0
	430	460	31.6
WG	81	472	23.0
	122	859	63.6
	131	824	21.7

DRAFT

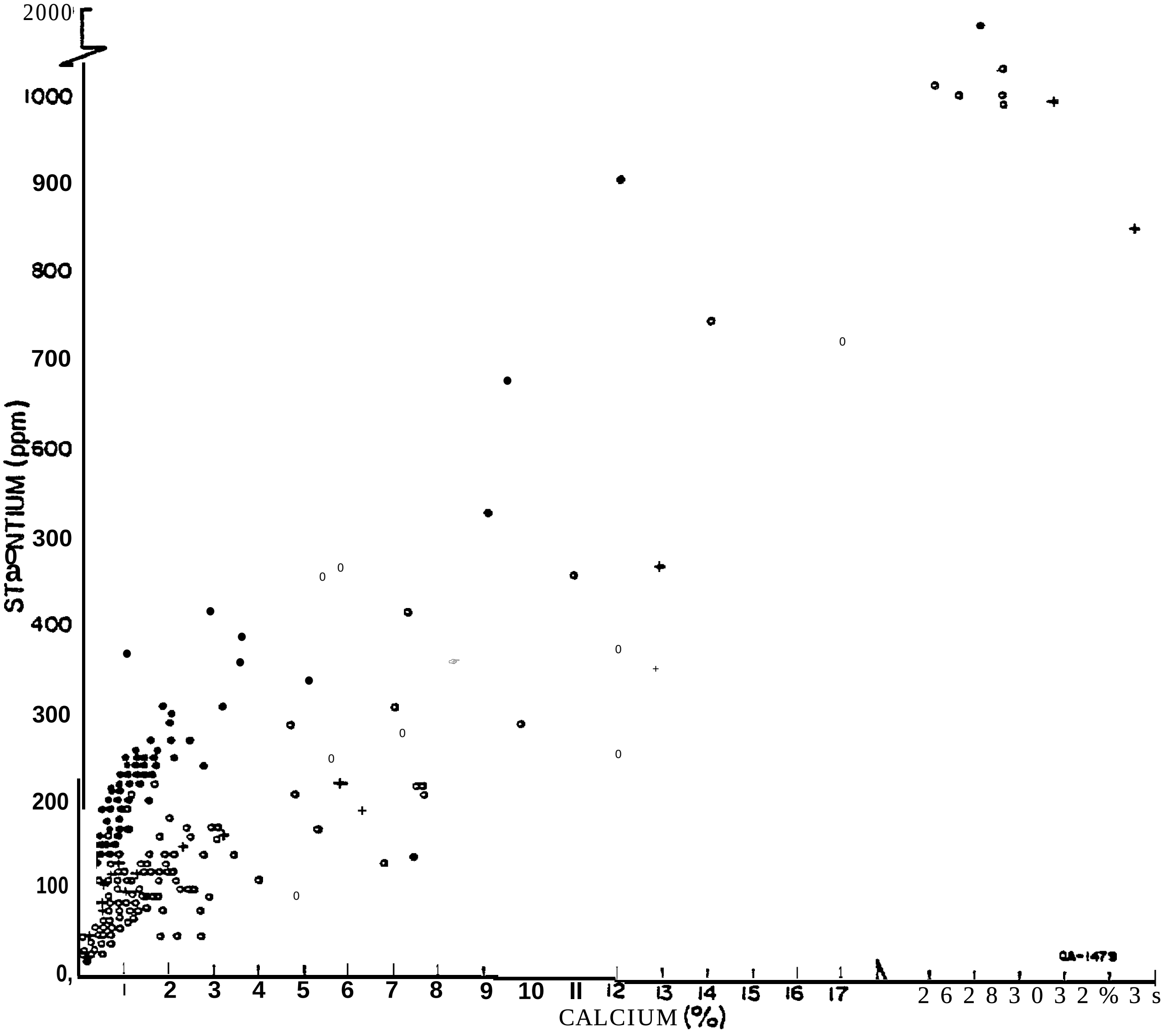
and in this study (correlation coefficient of 0.971, fig. 23). The average concentration of strontium in bay sediments containing insignificant amounts of shell material is about 100 ppm.

Shelf. sediments.--Strontium concentrations range from less than 95 to 1,900 ppm; however, most shelf sediments contain between 100 and 300 ppm (pi. IVC). The two extremes are anomalous and isolated samples; the highest concentration comes from shelly sediments between stations 3091 and 31”35. Lowest concentrations occur in the vicinity of Bolivar Roads and San Luis Pass where sand is abundant. Strontium abundance is generally uniform over large areas and is substantially higher in sediments from the inner shelf than in sediments from adjacent bays. In fact the positive correlation between strontium and calcium (fig. 23) suggests two different populations with nearly all shelf sediments containing more strontium than bay sediments having comparable amounts of calcium.

Zinc

Bay sediments---Concentrations of zinc (Zn) in bay sediments range from less than 22 ppm to more than 200 ppm (pi. IVD). The highest measured concentration was 590 ppm in sediments collected at a station in Buffalo Bayou (Houston Ship Channel). In bay sediments, high values of zinc occur in Trinity and Galveston Bays. The highest concentration of 270 ppm (station 265 in Trinity Bay) was measured in sediments composed of about 85% mud, but two other high concentrations occurred in sediment composed predominantly of shell and shell fragments (stations 143 and 172, app. B). It is possible that these two latter high values of zinc are related to an enrichment of zinc by oysters (Ferrell and others, 1973). Moffett (1975) reported relatively high levels of zinc (612 mg/kg) in oysters at Redfish Reef, which is near stations 142 and 172 in Trinity Bay. Many other sediments with high shell content in the Galveston Bay system, however, have low zinc concentrations (<22 ppm).

Although a visual comparison of maps depicting textural distribution (pi. I) with zinc distribution (pi. IVD) suggests a general, positive relationship between fine-grained sediment and zinc content, simple regression analysis of zinc and mud concentrations, using 43 samples,



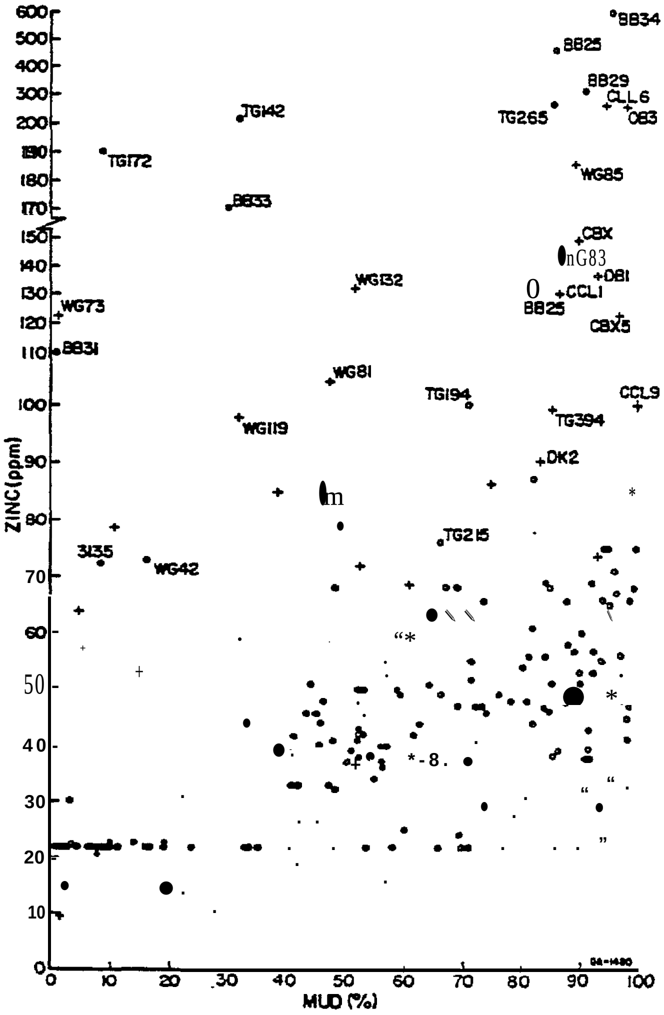
o Bay sediments; r = 0.971, n = 78
• Shelf sediments; r = 0.707, n = 102

Figure 23. Scattergram of strontium and calcium (r = correlation coefficient; n = number of samples).

did not yield a positive correlation (r=- 0.099). This can be partly attributed to the fact that many samples (35) for which mud content had been determined were not used in the regression analysis because the zinc concentrations were below the minimum detection limit of <22 ppm. Most of these samples had low percentages of mud.

In a scattergram of zinc and mud (fig. 24), high values of zinc are, overall, more closely associated with muds, and low values more so with sands. But there are many exceptions that stand out as anomalous concentrations of zinc (fig. 24). Many of these anomalies are probably associated with anthropogenic sources of zinc such as in Buffalo Bayou (Houston Ship Channel) where high values have been previously reported (Warshaw, 1976). Among other anomalous concentrations, are those from Clear Lake, Offatt Bayou, and Chocolate Bayou. There are known (permitted) industrial discharges of zinc along Chocolate Bayou (Texas Department of Water Resources, 1977, unpublished reports). Moffett (1975) reported concentrations of zinc as high as 775 mg/kg in oysters in Chocolate Bay. High levels of zinc (12,540 mg/kg) in sediments in Clear Lake have been previously reported by the Texas Department of Water Resources (1981).

Shelf sediments.--Zinc in surface sediments from the inner shelf ranges from less than 10 to 110 ppm (pl. IVD). Highest concentrations are usually limited in areal extent. The maximum values of zinc are substantially lower than those found in sediments of adjacent bays, especially Trinity, Galveston, and East Bays. Zinc concentrations generally increase in an offshore direction. Lowest concentrations occur where sand is abundant (near Bolivar Roads, along Galveston Island, and near San Luis Pass) and highest concentrations coincide with fine-grained sediments (fig. 24). Sediments containing more than 65 ppm zinc are limited to single sample stations or two larger trends that extend from station 3135 to 3157 and from 3269 to 3287.



0 Bay sediments; Zn analyses by USGS; r .-0.099
+ Bay sediments; Zn analyses by Bureau of Economic Geology
● Shelf sediments; Zn analyses by USGS; r = 0.511

Figure 24. Scattergram of zinc and mud. (Letters and numbers shown next to plotted points are sample station numbers--BB □ Houston Ship Channel/Buffalo Bayou, CBX = Cedar Bayou, CCL = Clear Lake, DB = Dollar Bay, OB . Offatt Bayou, TG . Trinity/Galveston Bay, WG = West Bay, 3135 = shelf station--see plate VI and appendix B; r = correlation coefficient.)

DRAFT

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, physiochemical 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.

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; 3enne, 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 Galveston-Houston area, three principal methods were used: (1) visually comparing the mapped distribution of sediments as defined by grain-size analyses (pi. I), with the mapped distribution of element concentrations (pls. II through IV); (2) conducting simple regression analyses and plotting trace metal concentrations against percent mud (<63 µm), percent clay (<3.9 µm), percent TOC or parts-per-million oxides of manganese (figs. 13 through 24); and (3) computing and mapping the distribution of the ratio of trace element concentrations to percent clay, percent total organic carbon or percent mud. The third method, although relatively effective in normalizing trace element concentration with respect to grain-size and TOC, was found less desirable for reporting results than methods 1 and 2. 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 Galveston-Houston area can be assessed by comparing mean and highest values with average concentrations measured in sedimentary shales, nearshore sediments, and other sediments apparently unaffected by human contributions (table 5). These latter concentrations are thought to represent “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 Houston area (Warshaw, 1976). Also included in table 5 for comparison purposes are some high concentrations of trace metals measured in estuarine sediments (Warshaw, 1976).

Average trace-element concentrations in muds of the Galveston-Houston area are comparable to or lower than “base line” levels for all elements (table 5). The highest concentrations for eight elements, barium ,“ boron, chromium, copper, lead, manganese, nickel, and zinc, however, stand out compared to “base line” values (table 5). 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 6). (Screening levels have not been established for barium, boron, 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

DRAFT

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

	Galveston-Houston Area’				Baseline Levels					Contaminated Sediments
	Bay sediments (muds)		Shelf sediments (muds)							
	mean	high	mean	high	Shale[2]	Nearshore sediment[3]	Clays and shales’	15th- 16th century sediment in Rhine estuary[5]	Modern marine argillaceous sediment[6]	Highest estuarine sediment value, Texas coast’
Barium	413	1,600	538	1,300	580	750	800			910
Boron	79	148	70	8a	100		100		90	
Chromium	55	120 150”	45	98	90	100	100	63	68-72	134
Copper	28	130 160”	18	34	4.5	48	57	21	37	1,510
Iron	26.000	43.000 62,000”	30,000	37.000	47,200		33,300			
Lead	34	140 260”	19	24	20	20	20	31	21	340
Manganese	400	1.400 1,800”	783	1.300	850	850	670			1,400
Nickel	26	113	28	34	68	55	95	33	40	160
Zinc	105	275 590*	53	110	95	95	80	93		4,900

[1] Appendix C; muds = sediments > 75% mud (< 63 microns in particle size)
[2] Turekian and Wedepohl (1961)
[3] Wedepohl (1960)
[4] Vinogradov (1962)
‘de Groot and others (1976)
[6] Potter and others (1963)
[7] Warshaw (1976)
“Buffalo Bayou (Houston Ship Channel)

DRAFT

Table 6. 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

found in channel sediments such as the Houston Ship Channel along Buffalo Bayou where industrial and municipal discharges have been widely publicized and high levels of trace metals (chromium, copper, lead, and nickel) have been previously reported (Warshaw, 1976; Texas Department of Water Resources). 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. Sediment samples that plot outside the "norm" can be seen in scattergrams for barium, boron, chromium, copper, iron, lead, manganese, nickel, and zinc (figs. 14 through 24). 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 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 Galveston-Houston area, trace metals have similar distribution patterns. For example, some of the highest concentrations of chromium (pi. 111A), copper (pi. IIIB), iron (pi. IIIC), lead (pl. HID), nickel (pi. IVB), and zinc (pi. IVD) occur in Trinity Bay, upper Galveston Bay, and the inland half of East Bay. Although trace metal distribution patterns in these areas generally mimic the finer-grained sediments (muds), locally trace metal concentrations are anomalous with respect to associated mud content. One probable source of some trace metals in bay sediments, is the Houston Ship Channel/Buffalo Bayou. The transport of trace metals into the bays may follow a scenario similar to that proposed for selected elements in Corpus Christi Bay (Holmes and others, 1974) and Matagorda Bay (Holmes, 1977). The redistribution of trace metals in these two bays was attributed in part to hydrodynamic and oxidation-reduction conditions set up by the ship channels, which connect the Gulf of Mexico to inner harbors. In addition to the ship channel, a probable source of trace metals in sediments in Trinity Bay is the Trinity River where higher than normal levels of heavy metal particulates have been reported in river water (Texas Department of Water Resources, 1978). Trace metal concentrations in sediments of East Bay may be related, in part, to bay and estuary hydrodynamics. Muds and associated trace metals in East Bay appear to be connected to similar areas in Trinity Bay, and may have been partly deposited by currents moving from Trinity Bay around Smith Point (between Smith Point and Hanna Reef) eastward toward Rollover Pass and the Intracoastal Waterway. Simulated flow patterns for the Trinity-San Jacinto estuary indicate that net flow is from Trinity Bay around Smith Point and into East Bay during several months of the year (Texas Department of Water Resources, 1981). The possibility that muds and trace metal concentrations are related to local sources, associated either with natural occurrences or human activities, cannot be discounted in any area. There are hundreds of waste discharge points, industrial and municipal, around the bay-estuary and lagoon, and river-bayou systems in the Galveston-Houston area (Blevins and Novak, 1975).

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 scatter grams of copper. That zinc concentrations in bay and shelf sediments

DRAFT

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 anthropogenie input of zinc into bay sediments.

A comparison of trace element concentrations in bay and shelf sediments in the Galveston-Houston area, shows 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 (figs. 14, 19, 21, and 22). Accordingly, the mean concentrations of these elements in shelf muds (sediments composed of 75% or more of silt and clay) are 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) are 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).

Comparisons of trace-metal levels in sediments from the Corpus Christi area (White and others, 1983) with those in the Galveston-Houston area, show that for chromium, copper, lead,

DRAFT

and nickel, the mean concentrations in bay muds of the Galveston-Houston area are about 1.5 to 2 times higher than the Corpus Christi area. In shelf muds of the Galveston-Houston area, chromium, copper, and lead are about three-fourths the concentration measured in shelf muds of the Corpus Christi area, whereas nickel is about 1.3 times that measured in the Corpus Christi area. Barium, which has been linked to the use of barite in drilling muds (Holmes, 1974), has a mean concentration in bay muds of the Corpus Christi area of about 2 times that of the Galveston-Houston area bay muds. Other chemical element relationships between the Galveston-Houston and Corpus Christi area are shown in table 7.

Differences in trace metal concentrations in bay and shelf sediments in the Galveston-Houston area and in the Corpus Christi area may be the result. of many variables other than anthropogenic contributions, including different mineralogical sources and provinces. Heavy minerals associated with Gulf sediments in the Corpus Christi area, for example, are derived in part from rivers along the northeastern part of the coast (Bullard, 1942). Among the rivers providing 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 Brazes, 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 Galveston-Houston area compared to Corpus Christi area), are differences in clay mineralogy, total organic carbon, and physiochemical 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

Table 7. Comparison of mean concentrations of selected elements in bay and inner shelf muds (sediments composed of over 75% silt and clay) in the Galveston-Houston and Corpus Christi submerged lands. (Data from USGS chemical analysis).

		Galveston-* Houston area	Corpus Christi area
Barium (ppm)	Bay	410	800
	Shelf	538	478
Boron (ppm)	Bay	79	75
	Shelf	70	94
Chromium (ppm)	Bay	56	26
	Shelf	45	59
Copper (ppm)	Bay	27	15
	Shelf	18	24
Iron (ppm)	Bay	24,000	23,400
	Shelf	30,000	31,900
Lead (ppm)	Bay	34	17
	Shelf	19	25
Manganese (ppm)	Bay	475	535
	Shelf	783	560
Nickel (ppm)	Bay	22	15
	Shelf	28	22
Zinc (ppm)	Bay	62	93
	Shelf	53	60

*excludes sediments from Houston Ship Channel/Buffalo Bayou.

elements showed definite reentrant patterns (barium, boron, chromium, copper, iron, manganese, lead, strontium).

The association of the reentrant with what sometimes become temporary tidal passes, or storm washover areas, suggests that the reentrant are formed by sediments deposited by either storm flood or ebb tides or both. The possibility that the reentrant are related to ebb currents perhaps indicates that flocculation (of inorganic and organic particulate 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 physiochemical 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) gulf ward, thereby contributing to the higher levels of trace elements in the reentrant.

Maps of trace element distribution for the Port Lavaca and Bay City - Freeport map areas (fig. 1) also have trace-element reentrant associated with tidal passes. Lobes of sediments containing higher than normal trace element concentrations also extend gulf ward from the mouths of the Colorado, Brazes, 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 particulate 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 Galveston-Houston area, there are two major tidal inlets or passes--Bolivar Roads and San Luis Pass (fig. 4). Sediments containing high concentrations of trace metals on the shelf occur immediately southwestward from each of these two passes. These trace-metal highs generally coincide with the finest-grained sediments (mean grain size of 6 to 7ϕ; pl. ID) on the inner shelf.

The theory involving polar air masses for sediment movement on to the Continental Shelf proposed by Holmes (1982) for northern bay systems, may be applicable to the Galveston-Houston bay and inner shelf systems. In other words, 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 Bolivar Roads and San Luis 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. If this scenario is correct, then the lobes of mud on the inner shelf southwest of the passes are areas of active deposition. Supporting this concision are the observations that (1) the muds in these areas are relatively thick (U.S. Army Corps of Engineers core data), and (2) relict muds are not present in surface sediments (McGowen and Morton, 1979). The tidal passes are not the only possible sources of mud in these areas, however. For example, the muddy area southwest of San Luis Pass connects to a larger area of mud centered on and apparently deposited by the Brazes River.

Whatever the origin of the reentrant or trace-metal highs in the vicinity of the passes, whether formed (1) in conjunction with flood tides or ebb tides or both, or (2) by some other process, they appear to be real features and not products of the semiquantitative analytical methods. More detailed studies in shelf areas and tidal passes along the remainder of the coast may help resolve some of the unanswered questions.

BENTHIC MACROINVERTEBRATES

by Thomas R. Calnan, Russell S. Kimble, and Thomas G. Littleton

assisted by James A. DiGiulio, Gary J. Steck, John H. Wilkins,
Joseph E. Sullivan, Lisa R. Wilk, and Stephen M. Robertson

Introduction

This benthic macroinvertebrate study provides information on benthic populations in the State-owned submerged lands of the Galveston-Houston 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.

More benthic macroinvertebrate studies have probably been conducted in the bays and on the inner shelf of the Galveston-Houston area than on any other areas of the Texas Coast However, only the more relevant previous studies will be summarized in this report, especially those studies that have dealt with all macrofauna rather than with specific groups of organisms.

Probably the most pertinent study of the macrobenthos on the inner shelf in the Galveston-Houston area is that of Harper (1970). Harper studied the substrate preference and temporal distribution of 64 species of macroinvertebrates on the inner shelf from 10 to 36 ft (3 to 11 m) off Galveston. A dredge was used to sample five stations on each of two transects Harper constructed graphs on species abundance versus percent sand. He used numerica dominance and restricted substrate preference to select species characteristic of the three bottom types, sandy, mixed and muddy. On sandy bottoms the dominant forms were *Tellina iris* *Mulinia lateralis*, *Olivella mutica*, *Pyramidella crenulata*, *Onuphis eremita oculata*, *Owenia fusiformis*, *Isocheles wurdemanni* (Young) and *Ancinus depressus*. On mixed bottoms *Terebra protexta* was dominant, and on muddy bottoms *Nuculana concentric* and *Diopatra cuprea* were dominant.

Defenbaugh (1976) studied the benthic macroinvertebrates on the continental shelf from the northern Gulf of Mexico, primarily between Corpus Christi, Texas and Pensacola, Florida. He delineated 12 assemblages based on 365 species, mostly collected in a depth range of 58 to 589 ft (18 to 183 m), and on faunal assemblages from previous published records. Only one assemblage, Defenbaugh's inner shelf assemblage, occurs within the Galveston-Houston study area. This assemblage occurred from 13 to 65 ft (4 to 20 m) in depth and was characterized by sediments of soft mud, mixed sand and mud, or sand. Characteristic species included a large number of mollusks and crustacea and only two polychaetes, Diopatra cuprea and Onuphis eremita oculata.

Parker (1960), in his study of macroinvertebrate assemblages in bays and the continental shelf described an inner shelf zone whose bathymetric range was 9.8 to 62.2 ft (3 to 22 m). Characteristic organisms included Pinna serrata, Dinocardium robustum, Dosinia discus, Raeta plicatella, Spisula solidissima, and Mellita. However, none of Parker's samples were taken from the nearshore bottom off Galveston.

Henry (1976) sampled six stations monthly for 12 months in the tidal inlet, Bolivar Roads. His purpose was to compare benthic data from natural areas with those altered by dredging and dredged material disposal. Using cluster analyses on the 170 species collected during the 12 months, three site groups and five species groups were identified. The site groups included those stations on sandy bottoms, muddy bottoms, or in the ship channel. Benthic populations were bimodal in their seasonal distribution with peak densities occurring when temperature was rising (February to May) and a secondary peak occurring when temperatures were falling (November). Benthic populations in the ship channel were highly erratic. It was believed that this was due to erosion and deposition of sediments enhanced by channelization, and the presence of a few highly gregarious species. Henry also concluded that dredged material disposal was found to have a relatively short term effect on the benthic populations.

Most studies of the benthos in Galveston bays have been at selected sites within one bay system. Very few studies have attempted to characterize all bays. This is understandable because of the size and complexity of the four big bays, West, East, Galveston, and Trinity Bays and the smaller secondary bays and water bodies, including Chocolate, Bastrop, Christmas Tabbs, Dollar and Dickinson Bays, and Clear Lake, Moses Lake and the Houston Ship Channel.

Many studies have dealt with various pollution concerns, including oilfield brine effluent in Trinity Bay (Armstrong and others, 1979 and Mackin, 1971)? thermal pollution in Trinity Bay (Poff, 1973 and McBee, 1975), and general pollution concerns in upper Galveston Bay and Tabbs Bay (Gillard, 1974). Other bay studies include Gilmore and Trent's (1974) study on the abundance of macroinvertebrates in natural versus altered areas of West Bay, and general ecological surveys such as Moffett's (1975) study of Chocolate Bay and Reid's (1955) survey of East Bay. Reid primarily characterized the fish community, and except for some quantitative data on blue crab populations, other benthic invertebrates were only briefly mentioned. Only two studies, Parker (1960) and Holland and others (1973) included benthic data from all the big bays, Galveston, Trinity, East and West Bays, in the Galveston-Houston area.

Parker (1960) utilized data from previous published reports and from American Petroleum Institute collections to delineate six macrofaunal assemblages in the Galveston bays. All of Trinity Bay and most of upper Galveston Bay contained a river-influenced assemblage of *Rangia* spp., *Macoma mitchelli, Polymesoda carolinensis* and *Littoridina sphinctostoma*. Most of West Bay, East Bay, and lower Galveston Bay had an open or enclosed bay assemblage of primarily bivalves. The three remaining assemblages included an inlet assemblage near Bolivar Roads and San Luis Pass, an oyster reef assemblage in Galveston Bay, and an open bay margin assemblage along the margins of Bolivar Peninsula, parts of Galveston Island, and along the bay margins just north and south of the Texas City dike. Nearly all characteristic species in Parker's assemblages were mollusks. Polychaetes were not included in his species lists.

Holland and others (1973) used various diversity indices to describe benthic communities in the Galveston Bay system. A discussion of their study as it relates to diversity data from this report is included in the total species diversity section.

Gillard (1974) took dredge samples from 17 stations in Tabbs Bay and upper Galveston Bay over an 18 month period from August 1970 through January 1972. Based on the community parameters of species and individual totals and diversity indices, four areas with similar benthic communities were delineated. Two areas were in Tabbs Bay, both upper and lower sections, and the other two areas were in upper Galveston Bay. One area in upper Galveston Bay included those stations close to the Houston Ship Channel and the other included all upper Galveston Bay stations exclusive of those near the channel edge. The area near the ship channel had a distinctive community composed of relatively few individuals, many species, and high diversity indices. Sediments in this area contained many *Diopatra cuprea* tubes that acted as substrates for epifauna and other invertebrates. Upper Tabbs Bay had depressed populations of mostly *Streblospio benedicti*. Gillard concluded that this area was affected by pollution from the Houston Ship Channel. Lower Tabbs Bay and upper Galveston Bay, exclusive of the stations near the ship channel, had similar communities. *Mediomastus californiensis* was dominant in these areas.

Moffett (1975) studied the hydrography and macro-biota in the Chocolate Bayou estuary from May 1969 to October 1971. Faunal samples at 23 stations were primarily collected by trawls and seine. Moffett listed many benthic invertebrates including live and dead mollusk species and gave general information on their abundance and location. Some of the common benthic species collected were *Loandalia fauveli*, *Nereis succinea*, *Glycera americana*, *Branchioasychis americana*, *Retusa candei*, *Macoma mitchelli*, *Mulinia lateralis*, and *Crassostrea virginica*. Live specimens of *Rangia cuneata* and *R. flexuosa* were also found in Chocolate Bay.

Benthic macroinvertebrates in West Bay were studied by Gilmore and Trent (1 974). The objectives of their study were to determine the relative abundance of the benthos in a natural marsh, a marsh area altered by dredging, bulkheading, and filling and an open bay area. Also, relative invertebrate abundance wit hin each area was compared to sediment size, amount of plant matter, and dissolved oxygen. Polychaetes, crustacea, and mollusks were only identified to the family level.

Based on comparisons of mean values for all groups combined, benthic organisms were more abundant numerically in the marsh than in the canals; they were least abundant in the bay. Only the bivalves were numerically most abundant in the bay. Polychaetes were most numerous in the canals, and crustaceans were over three times as abundant in the marsh as in the other two areas. Benthic organisms were generally most abundant in sediments with low to intermediate amounts of silt and clay.

The primary difference between this study and previous sampling programs is the greatly increased sample density that gives more control on the areal distribution of the organisms and assemblages, and a better understanding of the diversity of the bays and inner shelf. Other differences include differences in sampling techniques and sample analyses and temporal and climatic differences. These differences make it difficult to compare the results from this study with those of previous studies. However, some general comparisons can be made and these will be discussed in the invertebrate assemblage and total species diversity sections of this report.

Distribution in the Galveston-Houston Area

Two hundred seventy-seven macroinvertebrate species (9,978 individuals) were found in the 263 samples examined in the Galveston-Houston map area (table 8). Polychaetes were the most numerous species, followed by mollusks and crustaceans. Generally, polychaetes were dominant in the bays and on the inner shelf (table 8). Species counts for the three major groups (mollusks, polychaetes, and crustaceans) were higher on the inner shelf than in the bays (table 8). The highest total species count at a station (47 species) also was found on the inner shelf (pl. V). In the bays, West Bay had the most species. West Bay station 15 had the highest total species count, 32 species. Distributions of the polychaetes, mollusks, crustaceans and other phyla are discussed individually, and the distributions are related to bathymetry and sediment type.

Table 8. Abundance of the major taxonomic groups, Galveston-Houston area.

	Number of Stations Examined	All Species	All Individuals	Polychaete Species	Polychaete Individuals	Molluscan Species	Molluscan Individuals	Crustacean Species	Crustacean Individuals
Galveston Bay	70	102	1,266	41	809	32	273	29	184
Trinity Bay	35	19	213	7	127	7	72	5	14
East Bay	29	43	611	20	425	9	133	14	53
West Bay	42	130	3,646	48	1,230	42	1,330	40	1,086
Clear Lake, Houston Ship Channel, and San Jacinto River	7	7	11	4	7	1	1	2	3
Inner Shelf	80	176	3,872	73	2,132	53	838	50	902
Total	263	261	9,619	96	4,730	86	2,647	79	2,242

Mollusca

Eighty-six species of mollusks were identified from the Galveston-Houston study area, including forty-three gastropod and forty-three bivalves. Twenty-mine species occurred only on the shelf and thirty-four species only in the bays. In the bays, Mulinia lateralis was the most abundant species with nearl y one-third of the total number of individuals. Tellina versicolor was the most abundant species on the inner shelf. The species collected, including all dead species, are listed in appendix C. Table 9 lists the most abundant mollusks of each system, Although species numbers and content may change seasonally, temporal data were not taken in this study. Unless stated otherwise, all molluscan data in this report is based solely on live material.

The location" of reefs of the oyster Crassostrea virginica, presented on the biological assemblages map (pi. V), is modified from Fisher and others (1972) and McGowen and Morton (1979). In addition, there are scattered and locally abundant clumps of C. virginica in many of the bays covered in this survey. The techniques of collecting used in this study did not allow further delineation of the reefs nor the location of the scattered clumps.

Bay-Estuary-Lagoon System

Galveston Bay.--Thirty-two species of mollusks were collected in Galveston Bay. These included fourteen gastropod and eighteen bivalve species.

Acteocina canaliculata and Odostomia impressa were the most abundant gastropod species, although neither species was as abundant as the abundant bivalve species (table 9). Acteocina was collected at 5 stations in sediments mostly composed of 80 to 100 percent sand. Odostomia occurred at two oyster reef or reef-flank stations.

Mulinia lateralis was by far the most abundant bivalve species accounting for over 35 percent of the total bivalve individuals. It was primarily found in sandy substrates of 60 to 100 percent sand.

DRAFT

Table 9. Most abundant molluscan species of the Galveston-Houston area.

Galveston Bay Gastropod	Number of individuals	Percent of all (71) gastropod individuals
Acteocina canaliculata	13	18.3
Odostomia impressa	10	14.1
Turbonilla Pyrgiscus) sp. A	9	12.7
Nassarius acutus	7	9.8
Texadina barretti	7	9.8
Texadina sphinctostoma	7	9.8
Bivalvia	Number of individuals	Percent of all (202) bivalve individuals
Mulinia lateralis	72	35.6
Petricola pholadiformis	26	12.9
Mysella planulata	21	10.4
Tellina texana	20	9.9
Trinity Bay Gastropoda	Number of individuals	Percent of all (40) gastropod individuals
Texadina barretti	15	37.5
Probythinella louisianae	13	32.5
Texadina sphinctostoma	12	30.0
Bivalvia	Number of individuals	Percent of all (32) bivalve individuals
Macoma mitchelli	13	40.6
Mulinia lateralis	8	25.0
Rangia flexuosa	7	21.9
East Bay Gastropoda	Number of individuals	Percent of all (15) gastropod individuals
Texadina barretti	7	46.7
Texadina sphinctostoma	7	46.7
Bivalvia	Number of individuals	Percent of all (118) bivalve individuals
Brachidontes exustus	86	72.9
Mulinia lateralis	12	10.2
Macoma mitchelli	12	10.2
West Bay Gastropod	Number of individuals	Percent of all (204) gastropod individuals
Acteocina canaliculata	135	66.2
Acteon punctostriatus	20	9.8
Bivalvia	Number of individuals	Percent of all (1, 127) bivalve individuals
Mulinia lateralis	483	42.8
Lyonsia h. floridana	252	22.4
Mysella planulata	173	15.4

Table 9. (cont.)

Clear Lake, Houston Ship Channel, San Jacinto River	Number of individuals	Percent of all (1) individuals
Bivalvia		
Mulinia lateralis	1	100.0

Inner Shelf	Number of individuals	Percent of all (483) gastropod individuals
Gastropod		
Nassarius acutus	98	20.4
Natica pusilla	82	17.0
Parvanachis obesa	73	15.2
Vitrinella floridana	71	74.8

	Number of individuals	Percent of all (356) bivalve individuals
Bivalvia		
Tellina versicolor	118	33.1
Nuculana concentric	99	27.8
Abra aequalis	33	9.3

Numbers of species and individuals at stations in Galveston Bay were generally low. Stations in lower Galveston Bay had the highest individual and species counts; none of the stations in upper Galveston Bay had more than four species. Station 10, a bay margin station in lower Galveston Bay, had the highest species count, 6 species.

Trinity Bay.--Only 7 species of mollusks were found in Trinity Bay. Most of the 7 species such as *Texadina sphinctostoma*, *T. barretti*, and *Rangia flexuosa* generally occur in the upper reaches of estuaries where salinities average between 5 and 10 ppt but may become fresh (<0.5 ppt) during periods of high river flow and rise above 15 ppt in periods of low freshwater inflow (Hopkins and others, 1973).

The only three gastropod collected in Trinity Bay were almost equally abundant (table 9). *Texadina barretti* was the most abundant species, accounting for almost 38 percent of the total gastropod individuals. All gastropod species preferred muddy sediments of 0 to 40 percent sand.

Macoma mitchelli was the most abundant bivalve in Galveston Bay. Although *Macoma* was collected in both sandy and muddy sediments, it was most often found in muds (<20 percent sand). The two other abundant bivalve species, *Mulinia lateralis* and *Rangia flexuosa*, preferred sandy (>80 percent sand) sediments. *Rangia cuneata*, reported by other authors as a dominant mollusk in Trinity Bay (Hopkins and others, 1973), was not found living in any of the Galveston bays; however, dead shell occurred in all the bays and on the inner shelf.

East Bay. --Nine species and 133 individuals were collected in East Bay. Station 200, with over 60 percent shell, had the highest species (7) and individual number (105). *Brachidontes exustus*, the most abundant mollusk, occurred only at Station. 200. Other stations in East Bay had two molluscan species or less; nineteen of the 29 stations had no live mollusks.

Clear Lake, Houston Ship Channel, San Jacinto River.--*Mulinia lateralis* was the only species found living in Clear Lake. No live mollusks were found in the San Jacinto River or the Houston Ship Channel.

West Bay (including Chocolate, Christmas, and Bastrop Bays) .--In the samples from West Bay, 1 ,330 individual mollusks were counted representing 18 gastropod and 24 bivalve species.

Bivalves constituted 85 percent of the total number of molluscan individuals. *Mulinia lateralis* was by far the most abundant and ubiquitous bivalve with 43 percent of the bivalve individuals and over 36 percent of all molluscan individuals. Also, *Mulinia* occurred at 86 percent of the West Bay stations. The three most abundant bivalves accounted for over 80 percent of all bivalve individuals (table 9). *Acteocina canaliculata,* the most abundant gastropod, made up over 66 percent of the total gastropod individuals.

West Bay stations 92 and 93 had the highest species (15 at station 92) and individual numbers (163 at station 93) of any stations in the Galveston-Houston map area. Both stations were nearly 7 ft (2.1 m) deep and had sediments of muddy sand (60 to 80 percent sand).

The only station with seagrass was station 126 in Christmas Bay. Gastropod species that typically occur in marine grassflats, such as *Bittium varium* and *Cerithium lutosum* (White and others, 1983) were not collected at station 126. The bivalves *Amygdalum papyrium, Lyonsia h. floridana,* and *Laevicardium mortoni,* were the most abundant species at station 126.

Inner Shelf

Fifty-three species of mollusks were found living on the inner shelf in the study area, including 30 gastropod and 23 bivalve species. A total of 838 individuals were counted.

Four species of gastropod, *Nassarius acutus, Vitrinella floridana, Natica pusilla,* and *Parvanachis obesa,* accounted for over 67 percent of the total number of gastropod individuals. *Nassarius acutus* was the most abundant gastropod with over 20 percent of the total. *Vitrinella floridana* occurred primarily in substrates of 20 to 40 percent sand with no individuals living at stations with substrates of 60 to 100 percent sand. *Natica pusilla* and *Nassarius acutus* were generally found in sandier substrates of 40 to 100 percent sand.

Of the 355 total bivalve individuals, over 60 percent were of two species, *Nuculana concentric* and *Tellina versicolor*. *Tellina versicolor* was generally found in sandy substrates of 60 to 100 percent sand, whereas, *N. concentric* only occurred in muddier substrates of O to 60 percent sand.

Polychaeta

Ninety-six species numbering 4,730 individuals were found in the 263 samples from the Galveston-Houston area. *Paraprionospio pinnata* and *Magelona* cf. *phyllisae* were the most abundant and ubiquitous species on the inner shelf (table 10). In the bays, *Mediomastus californiensis* was most abundant. A list of all polychaete species occurring in the Galveston-Houston area is included in appendix C. Distribution of sediment, expressed as percent sand and referred to in this section, is shown on plate IC. Species number and species content may change seasonally.

Bay-Estuary-Lagoon System

Galveston Bay.--Forty-one species (809 individuals) were taken from the 70 stations examined in Galveston Bay. Highest species counts occurred at several stations between the Texas City Ship Channel and Galveston Island. Species counts were generally higher in lower Galveston Bay than in upper Galveston Bay. Eight stations in upper Galveston Bay had no polychaete species; whereas, all stations in lower Galveston Bay had at least one species. The highest species count, 11, occurred at station 37, just south of the Texas City Ship Channel. *Mediomastus californiensis* and *Streblospio benedicti* constituted almost 45 percent of all polychaete individuals found (table 10). Individual counts for *Mediomastus californiensis* and *Streblospio benedicti* were generally highest in upper Galveston Bay.

Trinity Bay.-- Trinity Bay had the least number of polychaete species and individuals of any bay system in the Galveston area, only seven species and 127 individuals. None of the stations had more than four polychaete species. *Mediomastus californiensis*, the dominant species, made up almost 68 percent of all polychaete individuals.

East Bay.--Twenty species and 425 individuals were found at the 29 stations in East Bay. The highest species and individual counts were at station 200. *Parandalia fauveli* and *Mediomastus californiensis* were the most abundant species, occurring at most stations in East Bay.

Table 10. Most abundant polychaete species
of the Galveston-Houston area.

Inner Shelf	Number of individuals	Percent of all (2,130) individuals
Paraprionospio pinnata	272	12.8
Magelona cf. phyllisae	267	12.5
Chone duneri	144	6.8
Diopatra cuprea	116	5.4
Loimia medusa	106	5.0
Lumbrineris tenuis	81	3.8
Armandia maculata	78	3.7
Haploscoloplos foliosus	78	3.7
Nereis micromma	77	3.6
Sigambra tentaculata	63	3.1

Galveston Bay	Number of individuals	Percent of all (809) individuals
Mediomastus californiensis	225	27.8
Streblospio benedicti	138	17.1
Polydora ligni	86	10.6
Nereis succinea	67	8.3
Glycinde solitaria	50	6.2
Tharyx marioni	28	3.5
Parandalia fauveli	26	3.2
Paraprionospio pinnata	24	3.0
Euclymene lombricoides	21	2.6

Trinity Bay	Number of individuals	Percent of all (127) individuals
Mediomastus californiensis	86	67.7
Parandalia fauveli	19	15.0
Capitella capitata	10	7.9

East Bay	Number of Individuals	Percent of all (425) Individuals
Parandalia fauveli	88	20.7
Mediomastus californiensis	78	18.4
Polydora ligni	51	12.0
Streblospio benedicti	42	9.9
Paraprionospio pinnata	35	8.2
Glycinde solitaria	35	8.2
Nereis succinea	34	8.0

West Bay	Number of individuals	Percent of all (1,230) individuals
Aricidea fragilis	183	14.9
Mediomastus californiensis	155	12.6

Table 10. (cont.)

Haploscoloplos fragilis	123	10.0
Paraprionospio pinnata	121	9.8
Clymenella torquata	99	8.0
Glvcinde solitaria	99	8.0
‘pio benedicti	49	4.0
Tharyx marioni	35	2.8
Clear Lake, Houston Ship Channel, San Jacinto River	Number of individuals	Percent of all (7) individuals
Mediomastus californiensis	3	42.8
Streblospio benedicti	2	28.5

Clear Lake, Houston Ship Channel, San Jacinto River---Polychaetes were not found in the Houston Ship Channel or the San Jacinto River. Station 5 was the only station in Clear Lake with polychaetes (4 species).

West Bay (including Chocolate, Christmas, and Bastrop Bays).--Species and individual counts at some West Bay stations were among the highest in the map area. Station 15 had the highest species count, 17, of any bay station in the Galveston-Houston area. West Bay also had the highest total species count, 48, of any bay system. Aricidea fragilis was the most abundant species, although most individuals occurred at only two stations.

Inner Shelf

Seventy-three species (2, 132 individuals) were found in the 80 shelf samples. Species counts were generally highest at stations I to 3 mi (1.6 to 4.8 km) offshore from approximately 3 mi (4.8 km) north of San Luis Pass to 7 mi (1 1.2 km) south of the pass. The highest species count, 22, was at station 2953, 1 mi (1.6 km) offshore in sediment of 92 percent sand and at a depth of approximately 25 ft (8.3 m).

Paraprionospio pinnata and Magelona cf. phyllisae, the most abundant species, occurred at 47 and 55 stations respectively. Both P. pinnata and M. cf. phyllisae were two of the most abundant species on the inner shelf in the Corpus Christi area (White and others, 1983). However, Owenia fusiformis, the most abundant polychaete on the Corpus Christi inner shelf, was found at only 5 stations (13 individuals) on the inner shelf in the Galveston-Houston area.

Crustacea

Seventy-nine species (2,242 individuals) were identified from the inner shelf and bays in the study area.

The decapods represented by 34 species were the most abundant order. The amphipod Ampelisca abdita was the most abundant species and the cumacean Oxyurostylis salinoi was the most ubiquitous. A complete listing of all crustacea and their distribution can be found in appendix C. Species number and species content may change seasonally.

Table 11. Most abundant crustacean species of the Galveston-Houston area.

Galveston Bay	Number of individuals	Percent of all (184) individuals
Cerapus tubularis	28	15.2
Melita nitida	23	12.5
Listriella bahia	16	8.7
Leptochelia rapax	14	7.6
Trinity Bay	Number of individuals	Percent of all (14) individuals
Corophium louisianum	8	57.1
East Bay	Number of individuals	Percent of all (53) individuals
Ampelisca abdita	13	24.5
Lepidactylus sp.	8	15.1
Xenanthura brevitelson	7	13.2
West Bay	Number of individuals	Percent of all (1,086) individuals
Ampelisca abdita	600	55.2
Cerapus tubularis	85	7.8
Acanthohaustorius sp.	55	5.1
Cymadusa compta	46	4.2
Ampelisca verrilli	44	4.0
Clear Lake, Houston Ship Channel, San Jacinto River	Number of individuals	Percent of all (3) individuals
Oxyurostylis salinoi	2	66.7
Inner Shelf	Number of individuals	Percent of all (902) individuals
Ampelisca agassizi	200	22.2
Oxyurostylis salinoi	176	19.5
Pinnixa sayana	145	16.1
Pilumnus sp.	83	9.2

Bay-Estuary-Lagoon System

Galveston Bay.-- Twenty-nine species (184 individuals) were identified from Galveston Bay, Only two stations, stations 10 (8 species) and 144 (6 species) it-t lower Galveston Bay, had more than two species. Cerapus tubularis was the most abundant, species with all 28 individuals occurring at station 10 (table 11).

Trinity Bay.--Only 5 stations in Trinity Bay had crustaceans. The highest number of species, three, was at station 427. Corophium louisianum was the most abundant species with only 8 individuals.

East Bay.- -Fourteen species (53 individuals) occurred in East Bay. Only three stations had more than one species. The amphipod Ampelisca abdita was the most abundant species.

Clear Lake, Houston Ship Channel, and San Jacinto River. --Oxyurostylis salinoi was the only crustacean found in samples from the Houston Ship Channel. Edotea montosa was the only crustacean found in Clear Lake.

West Bay (including Chocolate, Christmas, and Bastrop Bays)--- West Bay contained the most diverse fauna of the bay systems in the Galveston-Houston area. Forty species (1,086 individuals) were identified. Ampelisca abdita was the dominant species with over 55 percent of the total number of individuals. However, most of the individuals occurred at only two stations, station 3 and 6, in the northern part of West Bay. Station 122 in Bastrop Bay with 1(species had the highest number of species of any bay station in the map area. Only four stations had no crustacean species and three of those occurred in Chocolate Bay.

Inner Shelf

Fifty species (902 individuals) occurred on the inner shelf. Dominant species were generally found in muddy substrates. The only dominant species occurring primarily in sandy substrates was Oxyurostylis salinoi.

Stations 1 to 3 mi (1.6 to 4.8 km) off shore from just south of Bolivar Roads to approximately 3 mi (4.8 km) south of San Luis Pass had the highest number of species and

DRAFT

individuals. Several isolated stations farther offshore also had fairly high species counts, including stations 3135, 3355, 3337, and 3427. The highest species count, 8, occurred at two stations, 2976 and 3135. Although both stations 2976 and 3135 had sediment of >80% sand, station 2976 was only two mi (3.2 km) offshore at a depth of approximately 30 to 36 ft (9.1 to 10.9 m), station 3135 was 7 mi (11.2 km) offshore at a depth of approximately 54 to 60 ft (16.3 to 18.2 m).

Other Phyla

Nine phyla besides Annelida, Mollusca, and Arthropoda occurred in the Galveston-Houston area. They were Cnidaria, Nemertinea, Platyhelminthes, Phoronida, Sipunculida, Echinodermata, Pogonophora, Hemichordata, and Chordata. Species found in these phyla are listed in appendix C. Certain groups--Cnidaria, Nemertinea, Pogonophora, and Platyhelminthes--were so little known or difficult to identify that most identifications in these groups were not to species level.

The nemerteans (probably several species) were the most abundant of the nine other phyla, occurring in all the bays and on the inner shelf. Nemerteans occurred at 19 stations (24 percent) on the inner shelf.

Echinoderms occurred in West Bay and at 20 stations (25 percent) on the inner shelf. Two echinoderm classes-- Holothurioidea (sea cucumbers) and Ophiuroidea (brittle stars)-- were found on the inner shelf.

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 greatest in a depth range of 12 to 36 ft (3.6 to 11.0 m) (fig. 25). The average number of species per station for all groups in a depth range of 12 to 36 ft (3.6 to 11.0 m) was 20.3, whereas the average for stations in a depth range of 36 to 60 ft (11.0 to 18.4 m) was 13.7 (table 12). South of Bolivar Roads, the 30-ft

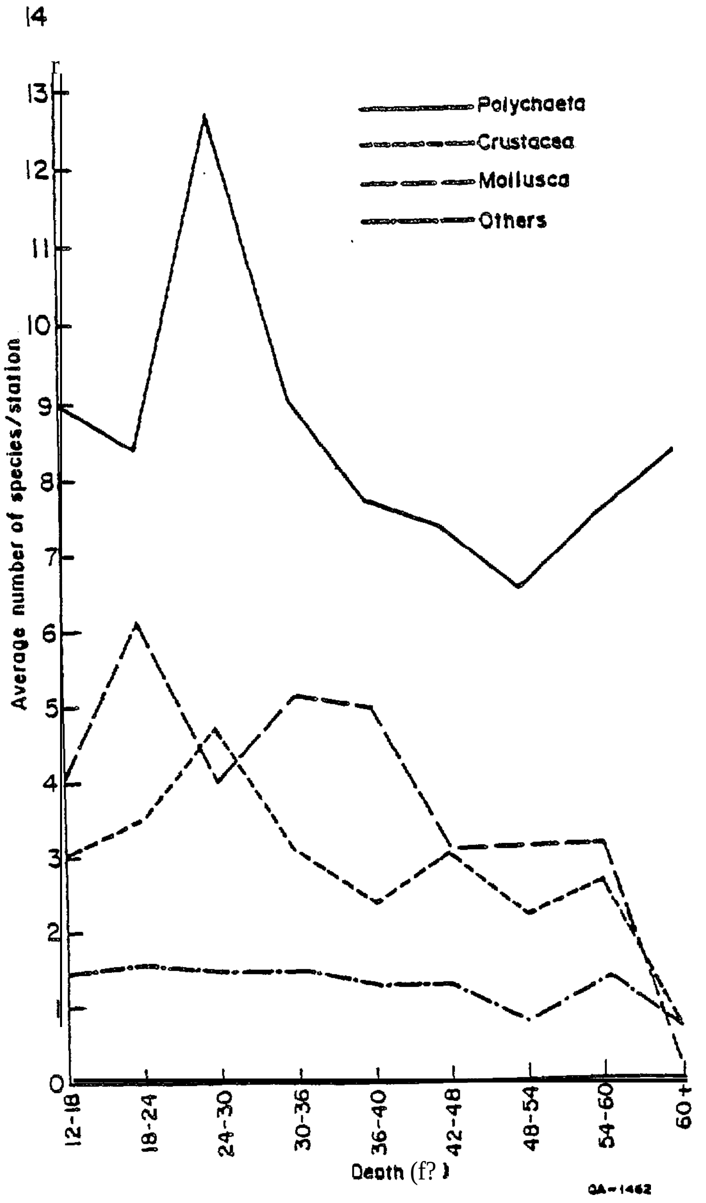


Figure 25. Distribution by depth of the average number of live species per station of the major groups.

DRAFT

Table 12. 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
Polychaeta	12-36 (3.6-11.0)	9.7	36-60+ (11.0-18.4)	7.3
Mollusca	12-42 (3.6-12.9)	5.1	42-60+ (12.9-18.4)	2.6
Crustacea	12-36 (3.6-11.0)	3.6	36-60+ (11.0-18.4)	2.5
Other groups	12-42 (3.6-12.9) -	1.4	42-60+ (12.9-18.4)	1.1
Total	12-36 (3.6-11.0)	20.3	36-60+ (11.0-18.4)	13.7

(9.2 m) contour generally follows the boundary between the sandier and muddier sediments North of Bolivar Roads, nearly all stations have mixed sediment of 20 to 60 percent sand (pl. 1C).

The mollusks, crustacea, and polychaetes exhibited a decrease in the average number of species per station beyond a certain depth range (table 12). 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 30 to 36 ft (9.2 to 11 m).

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 Galveston-Houston area extreme fluctuations in temperature and salinity are common and may play a more significant role in invertebrate distribution than does substrate. However, no single environmental factor governs the population dynamics of either the bay or inner shelf.

DRAFT

Animal-sediment associations have been discussed in several studies on the benthos in the Galveston-Houston area, most of which (Parker, 1960; Harper, 1970; Gillard, 1974; Defenbaugh, 1976; Henry, 1976) are mentioned in the introductory and macroinvertebrate assemblage sections of this report. The only study that is not discussed in other sections is Harry% (1976) report on the correlation of mollusks with substrate composition in lower Galveston Bay.

Harry (1976) took grab samples along an east-west transect and a north-south transect in lower Galveston Bay. He found that a certain amount of mud is favorable to molluscan abundance and that too little or too much results in depauperate faunas. Silt and clay in small amounts give a certain rigidity to sand substrates, so that tunnels made by infaunal species tend to stay open (Harry, 1976). Also, Harry noted that Galveston Bay currents may play a role in molluscan distribution by maintaining a particular substrate type at a particular place. Areas of high sand content have stronger prevailing currents than those where silt accumulates.

On the inner shelf and in the bays, scattergrams show the relationship between species number and sediment type. Numbers of all species (figs. 26 and 30) and numbers of species for each of the major taxonomic groups, mollusks, polychaetes, and crustacea, are plotted against percent sand (figs. 27 to 29 and 31 to 33). Also, histograms depicting faunal distribution versus sediment type along two inner shelf transects show sediment-faunal relationships for the total number of species (fig. 34) and for each of the major taxonomic groups (figs. 35 to 37).

In general, on the inner shelf there is a positive correlation between number of species and percent sand. Stations with higher percentages of sand generally had more benthic species, although there is a wide spread in numbers of species in both muddy and sandy sediments (figs. 26 to 30). The positive correlation between percent sand and species number is stronger for total species (fig. 26) and polychaete and crustacean species (figs. 28 and 29) than for mollusks (fig. 27).

Histograms (figs. 34 to 37) of two inner-shelf transects show that highest species and individual counts occur either 1 or 2 mi (1.6 or 3.2 km) offshore in predominantly sandy sediments. After reaching their peak at stations 1 or 2 mi (1.6 or 3.2 km) offshore, species and individual

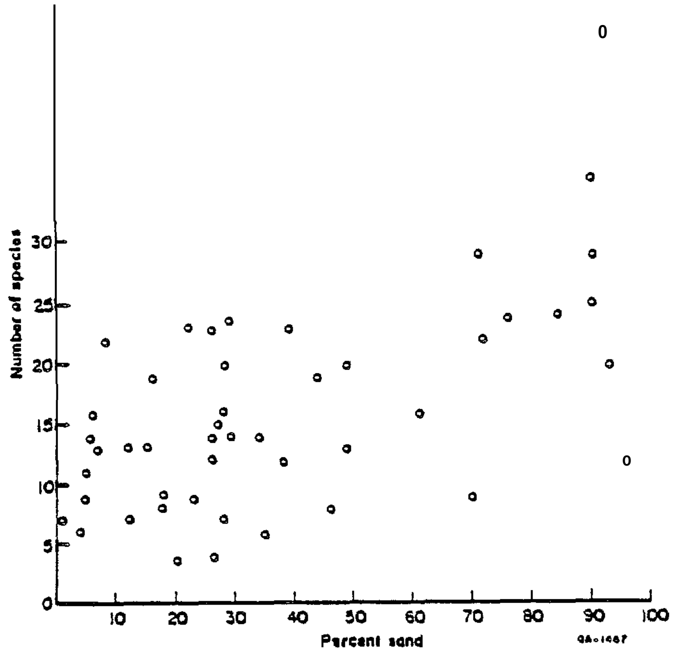


Figure 26. Scattergram of total species and sand on the inner shelf.
correlation coefficient (r) = 0.695

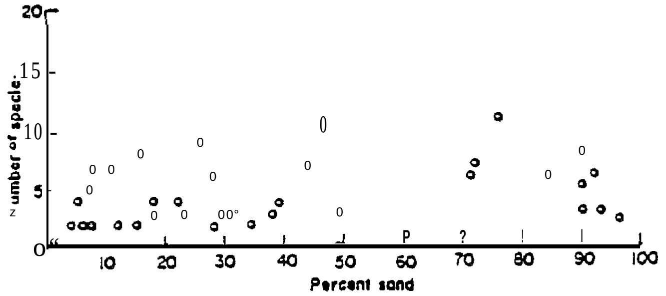


Figure 27. Scattergram of mollusks and sand on the inner shelf.
r = 0.340

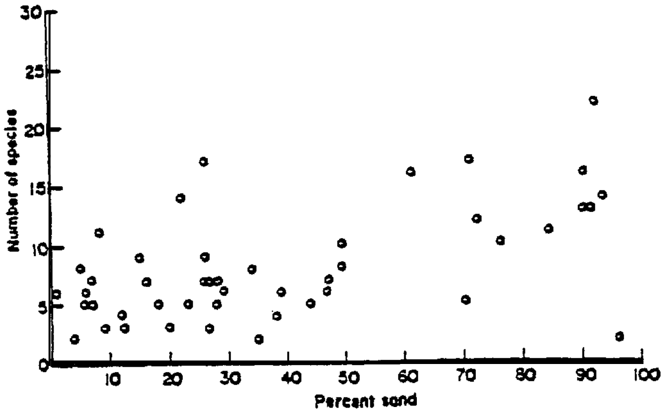


Figure 28. Scattergram of polychaetes and sand on the inner shelf.
r = 0.646

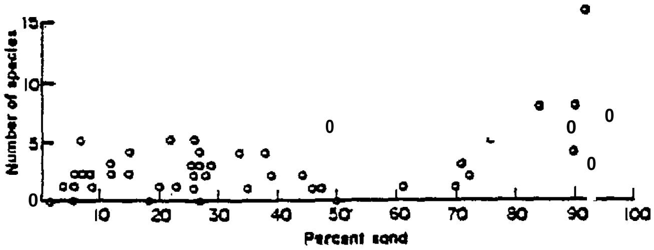


Figure 29. Scatter gram of crustacea and sand on the inner shelf.
r = 0.516

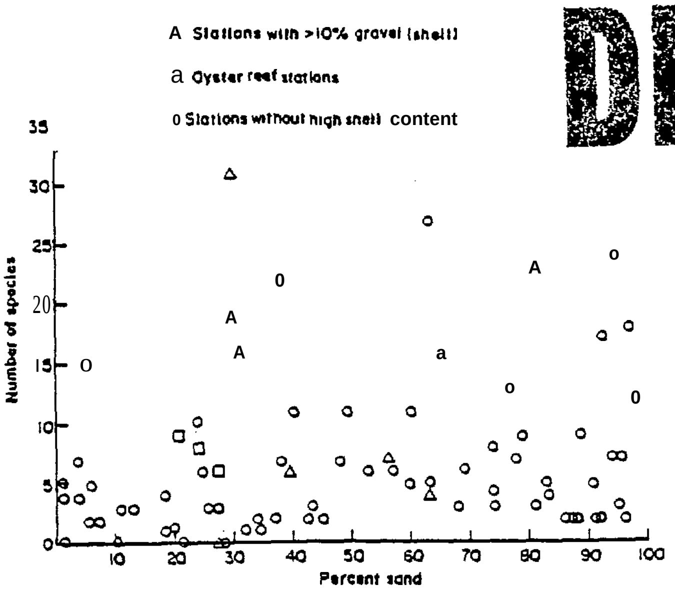


Figure 30. Scattergram of total species and sand in the bays.
Correlation coefficient (r) = 0.272

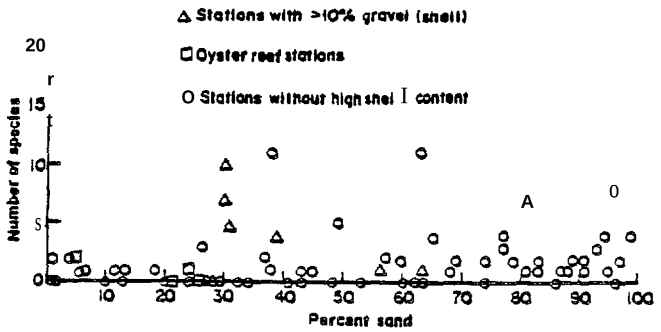


Figure 31. Scattergram of mollusks and sand in the bays.
r = 0.184

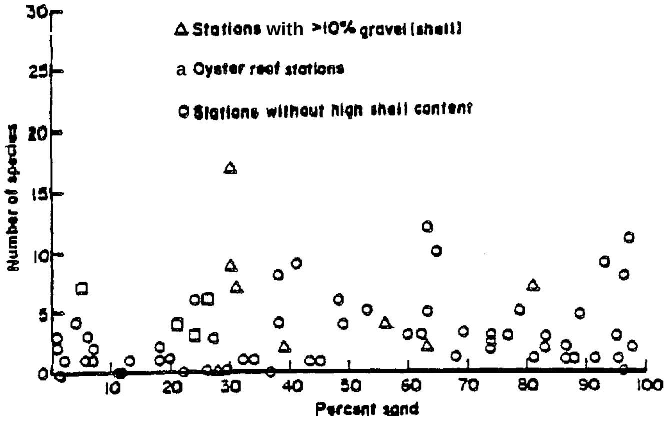


Figure 32. Scattergam of polychaetes and sand in the bays.
r = 0.156

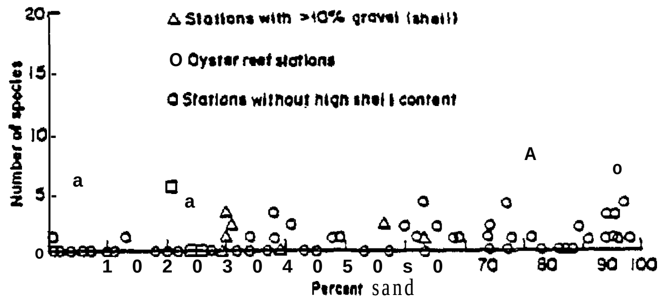


Figure 33. Scattergram of crustacea and sand in the bays.
r = 0.050

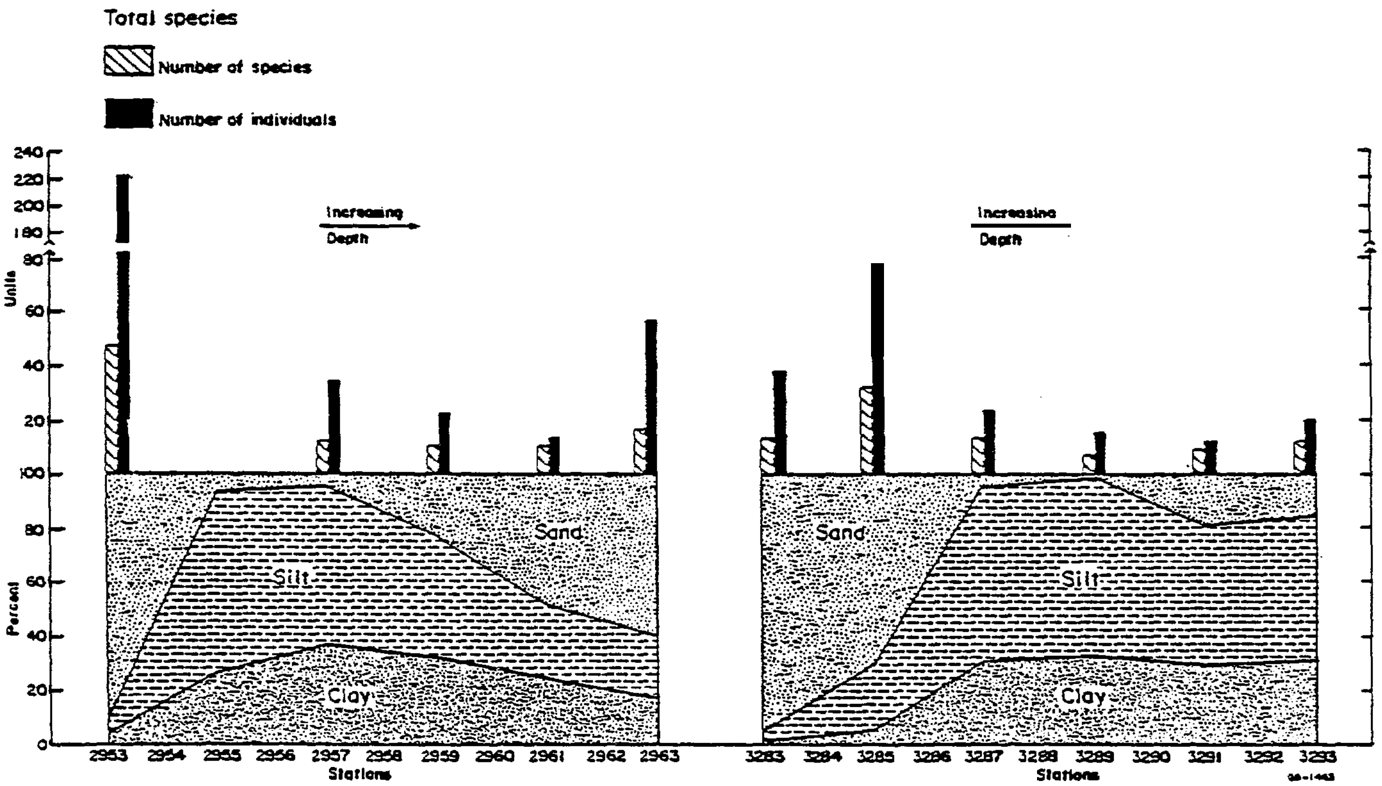


Figure 34. Total species distribution along two inner shelf transects.

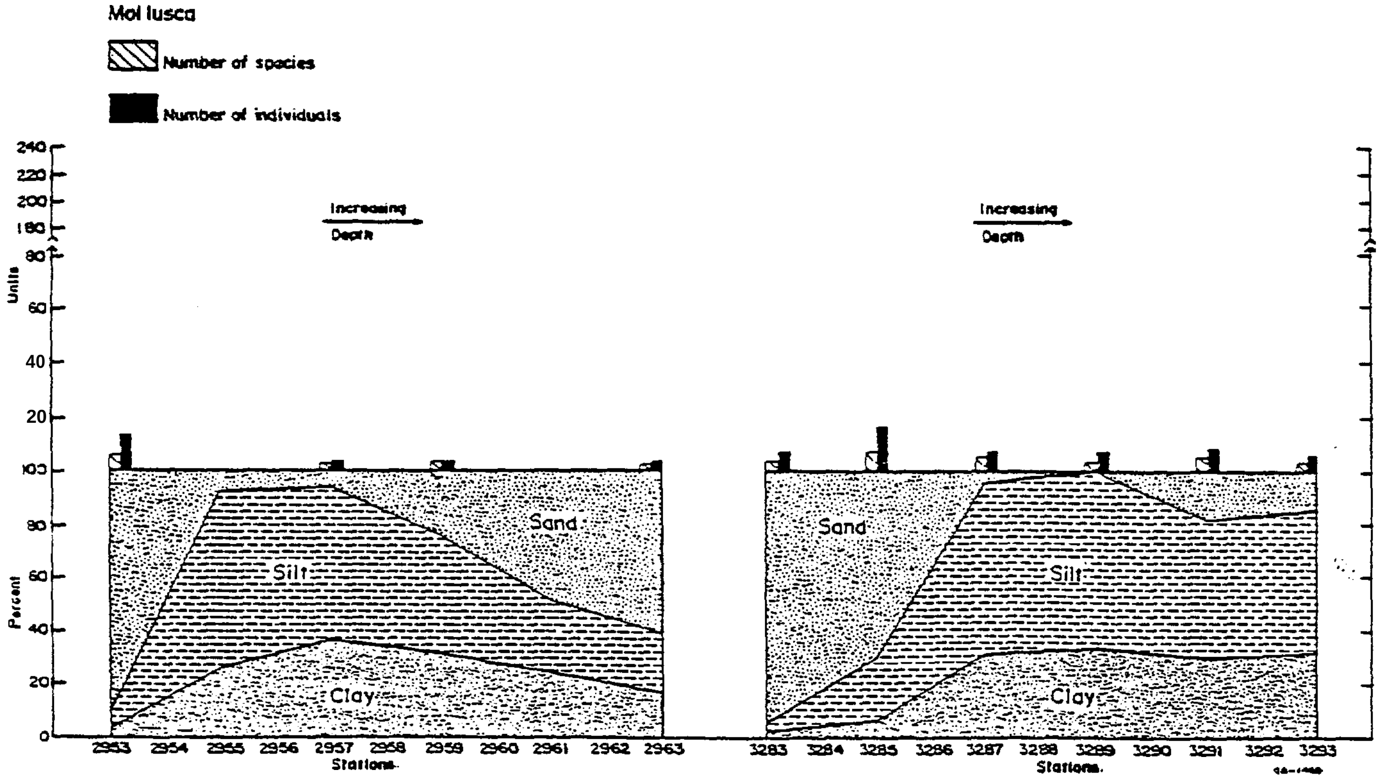


Figure 35. Molluscan distribution along two inner shelf transects. No live mollusks were present at station 2961.

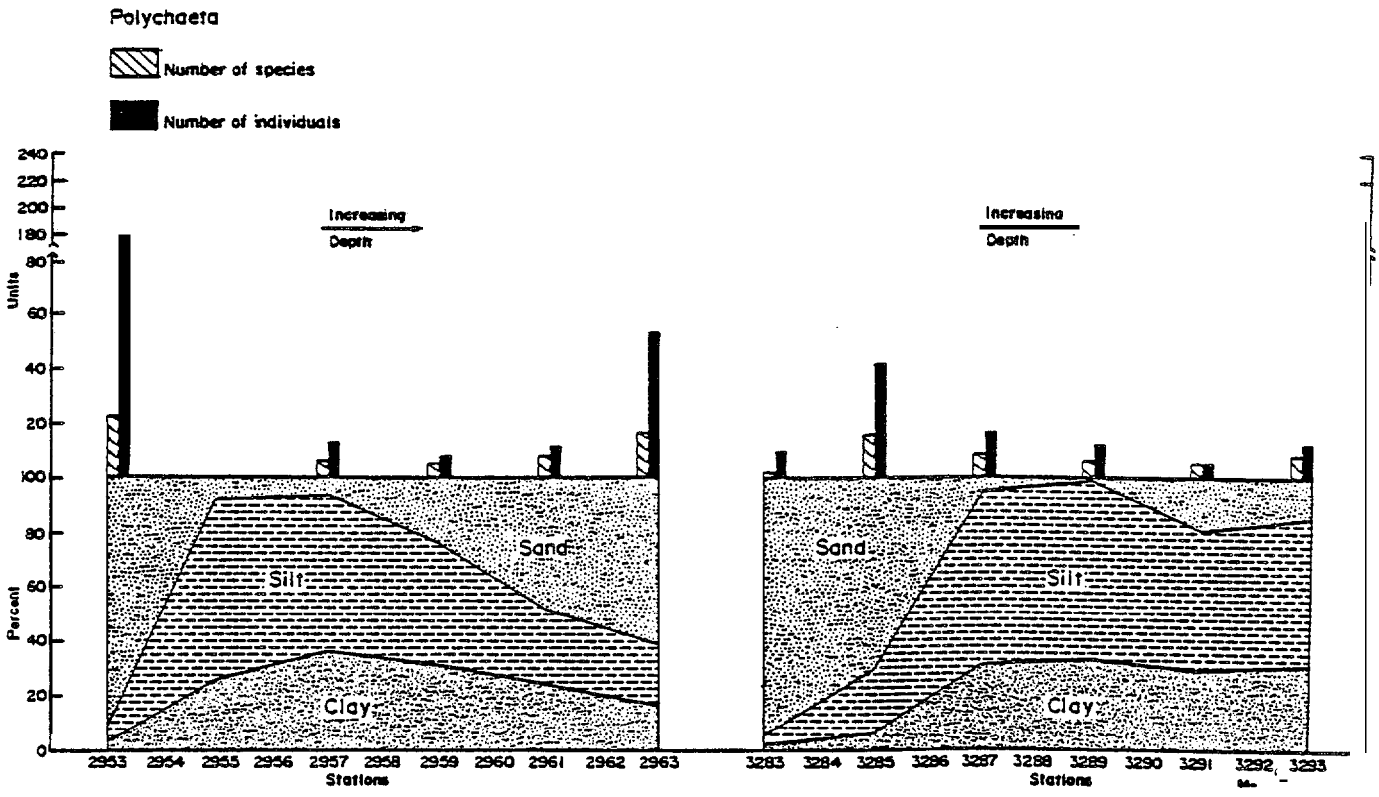


Figure 36. Polychaete distribution along two inner shelf transects.

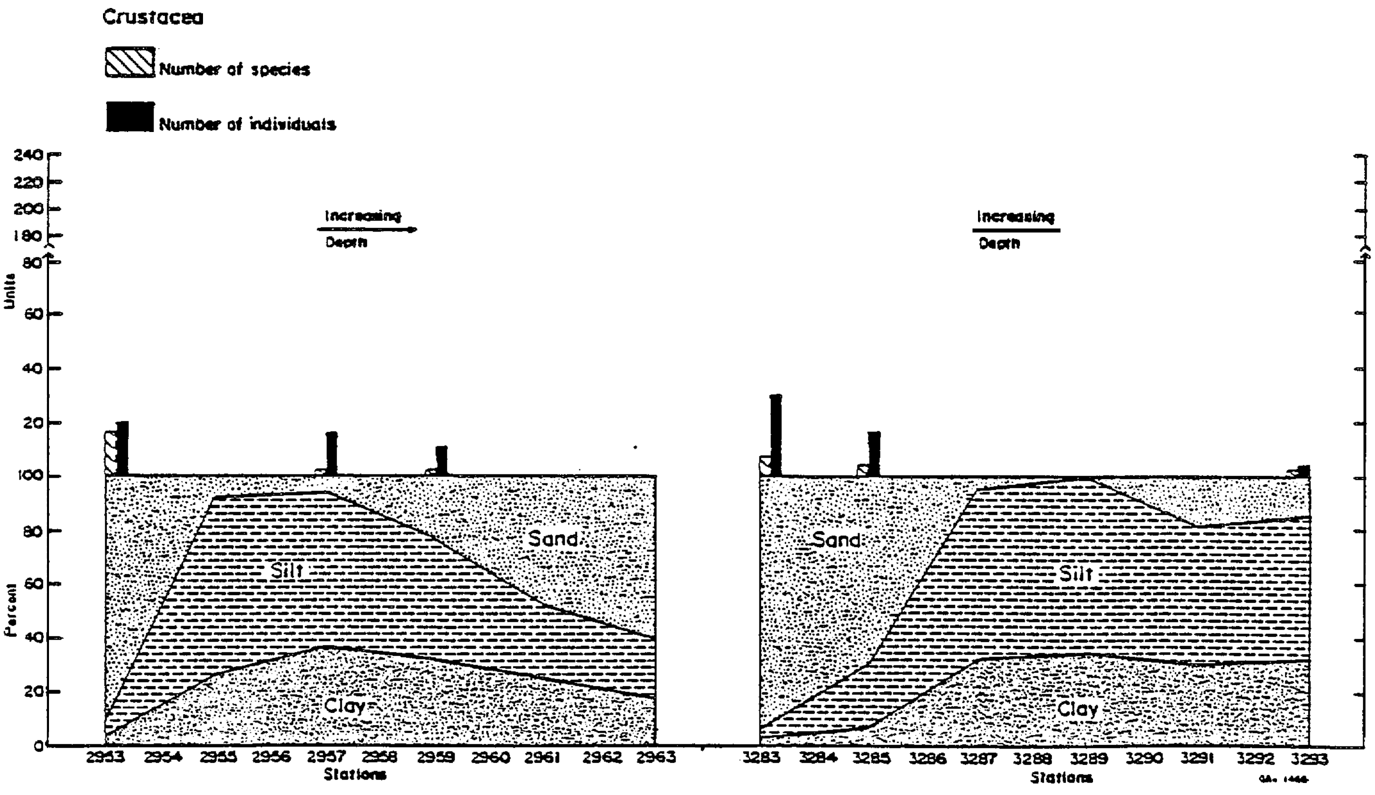


Figure 37. Crustacean distribution along two inner shelf tran[illegible]. No crustaceans were found at statons 2961, 2963, 3287, 3289, and 3291.

counts tend to decrease with increasing depth until at stations 9 or 11 mi offshore (14.4 or 17.6 km), species and individual counts may increase. Percent sand values at stations 9 and 11 mi (14.4 and 17.6 km) offshore are higher than at shallower stations, 5 and 7 mi (8.0 and 11.2 km) off shore. The numbers of crustacea from 5 to 11 mi (8.0 to 17.6 km) offshore are generally very low and only at station 3293, 11 mi (17.6 km)offshore, do they increase slightly (fig. 37). Numbers of mollusks on both transects are also low from 5to 11 mi(8.0 to 17.6 km) offshore and only increase at station 3291, 9 mi (14.4 km) offshore (fig. 35).

Total species counts and diversity indices shown on plate V also reflect sediment-faunal relationships. Highest total species numbers are generally found at stations south of Bolivar Roads and from 1 to 3 mi (1.6 to 4.8 km) offshore. Most of these nearshore stations have substrates of greater than 80 percent sand and from 6 to 47 species. However, several stations farther off shore than 3 mi (4.8 km) also have high species counts. For example, stations 3135, 3199, and 3427 occur 6 to 8 mi (9.6 to 12.8 km) offshore and have 30 to 33 species. Substrates at these stations range from 26 to 84 percent sand.

Diversity values (H') tend to be high at the nearshore, sand stations (pi. V). All but one of the stations occurring 1 mi (1.6 km) offshore have indices greater than 2.000. However, diversity values are not always highest at the nearshore, sandier stations; many stations farther offshore with muddy substrates also have high values.

In the bays, the correlation between percent sand and species number is lower than on the inner shelf. Scattergrams comparing species number with percent sand show a very broad scatter in both muddy and sandy sediments (figs. 30 to 33).

Stations with greater than 10 percent gravel (shell) generally have high species counts. Of the eight stations with greater than 10 percent shell, 6 occurred in lower Galveston Bay, one in West Bay and one in East Bay. Total species counts at the shelly stations in West and East Bays were the highest in those two respective bays.

Most stations in upper Galveston and Trinity Bays with both muddy and sandy sediments have few (1 to 3) or no species (pi. V). Other enviental factors such as salinity and temperature probably play a more important role than sediment in determining species distribution. Benthic populations in upper Galveston and Trinity Bays are probably subjected to greater stress from natural fluctuations in salinity than other parts of the Galveston Bay system. Holland and others (1973) found that the benthic community in Trinity Bay was highly stressed probably due to natural causes such as salinity changes.

High species counts in West Bay arid lower Galveston Bay generally occur at stations with sand or muddy sand near San Luis Pass and Bolivar Roads (pi. V). Also, as mentioned previously stations with high shell content (>10 percent), such as station 44 in lower Galveston Bay and station 15 in West Bay, also have high species counts.

Many of the assemblages depicted on the Distribution of Wetlands and Benthic Macroinvertebrates Assemblages map (pi. V) also reflect the dependency of benthic invertebrate species on particular substrates. The assemblages often closely follow sediment trends. Characteristic species are generally closely associated with a particular sediment type. A more detailed discussion of sediment and assemblage relationships can be found in the macroinvertebrate assemblage section.

Sediment size and TOC (total organic carbon) are closely correlated (fig. 13), muds usually contain more TOC than do sands. This relationship between organic carbon content and sediment texture influences the distribution of benthic macroinvertebrates (Purdy, 1964). Deposit feeders (invertebrates that feed on bottom deposits of nonliving organic detritus and associated microorganisms) are most often found in bay-center muds and deeper, muddy stations on the inner shelf. Suspension feeders (invertebrates that feed on microorganisms in surrounding waters) are more abundant in bay-margin sands and shallow (less than 48 ft or 14.6 m deep), sandy (60 to 100 percent sand) stations on the inner shelf.

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).

Holland and others, 1973, studied the structure of the benthic community in the Galveston Bay system to ascertain water quality. They applied various diversity indices, including the Shannon-Weaver (H') index, to data collected during four sampling periods in 1971 and 1972 at 5 stations in the Galveston Bay system. Two stations were located in the upper bay regions, one near the Houston Ship Channel and the Clear Lake region and the other in Trinity Bay. The three stations located in the lower bay were in the middle of West Bay, near the Texas City Ship Channel, and another in East Bay.

Holland and others, 1973, found that three of the stations were areas of “normal estuarine stress.” Normal estuarine stress was defined as stations with H’ values of macrobenthic communities above 2.0. The stations with normal stress were in upper Galveston Bay near Clear Lake, in East Bay, and in mid--West Bay. The stations in Trinity Bay and near the Texas City Ship Channel showed evidence of large amounts of stress. Holland and others, 1973, concluded that the Trinity Bay station was probably stressed due to natural causes, primarily salinity fluctuations and that the Texas City Ship Channel site showed intermittent stress possibly due to “man-made pollution."

Caution should be used in making interpretations from the diversity index, (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'=0.000- 1.499), medium (H’= 1.500- 1.999), high (H'=2.000-2.499), and very high (H'-2.500 and greater) diversity. These groupings are color coded on the Distribution of Wetlands and Benthic Macroinvertebrates Map (pi. V). In the text, any mention of “high diversity,” or other grouping, will be referring to that particular subjective classification.

Bay-Estuary-Lagoon System

Most of Galveston Bay exhibited low to moderate diversity values. The only high to very high values occurred in lower Galveston Bay at 6 stations between the Texas City Ship Channel and Galveston Island, at stations 44 and 70 near the Houston Ship Channel, and at station 144 near Hanna Reef. Station 44 with 31 percent sand and 66 percent gravel had the highest index, 2.556. Trinity Bay had the lowest median diversity 0.860 of any bay in the map area. All but one station in Trinity Bay had low indices. Station 442 with an index of 1.771 had the highest value in Trinity Bay.

Diversity in East Bay was low to moderate. Only station 222 had a high value.

West Bay had the highest median diversity of the bays in the map area (fig. 38). Most of West Bay had moderate to high values. Indices in the southern part of West Bay and in Bastrop and Christmas Bays were generally high.

Inner Shelf

Diversity indices on the inner shelf were generally high to very high with a median H' value of 2.293 (fig. 38). Low values occurred at only 8 of the 80 examined stations (10 percent). Most nearshore, sandy stations had high to very high values. Of the stations occurring only 1 mi (1.6 km) off shore, only stations 2909 and 3327 had H' values of less than 2.000. Three stations, 3129, 3195, and 3427 had H' values of greater than 3.000. Stations 3129 and 3195 were in sediments of greater than 80 percent sand. Station 3427 with 40 to 60 percent sand had the highest H' value, 3.066. However, high H' values were not restricted to the nearshore, sandy stations, as all but three stations occurring 11 mi (17.6 km) offshore had high to very high values.

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

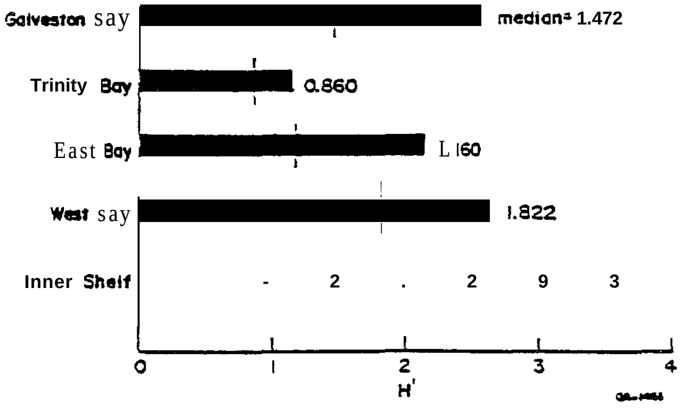


Figure 38. Range and median values of diversity (H') for macroinvertebrates in the bays and on the inner shelf.

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 y 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 (Cliff ord 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 Galveston-Houston 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 (pi. 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 13 lists number of species and individuals and some physical characteristics for each assemblage. A listing of the characteristic species is given in table 14.

Bay-Estuary-Lagoon System

The six assemblages mapped in the bays are open bay center, oyster reef, grassflat, bay margin, inlet-influenced, and river-influenced assemblage. Many assemblages retain the same name in different systems, but faunal content varies.

Cluster analysis of data from stations in the bay systems in the Galveston-Houston 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 hydrographic variability y in the bays. Many species occur in a majority of the assemblages, as well as in each bay system.

DRAFT

‘I’able 13. Characteristics of benthic faunal assemblages in the Galveston-Houston area.

Assemblage	Total number of stations	Average number of		Average percent sand per station	Approximate depth range ft(m)		Range in diversity (H')
		species per station	individuals per station				
Galveston-Trinity-East Bays							
Oyster reef	7	10.3	42.0	44.1	2-11	(0.6-3.4)	1.15-2.23
River influenced	76	3.5	13.7	35.7	2-12	(0.6-3.7)	0.00-2.15
Open bay center	19	5.4	11.7	35.1	5-11	(1.5-3.4)	0.00-2.00
Bay margin	12	6.6	18.1	77.6	2-5	(0.6-1.5)	0.56-2.49
Inlet influenced	20	9.9	23.6	59.2	4-19	(1.2-5.8)	0.58-2.56
West Bay							
Oyster reef	1	9.0	23.0	21.3	1	(0.3)	2.17
Grassflat	1	24.0	290.0	30.0	1	(0.3)	2.39
River influenced	5	5.0	14.0	55.0	3-13	(0.9-4.0)	0.00-1.59
Open bay center	5	12.0	74. (J	47.7	6-8	(1.8-2.4)	0.57-2.42
Bay margin	16	15.0	113.0	72.9	2-8	(0.6-2.4)	0.90-2.45
Inlet influenced	14	16.0	%7.0	65.3	2-7	(0.6-2.1)	0.76-2.62
Inner Shelf							
Nearshore	12	25.0	130.2	86.5	18-36	(5.5-11.0)	1.45-3.02
Transitional	27	12.9	32.7	33.5	18-60+	(5.5-18.3)	1.40-2.99
Outer	40	14.4	41.6	33. i	30-60+	(9.1-18.3)	0.88-3.07

Table 14. Characteristic species in macroinvertebrate assemblages of the Galveston-Houston area.

Bay-Estuary-Lagoon
Galveston-Trinity-East Bays

- River Influenced
  - Mollusca
    - Bivalvia
      - *Mulinia lateralis*
      - *Macoma mitchelli*
      - *Rangia flexuosa*
    - Gastropoda
      - *Texadina sphinctostoma*
      - *Vioscalba louisianae*
      - *Texadina barretti*
  - Polychaeta
    - *Parandalia fauveli*
    - *Streblospio benedicti*
    - *Capitella capitata*
    - *Mediomastus californiensis*
    - *Polydora ligni*
  - Crustacea
    - *Corophium louisianum*

- Inlet Influenced
  - Mollusca
    - Bivalvia
      - *Mulinia lateralis*
      - *Lyonsia hyalina floridana*
      - *Tellina texana*
    - Gastropoda
      - *Turbonilla* cf. *interrupta*
      - *Nassarius acutus*
  - Polychaeta
    - *Owenia fusiformis*
    - *Apoprionospio pygmaea*
    - *Onuphis eremita oculata*

- Bay Margin
  - Mollusca
    - Bivalvia
      - *Amygdalum papyria*
  - Polychaeta
    - *Streblospio benedicti*
    - *Paraprionospio pinnata*
    - *Tharyx marioni*
    - *Owenia fusiformis*

Table 14. (cont.)

- Crustacea
    - *Oxyurostylis salinoi*
    - *Monoculodes nyei*
    - *Cerapus tubularis*
    - *Leptochelia rapax*

Open Bay Center

- Mollusca
    - Bivalvia
        - *Mulinia lateralis*
- Polychaeta
    - *Paraprionospio pinnata*
    - *Pseudeurythoe ambigua* (East Bay)
    - *Parandalia fauveli*
    - *Sigambra* spp. (East Bay)
- Crustacea
    - *Acetes americanus*

Oyster Reef

- Mollusca
    - Gastropoda
        - *Odostomia impressa*
        - *Texadina sphinctostoma*
    - Bivalvia
        - *Crassostrea virginica*
        - *Ischadium recurvum*
        - *Brachidontes exustus*
        - Mulinia lateralis
- Polychaeta
    - *Nereis succinea*
    - *Polydora ligni*
    - *Mediomastus californiensis*
    - *Streblospio benedicti*
    - *Parandalia fauveli*
- Crustacea
    - *Melita nitida*
    - *Rithropanopeus harrisii*
    - *Cassidinidea lunifrons*

West Bay (including Christmas, Bastrop, Chocolate Bays)

Grassflat

- Mollusca
    - Bivalvia
        - *Amygdalum papyrium*
        - *Laevicardium mortoni*

Table 14. (cont.)

- Polychaeta
  - *Chone duneri*
  - *Nereis succinea*
  - *Streblospio benedicti*
- Crustacea
  - *Ampelisca abdita*
  - *Edotea montosa*
  - *Cerapus tubularis*
  - *Listriella* sp.

Oyster Reef
- Mollusca
  - Bivalvia
    - *Crassostrea virginica*
    - *Ischadium recurvum*
- Polychaeta
  - *Nereis succinea*
- Crustacea
  - *Grandidierella bonnieroides*
  - *Oxyurostylis salinoi*
  - *Rithropanopeus harrisii*

River Influenced
- Mollusca
  - Gastropoda
    - *Texadina barretti*
  - Bivalvia
    - *Macoma mitchelli*
    - *Mulinia lateralis*
- Polychaeta
  - *Parandalia fauveli*
  - *Haploscoloplos fragilis*
  - *Paraprionospio pinnata*
  - *Glycinde solitaria*

Open Bay Center
- Mollusca
  - Bivalvia
    - *Mulinia lateralis*
    - *Mysella planulata*
    - *Lyonsia hyalina floridana*
- Polychaeta
  - *Paraprionospio pinnata*
  - *Gyptis brevipalpa*
  - *Cossura delta*
  - *Mediomastus californiensis*
  - *Melinna maculata*

Table 14. (cont.)

- Inlet Influenced
  - Mollusca
    - Gastropod
      - Turbonilla cf. interrupta
      - Acteocina canaliculata
    - Bivalvia
      - Mulinia lateralis
      - Periploma margaritaceum
      - Mysella planulata
      - Lyonsia hyalina floridana
  - Polychaeta
    - J?araprionospio pinnata
    - Clymenella torquata
    - Owenia fusiformis
    - Mediomastus californiensis
  - Crustacea
    - Ampelisca brevisimulata

- Bay Margin
  - Mollusca
    - Gastropoda
      - Acteocina canaliculata
      - Acteon punctostriatus
    - Bivalvia
      - Mulinia lateralis
      - Ensis minor
  - Polychaeta Lyonsia hyalina floridana
    - Mediomastus californiensis
  - Crustacea
    - Ampelisca abdita
    - Ampelisca brevisimulata
    - Oxyurostylis salinoi

- Inner Shelf
- Nearshore
  - Mollusca
    - Bivalvia
      - Tellina versicolor
    - Gastropod
      - Nassarius acutus
      - Natica pusilla
  - Polychaeta
    - Mediomastus californiensis
    - Onuphis eremita oculata
    - Loimia medusa
    - Spiophanes bombyx

DRAFT

Table 14. (cont.)

      - *Chone duneri*
      - *Magelona* cf. *phyllisae*
      - *Apoprionospio pygmaea*
  - Crustacea
      - *Oxyurostylis salinoi*

- Transitional
  - Mollusca
    - Bivalvia
      - *Nuculana concentric*
    - Gastropod
      - *Natica pusilla*
  - Polychaeta
      - *Ninoe nigripes*
      - *Cossura delta*
      - *Magelona* cf. *phyllisae*
      - *Paraprionospio pinnata*

- Outer
  - Mollusca
    - Bivalvia
      - *Nuculana concentric*
    - Gastropoda
      - *Vitrinella floridana*
      - *Volvulella texasiana*
  - Polychaeta
      - *Ninoe nigripes*
      - *Asychis carolinae*
      - *Diopatra cuprea*
      - *Clymenella torquata*
      - *Paraprionospio pinnata*
      - *Magelona* cf. *phyllisae*
      - *Armandia maculata*
  - Crustacea
      - *Ampelisca agassizi*
      - *Pilumnus* sp.
      - *Automate evermanni*
      - *Pinnixa sayana*

Galveston-Trinity-East Bay

The Galveston-Trinity-East Bay complex has five of the six designated bay assemblages; only the grassflat assemblage is not present. The river-influenced assemblage has the greatest area, covering all of Trinity Bay, upper Galveston Bay, and part of East Bay. It also covers Tabbs Bay, Clear Lake, Moses Lake, Dickinson Bay and Buffalo Bayou. The oyster reef stations occur primarily in mid-Galveston Bay, and virtually divide Galveston Bay into an upper and lower section. Lower Galveston Bay contains primarily an inlet-influenced and an open bay center assemblage. Bay margin stations occur primarily on the bayside of Bolivar Peninsula and along the bay margins near Texas City.

The river-influenced assemblage contains a group of ubiquitous bay species, including *Mulinia lateralis, Capitella capitata, Streblospio benedicti,* and *Mediomastus californiensis,* and brackish water species such as *Macoma mitchelli, Texadina sphinctostoma,* and *Rangia flexuosa,* that occur in parts of estuaries where salinities range from fresh to brackish over extended periods of time. The river-influenced assemblage is subjected to greater natural saline fluctuations than other bay assemblages, and the community is probably highly stressed (Holland and others, 19-73). Diversity indices are low (pi. V) and the average number of species per station is the lowest of the 5 bay assemblages (table 13).

In contrast to the river-influenced assemblage, stations containing an inlet-influenced assemblage have moderate to high diversities. Most of the high to very high diversity values in the Galveston-Trinity-East Bay complex are. found at stations with the inlet-influenced assemblage. This assemblage, composed primarily of mollusks, contains some species that are restricted to the area near Bolivar Roads and Rollover Pass, although many are also found inhabiting the inner shelf. More stable salinities may be the reason for higher diversity values than at stations containing the other bay assemblages. Sediment type is more variable than the predominantly muddy sediments in Trinity and upper Galveston Bay.

Stations containing an oyster reef assemblage are primarily on or near previously mapped reefs. Station 10, on the bay margin near West Bay, is the only station with no previously mapped reef nearby. The oyster reef assemblage is probably more extensive than is shown on the assemblage map (pi. V), but the sampling techniques used in this study did not allow further delineation of the reefs. The oyster reef assemblage is dominated by the mollusks *Crassostrea virginica*, *Ischadium recurvum*, *Brachidontes exustus*, and *Mulinia lateralis*. The ubiquitous polychaetes *Mediomastus californiensis* and *Streblospio benedicti* were also abundant. The oyster reef assemblage has the highest species and individual averages per station (table 13) of the five bay assemblages.

The bay margin assemblage is limited to shallow, sandy stations in lower Galveston and East Bays. Most stations are less than 1 mi (1.6 km) offshore and less than 4 ft (1.2 m) deep. Crustaceans are more abundant in the bay margin assemblage than in the others.

The open bay center assemblage is in lower Galveston Bay and East Bay. Polychaetes are the predominant group. Species and individual averages per station are low but not as low as the open bay center depauperate assemblage in Corpus Christi Bay (White and others, 1983). Most open bay center stations are muddy and relatively deep (table 13).

Parker's (1960) river-influenced, oyster reef, and open bay margin assemblages have similar distributions to the river-influenced, bay margin and oyster reef assemblages in this study. Most characteristic species (primarily mollusks in Parkerts assemblages) found in the two studies are different except for a few species occurring in the river-influenced assemblages and *Crassostrea virginica* and *Ischadium recurvum* in the oyster reef assemblages. Molluscan species present in both river-influenced assemblages include *Macoma mitchelli*, *Rangia flexuosa*, and *Littoridina sphinctostoma=Texadina sphinctostoma*.

The enclosed bay, inter-reef assemblage in Parker's study includes all of East Bay and most of the middle and upper parts of Galveston Bay. This assemblage generally corresponds to the distribution of the open bay center assemblage in this study except that the open bay center assemblage does not extend into upper Galveston Bay. The only characteristic species these two assemblages have in common is *Mulinia lateralis*.

The areal distribution of Parker's inlet and open bay center assemblages is close to the distribution of the inlet-influenced assemblage in this study. Only two molluscan species, *Nassarius acutus* and *Mulinia lateralis*, are in the inlet-influenced assemblage and in Parker's open bay center assemblage.

West Bay (including Chocolate, Christmas, and Bastrop Bays)

The West Bay area, including Chocolate, Christmas, and Bastrop Bays has all 6 of the designated bay assemblages. However, only three assemblages, an inlet-influenced, open bay center, and bay margin assemblage, occur in West Bay. All of Chocolate Bay contains a river-influenced, low-salinity assemblage and an oyster reef and grassflat assemblage occurs at only one station each in Bastrop and Christmas Bays.

A bay center assemblage is found primarily at the muddier, deeper parts of West Bay. Bivalves and polychaetes were dominant. Species and individual averages (table 13) are low.

In contrast to the bay center assemblage, stations having an inlet-influenced assemblage are sandy and have high species diversity. This assemblage occurs at the north and south end of West Bay near San Luis Pass and Bolivar Roads. The inlet-influenced assemblage contains species found on the inner shelf and in the bay near the tidal inlets. It also contains a ubiquitous group including *Mulinia lateralis, Acteocina canaliculata*, and *Paraprionospio pinnata*.

The shallow bay margin assemblage occurs in West Bay, Bastrop, Christmas Bays and is primarily characterized by mollusks and crustaceans. Only one polychaete, *Mediomastus californiensis*, is predominant.

Station 126 in Christmas Bay is the only station in the Galveston-Houston area with a grassflat assemblage. Generally, species occurring at this station are typical of other grassflat assemblages on the Texas coast (White and others, 1983) except for the small number of gastropod present. Crustacea are dominant.

An oyster reef assemblage is found only at station 122 in Bastrop Bay. An extensive oyster reef, Carancahua reef, almost splits West Bay in half; however, no stations were examined from on or near this reef.

A river-influenced assemblage is found at all stations in Chocolate Bay. Species occurring in this assemblage are primarily brackish water species, such as *Macoma mitchelli, Texadina barretti,* and *Parandalia fauveli* and the ubiquitous *Mulinia lateralis, Paraprionospio pinnata,* and *Glycinde solitaria.*

According to Parker (1960), most of West Bay contains either an open bay center or enclosed bay center assemblage. The enclosed bay center assemblage also includes all of Chocolate Bay. A bay margin and inlet assemblage are also present in Parker's study; however, their areal distribution is less than the same assemblages in this study.

Inner Shelf

Cluster analysis separated the inner-shelf fauna into three assemblages: a nearshore assemblage, characterized by shallow bathymetry and high sand substrates; a transitional assemblage with species that are present in both the nearshore and outer assemblage; and an outer assemblage characterized by a high number of polychaete species. Polychaetes were dominant in all assemblages. Characteristic species for each of these assemblages are shown in table 14.

The relationship between sediment type and assemblage distribution on the Galveston-Houston inner shelf is more complex than in the Corpus Christi area. On the Corpus Christi inner shelf, grain size typically decreases offshore and passes gradationally from sand through muddy sand and sandy mud to mud (McGowen and Morton, 1979). Assemblage boundaries generally followed the gradational trend with the nearshore assemblage restricted to the sands (average of 88 percent sand), the transitional assemblage in mixed sediment (average of 51 percent sand), and an outer assemblage in muds (average of 18 percent sand) (White and others, 1983).

Mud and sandy mud are much more predominant in the Galveston-Houston area than in the Corpus Christi area. Sand is generally limited to stations 1 to 2 mi (1.6 to 3.2 km) offshore; the greatest extent of sand is associated with the ebb-tidal deltas at Bolivar Roads and San Luis Pass. The nearshore assemblage boundary generally corresponds to the sand trend.

Grain size decreases offshore in the Galveston-Houston area, but the decrease is generally not as gradual as on the Corpus Christi inner shelf. Therefore, the transitional assemblage boundaries, especially the boundary between the transitional and offshore assemblage, is not as well defined as in the Corpus Christi area. The average percent sand for stations in the transitional and the offshore assemblages is nearly the same, although the transitional assemblage includes stations with a wider range in percent sand values than in the offshore assemblage.

Nearshore Assemblage

The nearshore assemblage extends from the southern edge of the map area to Bolivar Roads, and primarily includes stations 1 mi (1.6 km) offshore in sandy sediment. Nearshore assemblage stations are generally shallow with a maximum depth of 36 ft (10.9 m). Sediment composition for the 12 nearshore assemblage stations ranges from 70 to 95 percent sand.

Average number of species and individuals per station (table 13) is highest in the nearshore assemblage than for stations in the other two assemblages. Although polychaetes are dominant, mollusks are also abundant.

Most of the characteristic species listed in Harper's (1970) sandy bottom community, in Defenbaugh's (1976) inner shelf assemblage, and in Parker's (1960) inner shelf zone were not abundant in the nearshore assemblage. *Onuphis eremita oculata* was the only species occurring in the nearshore assemblage and both Defenbaugh's and Harper's communities. Differences in sampling techniques areal coverage, and density of sampling account for most of the assemblage differences.

Nassarius acutus, an abundant gastropod species in the nearshore assemblage, was the most abundant species in Harper's study area, although it was not restricted to a particular bottom type and thus not a characteristic species in any of Harper's assemblage. Defenbaugh listed *N. acutus* in his inner shelf assemblage. Parker (1960) said *N. acutus* was characteristic of the pro-delta slope and the open bay center assemblages where muddy sediments were predominant. In this study, *N. acutus* also occurs at muddy stations in the transitional and off shore assemblages, but it is abundant at sandy nearshore stations. Although *N. acutus* is not the most abundant mollusk on the inner shelf, it is the most abundant gastropod. It is also a characteristic species of the inlet-influenced assemblage in Galveston Bay.

Transitional Assemblage

The transitional assemblage is primarily limited to the northern and southern parts of the inner shelf. Except for six scattered stations, there is no transitional assemblage from San Luis Pass to Bolivar Roads. North of Bolivar Roads, the transitional assemblage replaces the nearshore assemblage, occurring at stations 1 mi (1.6 km) offshore and covering a fairly broad area from 4 to 7 mi (6.4 to 11.2 km) wide. From the southern edge of the map area to just north of San Luis Pass, the transitional assemblage is primarily between the nearshore and outer assemblage at stations from 2 to 7 mi (3.2 to 11.2 km) offshore.

Many of the transitional assemblage species occur either in “the outer or nearshore assemblages. The only species almost totally restricted to the transitional assemblage is the polychaete, *Cossura delta.* There are no characteristic crustaceans in this assemblage. Species and individual “averages per station are the lowest of the three assemblages. Sediment type at transitional assemblage stations is generally mixed with percent sand values ranging from 0.7 to 83.6 percent (average of 33.5 percent).

Only one species, *Terebra protexta*, characterized Harper's (1970) mixed bottom community. Other species present in this assemblage but not as abundant as *T. protexta* include *Abra aequalis*, *Corbula caribaea*, and *Acteon punctostriatus.* In the present study, only two specimens of *T. protexta* are present on the inner shelf.

Outer Assemblage

The outer assemblage covers a greater area than the other two inner-shelf assemblages. Most of the stations near the outer boundary of the study area contain an outer assemblage. In the northern and southern parts of the inner shelf, the outer assemblage extends from the transitional assemblage boundary to the limit of the study area, approximately 11 mi (17.6 km] from shore. However, from San Luis Pass to Bolivar Roads, the outer assemblage extends from the nearshore assemblage boundary to the outer limit of the study area and is approximately 9 to 10 mi (14.4 to 16 km) wide.

The average percent sand for stations in the outer assemblage is 33 percent, similar to the average for stations in the transitional assemblage. Polychaetes, especially *Magelona* cf. *phyllisae* and *Paraprionospio pinnata*, and the crustacean *Ampelisca agassizi* are dominant in this assemblage.

Dominant species in Harper's (1970) muddy bottom community include *Diopatra cuprea* and *Nuculana concentric*. Both species characterized the outer assemblage in this study. *Nuculana concentric* is also abundant in the transitional assemblage. All individuals of *N. concentric* are found in the range of 0 to 60 percent sand, with most individuals occurring in 0 to 20 percent sand.

Summary

The following significant findings resulted from this baseline study:

(1) Species distribution

(a) Polychaetes were dominant in both the bays and on the inner shelf.

(b) Highest total species counts in the bays occurred at stations near San Luis Pass and Bolivar Roads.

(c) Species counts on the inner shelf were generally highest in a depth range of 12 to 36 ft (3.6 to 11.0 m).

(2) Substrate-species relationships

(a) In general, on the inner shelf there is a positive correlation between number of species and percent sand. Stations with higher percentages of sand generally had more benthic species.

(b) Highest total species numbers were generally found at inner shelf stations south of Bolivar Roads and from 1 to 3 mi (1.6 to 4.8 km) offshore.

(c) In the bays, the correlation between percent sand and species number is lower than on the inner shelf.

(d) Bay stations with greater than 10 percent gravel (shell) generally have high species counts.

(3) Species diversity

(a) Most bay stations exhibited low to moderate diversity (H') values. High to very high values occurred in parts of lower Galveston Bay and in West Bay. West Bay had the highest median diversity of the bays in the study area.

(b) Diversity indices (H') on the inner shelf were generally high to very high. Low values occurred at only 10 percent of the stations.

(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 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 grass. flats, 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.

The wetland units described and mapped in this report (table 15) 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.

A major departure in this classification from that of the earlier atlas 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 determine 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

Table 15. Wetlands and associated environments,
Galveston-Houston 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
- Grass flats
- Salt-water marshes
  - Proximal marsh
  - Proximal marsh/open water, undifferentiated
  - Distal marsh
- Fresh- to brackish-water marshes
  - Low marsh
  - High marsh
- Fresh-water marshes
  - Low marsh
  - High marsh
- Sand or mud flats/marshes, undifferentiated
- Wetland/upland areas, undifferentiated
- Transitional areas
- Woodlands in fluvial areas and in poorly drained depressions
- Swamps

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) salt-water marsh and open water, undifferentiated -- used to map areas where open water is a significant component (as much as 50% or more) of a salt-water marsh, (3) wetland/upland area% undifferentiated--used to designate complex, difficult-to-separate mixtures of wetland and upland areas; and (4) 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 16. One change involves depicting wetlands that have developed on dredged spoil, rather than designating these areas as simply spoil.

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 northeast corner of the map area (primarily the Trinity River Valley), CIR-Stereoscopic photographs with a scale of 1:58,000, taken in 1981 by the National High Altitude Photography Program were used. Both series of photographs are comparable in most respects. The 1979 photographs were taken in November, and the 1982 photographs in January.

Table 16.. Comparison of wetlands classified in this report with those classified in the Environmental Geologic Atlas of the Texas Coastal Zone, Galveston-Houston area (Fisher and others, 1972). The X's indicate those units that are similar in characteristics or that encompass similar map areas.

DRAFT

CLASSIFICATION OF WETLANDS AND ASSOCIATED MAP UNITS DEFINED AND MAPPED IN THIS REPORT	CLASSIFICATION OF WETLANDS FROM ENVIRONMENTAL GEOLOGIC ATLAS ENVIRONMENTS AND BIOLOGIC ASSEMBLAGES MAP (From Fisher and others, 1972)															
	Beach	Washover channel and fan	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	Brackish-water marsh, closed system	Inland fresh-water marsh	Swamp	Frequently flooded fluvial areas	Fluvial woodlands	Poorly drained depressions	Subaqueous and subaerial spoil
Beaches	X															
Washover areas		X	X													
Sand flats, wind-tidal			X													X
Sand flats, high wind-tidal, includes barren fluvial-channel margins and bars			X			X										X
Shallow subaqueous flats, tidal pools. inland reservoirs and ponds. and natural ana navigation channels			X	X												
Beaches and berms					X	X										
Grassflats							X									X
Salt-water marshes																
Proximal marsh								X	X							X
Proximal marsh/open water, undifferentiated								X								X
Distal marsh								X	X							X
Fresh- to brackish-water marshes																
Low marsh								X	X	X						
High marsh					X			X	X							
Fresh-water marshes																
Low marsh											X					
Hiah marsh											X		X		X	
Sand or mud flats/marshes, undifferentiated			X					X								X
Wetland/upland areas, undifferentiated																
Transitional areas					X								X		X	
Woodlands in fluvial areaa and in poorly drained depressions												X		X	X	
												X				

In this report emphasis is placed on vegetative communities and 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 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, as recorded at a single tide gage in Trinity Bay, were more than 2.5 ft (0.75 m) above normal on the days the photographs were taken (Mary Johnson, U.S. Army Corps of Engineers, personal communication, 1984). 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 & 8). Both of

DRAFT

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 fresh- to 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).

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 (fig. 9). 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 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.

DRAFT

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 flats capped by algal mats and evaporite deposits along the lower coast (for example, in the Brownsville-Harlingen area).

Wetlands in the Galveston-Houston Area

Mapped Wetland Environments

Nineteen wetland environments are delineated within the Galveston-Houston area (pl. V, table 15). 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. Typical plants found in various wetland environments are listed in table 17.

Beaches

Gulf beaches lie between the Gulf shoreline and the edge of fore-island dunes in the Galveston-Houston 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, 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 arenas, 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 patens*, *Spartina spartinae*, *Ipomoea* spp. and *Croton punctatus* occur. Active (barren) washover areas have a very limited distribution in the Galveston-Houston 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

Table 17. Typical plants found in wetland environments mapped in the Galveston-Houston area. List compiled from field work and with reference to Adams and Tingley (1977), Benton and others (1979), Correll and Correll (1975), Fisher and others (1972), Fleetwood (undated), Hotchkiss (1970), Rice Center for Community Design and Research (1974), and White and others (1978).

ENVIRONMENT	SCIENTIFIC NAME	COMMON NAME
GRASSFLAT (subaqueous marine grasses)	Halodule beaudettei	shoalgrass
	Ruppia maritima	wigeongrass
	Thalassia testudinum	turtlegrass
SALT-WATER MARSH	Spartina alterniflora	smooth cordgrass
	Batis maritima	saltwort
	Salicornia virginica	glasswort
	Salicornia bigelovii	glasswort
	Distichlis spicata	seashore saltgrass
	Borrichia frutescent	sea ox-eye
	Monanthochloe littorals	shoregrass
	Juncus roemerianus	needle rush
	Suaeda sp.	seablite
	Lycium carolinianum	Carolina wolf berry
	Spartina spartinae	gulf cordgrass
	Spartina patens	marshhay cordgrass
	Iva frutescent	bigleaf sumpweed
	Iva angustifolia	sumpweed
	Limonium nashii	sea lavender
	Scirpus maritimus	salt-marsh bulrush
	Sporobolus spp.	dropseed
	Sesuvium portulacastrum	sea purslane
	Heliotropism curassavicum	heliotrope

Table 17. (cont.)

ENVIRONMENT	SCIENTIFIC NAME	COMMON NAME
FRESH- TO BRACKISH WATER MARSH	*Spartina spartinae*	gulf cordgrass
	Spartina patens	marshhay cordgrass
	Borrichia frutescent	sea ox-eye
	Distichlis spicata	seashore saltgrass
	Monanthochloe littorals	shoregrass
	Scirpus maritimus	salt marsh bulrush
	Scirpus americanus	three-square bulrush
	Scirpus californicus	California bulrush
	Scirpus olneyi	Olney bulrush
	Alternanthera philoxeroides	alligator weed
	Typha domingensis	tule
	Typha latifolia	common cattail
	Spartina cynosuroides	big cordgrass
	Phragmites australis	common reed
	Eleocharis parvula	dwarf spikerush
	Eleocharis spp.	spikerush
	Cyperus spp.	flatsedge
	Echinochloa crusgalli	barnyard grass
	Leptochloa spp.	sprangletop
	Bacopa monnieri	waterhyssop
	Aster tenuifolius	saline aster
	Aster subulatus	saltmarsh aster
	Aster spinosus	spiny aster
	Paspalum lividum	longtom
	Paspalum vaginatum	seashore paspalum
	Setaria geniculata	bristle grass
	Zizaniopsus miliacea	southern wildrice
	Solidago sempervirens	seaside goldenrod
	Baccharis halimifolia	groundsel bush
	Iva frutescent	bigleaf sumpweed
	Iva angustifolia	sumpweed
	Iva annua	seacoast sumpweed

Table 17. (cont.)

ENVIRONMENT	SCIENTIFIC NAME	COMMON NAME
FRESH- TO BRACKISH-WATER MARSH (cont.)	Sesuvium portulacastrum	sea purslane
	Salicornia spp.	glasswort
	Limonium nashii	sea lavender
	Lycium carolinianum	Carolina wolfberry
	Sporobolus spp.	dropseed
	Fimbristylis castanea	fimbry
	Hydrocotyle spp.	marsh pennywort
FRESH-WATER MARSH	Spartina spartinae	gulf cordgrass
	Typha latifolia	common cattail
	Typha domingensis	tule
	Scirpus americanus	three-square bulrush
	Scirpus californicus	California bulrush
	Paspalum lividum	longtom
	Eleocharis spp.	spikesedge
	Cyperus spp.	flatsedge
	Alternanthera philoxeroides	alligator weed
	Juncus spp.	rush
	Ludwigia spp.	seedbox
	Sagittaria spp.	arrowhead
	Pontedaria sp.	pickerel-weed
	Polygonum spp.	knotweed
	Phragmites australis	common reed
	Bacopa monnieri	waterhyssop
	Echinodorus spp.	burrhead
	Eichhornia crassipes	water hyacinth
	Rhynchosphora spp.	beakrush
	Fimbristylis spp.	fimbry
	Echinochloa crusgalli	barnyard grass
	Leptochloa spp.	sprangletop
	Spartina patens	marshhay cordgrass

Table 17. (cont.)

ENVIRONMENT	SCIENTIFIC NAME	COMMON NAME
FRESH-WATER MARSH (cont.)	Lemna spp.	duckweed
	Hydrocotyle spp.	marsh pennywort
	Zizaniopsus miliacea	southern wildrice
	Sesbania drummondii	rattlebush
	Baccharis halimifolia	groundsel bush
	Cephalanthus occidentals	buttonbush
	Salix nigra	black willow
TRANSITIONAL AREAS	Spartina spartinae	gulf cordgrass
	Cynodon dactylon	bermuda grass
	Borrichia frutescent	sea ox-eye
	Aster spinosus	spiny aster
	Paspalum monostachyum	gulfdune paspalum
	Paspalum lividum	longtom
	Panicum spp.	panicum
	Rynchospora spp.	beakrush
	Andropogon virginicus	broomsedge bluestem
	Andropogon glomeratus	bushy bluestem
	Iva annua	seacoast 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

Table 17. (cont.)

ENVIRONMENT	SCIENTIFIC NAME	COMMON NAME
FLUVIAL AND FLOOD PRONE WOODLANDS	Salix nigra	black willow
	Celtis spp.	hackberry/sugarberry
	Fraxinus spp.	ash
	Ulmus crassifolia	cedar elm
	Ulmus americana	american elm
	Quercus aquatica	water oak
	Quercus lyrata	overcup oak
	Quercus phellos	willow oak
	Quercus stellata	post oak
	Quercus virginiana	live oak
	Liquidambar styraciflua	sweetgum
	Ilex vomitoria	yaupon
	Cephalanthus occidentals	buttonbush
	Sapium sebiferum	chinese tallow
	Pinus taeda	loblolly pine
	Carya aquatica	water hickory
	Carya illinoinensis	pecan
	Populus deltoides	cottonwood
	Platanus occidentals	american sycamore
	Planera aquatica	water elm
	Acacia farnesiana	huisache
	Parkinsonia aculeata	retama
	Tamarix gallica	salt cedar
	Sabel minor	dwarf palmetto
	Taxodium distichum	bald cypress
	Acer negundo	boxelder
SWAMP	Taxodium distichum	bald cypress
	Planera aquatica	water elm
	Carya aquatica	water hickory
	Cephalanthus occidentals	buttonbush

have been mapped as marshes. For example, most of the fresh- to brackish-water marshes along the western half of Galveston Island occur in relict washover channels (pl. V). Washover channels that contain water, and washover fans that have become vegetated by marsh plants such as in back island areas of Galveston Island and Bolivar Peninsula are mapped accordingly, as water or marshes.

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

Shallow subaqueous flats were delineated (pi. 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 (pi. 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 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 algae mats. Flats mapped along river valleys are usually submerged less frequently by salt-water tides than by river flooding or precipitation. Locally, flats may have substrates containing more mud than sand and thus may be more accurately described as mud flats.

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 and locally muddy sand or shelly sand. These flats and the upland areas into which they grade are inundated during storms. Included within the higher sand-flat unit are barren fan deltas, which are flooded by storm tides, and fluvial channel deposits that include barren channel margins and bars occurring along rivers.

Wind-tidal flats are generally barren, because of intermittent salt-water flooding, pending, 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 (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,* and *Batis maritima*. Some tidal channels are fringed by *Spartina alterniflora* and locally by *Avicennia germinans.*

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 topographically higher features constructed by storm waves that pile up shell material at levels out of reach of the daily tides and waves. Only barren areas are included in this map unit. Where beaches and berms are low enough and are extensively vegetated with marsh plants, they are mapped as marshland.

Grassflats

The distribution of marine grasses (grassflats) was determined primarily from aerial photographs, but also 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 of limited distribution in the Galveston-Houston area and occur principally in patches along the margin of the Trinity delta, Follets Island, and Bolivar

Peninsula. Species occurring in grassflats along the Texas Coast include the following sperm atophytes: Halodule Beaudettei, Ruppia maritima, Thalassia testudinum, Halophila engelmannii, and Cymodocea filiformis. Ruppia maritima is predominant along the bay margins of the Trinity delta, where salinities are usually low; Halodule Beaudettei is apparently more abundant along the margins of the barrier islands (Fisher and others, 1972). More information on grassflats appears in the section on 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, fig. 39), from those areas less frequently flooded because of higher elevations and distal locations with respect to bay-estuarine water (distal salt-water marshes, fig. 40). Proximal salt-water marshes commonly contain one or more of the following species: Spartina alterniflora, Batis maritima, Salicornia virginica, Salicornia bigelovii, Distichlis spicata, Borrichia frutescent, Suaeda spp., Monanthochloe littorals, Juncus roemerianus, Lycium carolinianum, Iva frutescens and Aster sp. Many species grow in a range of elevations and therefore occur in both distal and proximal assemblages. Spartina alterniflora usually occurs only in the proximal community because its growth is limited to the intertidal zone. According to a study by Allan (1950), Spartina alterniflora has a tolerance to salinity in direct proportion to water depth. It is typically found in areas where the average water table is 4 inches above ground level (Allan, 1950).

Species typically present in the distal community include those listed for proximal areas, but the order and dominant type vary. Borrichia frutescens, Monanthochloe littorals, Distichlis

DRAFT

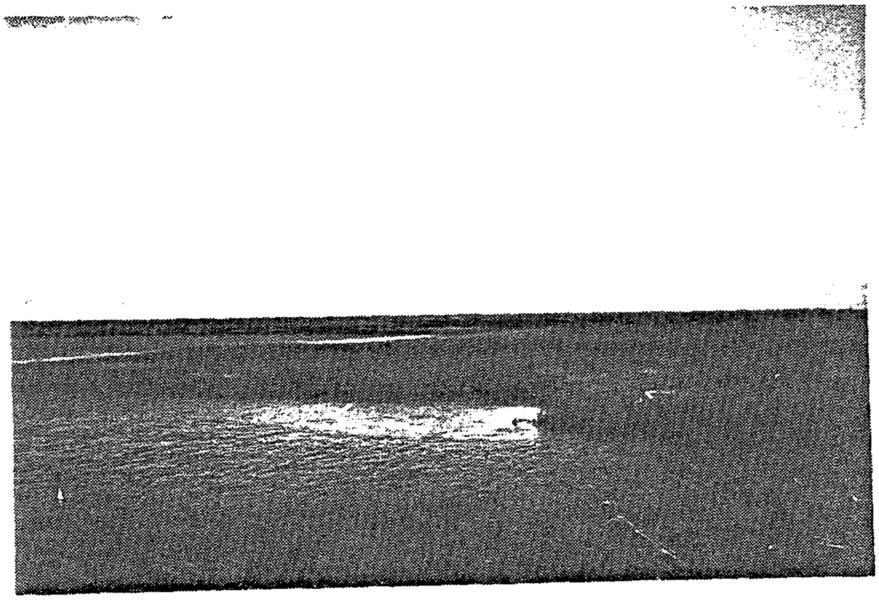


Figure 39. Proximal salt-water marsh on the bayward side of Galveston Island. *Spartina alterniflora* is abundant in this area.

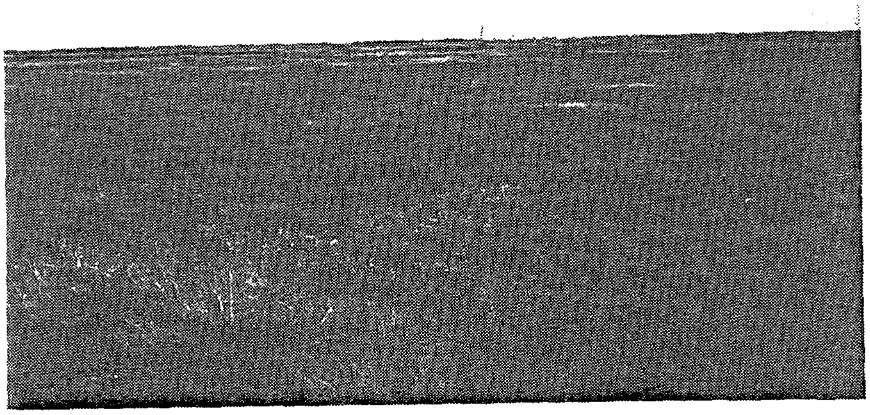


Figure 40. Distal salt-water marsh, Follets Island. Vegetation includes abundant *Monanthochloe littorals, Spartina patens* and other salt-water marsh species.

DRAFT

spicata, *Suaeda* spp., *Iva* sp., and *Aster* sp. 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 (table 17).

In addition to proximal and distal salt-water marshes, a third salt-water marsh unit is depicted on the wetlands map (pi. V)--proximal marsh and open water, undifferentiated. This unit encompasses complex mixtures of salt-water marsh vegetation and open water, where open water composes as much as 50 percent or more of the area. Marsh vegetation in such areas is predominantly *Spartina alterniflora*. One reason for delineating this marsh type as a separate map unit in the Galveston-Houston area, is that it appears to have evolved as a result of compactional subsidence (both natural and man-induced) and relative sea-level rise. Accordingly, there is reason to believe that most of these areas will eventually become areas of open water. Additional discussion in this regard is presented in the section on changes in wetland distribution, 1956-57 to 1979.

Fresh- to Brackish-Water Marshes

Fresh- to brackish-water marshes are transitional between the salt-water and fresh-water influenced environments. These areas are affected both by storm-tidal flooding from bay-lagoon or Gulf waters and by fresh-water inundation from rivers, precipitation and runoff, or ground water. Although the break between the salt, fresh to brackish, and fresh marsh is shown along distinct lines on the map, the boundary is actually gradational and its width may vary. Because the fresh- to brackish-water marsh unit encompasses a range in salinities from near fresh to near saline, the vegetation types cover a broad spectrum. Species range from those that are more typical of fresh-water marshes to species that occur in salt-water marshes. Although lack of long-term field data precludes the establishment of definite salinity values to define this map unit, salinities probably range from about 1 part-per-thousand (ppt) to about 18 ppt. Because some plant species can tolerate a relatively large range in salinities (Penfound and Hathaway, 1938, and Chabreck, 1972), there is an overlap of species from the fresh-water marsh to the fresh- to brackish-water marsh to the salt-water marsh. Also, vegetation communities that occur within the fresh- to brackish-water marsh units, are not necessarily y of the same species composition in all areas (Pl. V). For example, fresh- to brackish-water marshes mapped on the Trinity River bay-head delta have a different plant assemblage overall (nearer the fresh-water end of the salinity spectrum) than the fresh- to brackish-water marshes inland from West Bay and Christmas Bay (nearer the salt-water end of the salinity spectrum). The major reason for this difference is that salinities are lower in the area of the Trinity delta because of fresh-water inflows from the Trinity River, and because the delta is a significant distance from marine-water influence.

A list of plants that characterize fresh- to brackish-water marshes in the Galveston-Houston area is presented in table 17. Among those plants occurring in fresher areas are *Scirpus maritimus*, *Scirpus californicus*, *Scirpus americanus*, *Alternanthera philoxeroides*, *Bacopa monnieri*, *Typha* spp., *Paspalum lividum* , *Phragmites australis*, and *Eleocharis* spp. Plants occurring in more brackish areas include *Spartina patens*, *Spartina spartinae*, *Scirpus olneyi*, *Scirpus maritimus*, *Paspalum vaginatum*, *Juncus roemerianus*, *Borrichia frutescens*, *Aster tenuifolius*, *Aster subulatus*, *Lycium carolinianum*, *Monanthochloe littoralis*, *Distichlis spicata*, *Salicornia* spp., scattered *Batis maritima*, and locally *Spartina alterniflora*.

Fresh- to 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, figs. 41 and 42), and (2) areas that appear to be less frequently flooded, having a drier wetland-plant assemblage and less soil and surface moisture ("high" marshes figs. 43 and 44). Among the plants found in the lower marshes are *Scirpus* spp., *Typha* spp., *Eleocharis* spp., and *Bacopa monnieri*, whereas other species such as *Spartina spartinae* and *Spartina patens*, for example, are more COmmOn in the higher marshes. However, because there is a lot of variation, and many species occur in both the high and low marshes as mapped on plate V, a definitive list of plants characterizing each of these units is not possible without the

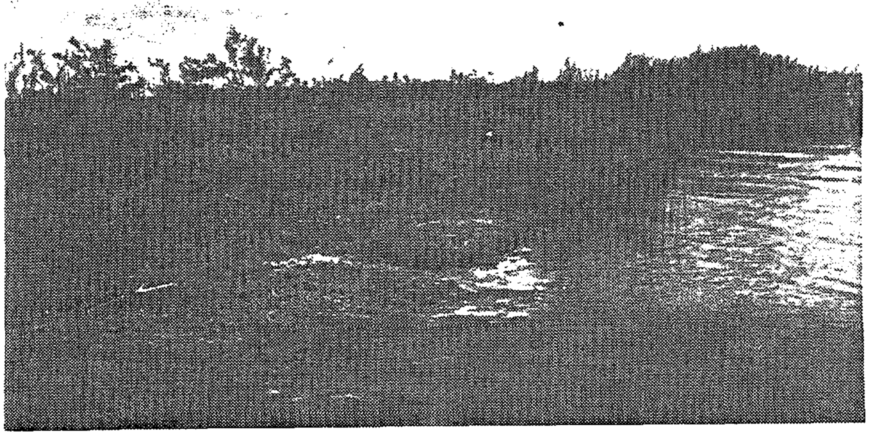


Figure 41. Low fresh- to brackish-water marsh along a distributary channel of the Trinity River delta near Trinity Bay. Vegetation includes Typha sp., Scirpus sp., Bacopa monnieri, and others.

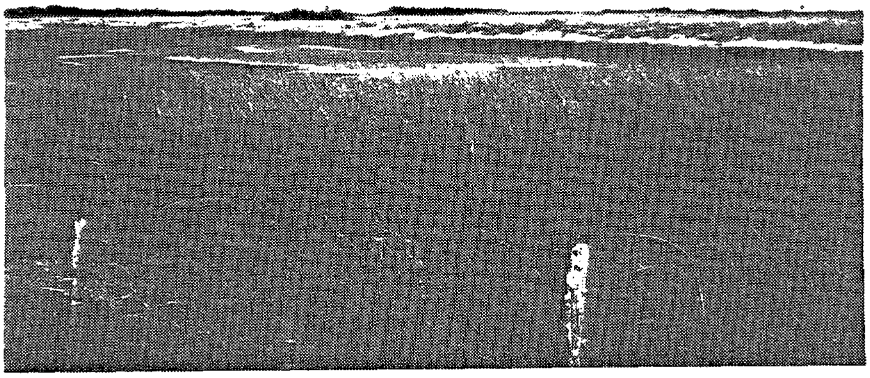


Figure 42. Low fresh- to brackish-water marsh in a swale on Galveston Island. Vegetation includes Scirpus californicus, Bacopa monnieri, and others.

DRAFT

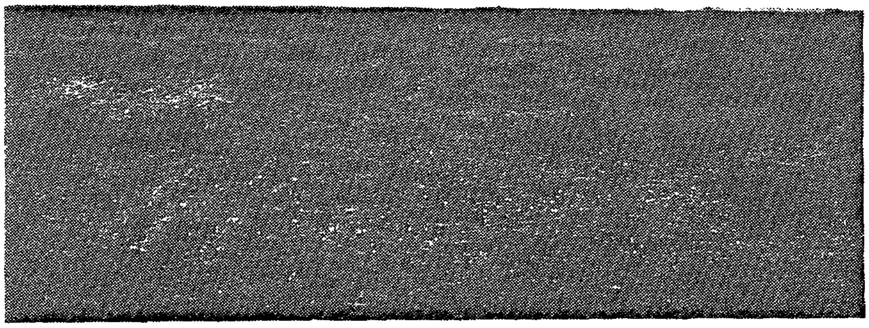


Figure 43. High fresh- to brackish-water marsh, Trinity River Delta. Vegetation includes Paspalum lividum, Paspalum vaginatum, Aster subulatus, Alternanthera philoxeroides, Setaria sp., Spartina patens, Lycium carolinianum, Echinochloa crusgalli, and others.

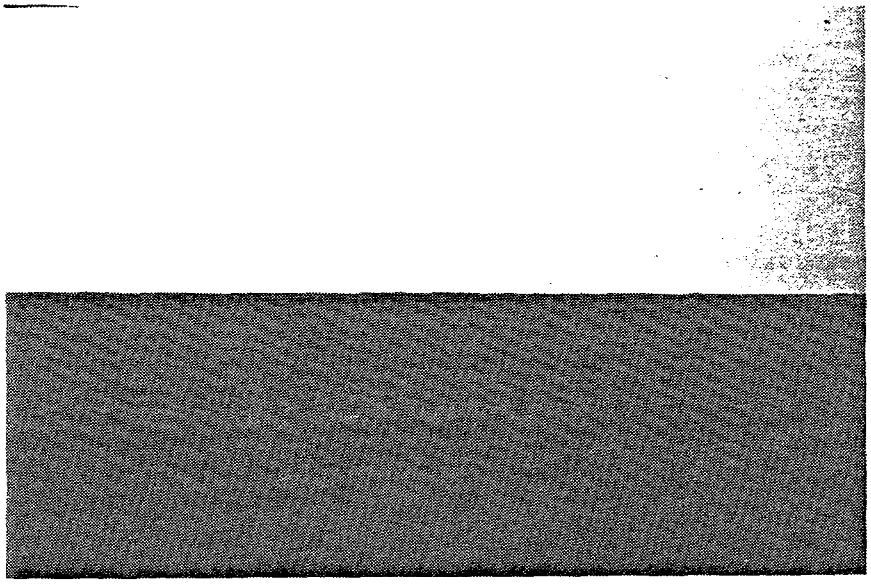


Figure 44. High fresh- to brackish-water marsh, Anahuac National Wildlife Refuge. Vegetation includes Spartina patens and Spartina spartinae.

collection of substantially more field data. Additional information with regard to species composition occurring in different areas is presented in a later section.

Fresh-Water Marshes

Fresh-water marshes occur inland along river or fluvial systems and in upland basins and depressions both on the mainland and on barrier islands. Fresh-water marshes on the barrier islands and peninsulas, however, are included in the fresh- to brackish-water marsh map unit on plate V. Environments in which the fresh marshes occur are generally beyond the limits of salt-water flooding except perhaps, locally, during hurricanes. 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*, *Phragmites australis*, *Eleocharis* spp., *Cyperus* spp., *Bacopa monnieri*, *Juncus* spp., *Ludwigia* sp., *Sagittaria* spp., and *Paspalum lividum* in wetter areas ("low" marshes); the drier areas ("high" marshes) are typified by such species as *Spartina spartinae*, *Paspalum* spp., *Polygonum* spp., *Panicum* spp., *Borrichia frutescens*, *Rhynchospora macrostachya*, *Fimbristylis* sp., *Aster spinosus*, *Spartina patens*, and scattered *Scirpus* spp., *Eleocharis* spp., and *Cyperus* spp. Shrubs such as *Sesbania drummondii*, *Parkinsonia aculeata*, and *Salix nigra* are scattered around the margins of some fresh-water marshes; *Sesbania* sp. is abundant in many low fresh-water marshes (table 17).

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*, occur in salt-, brackish- and fresh-water marshes. Drier fresh-water marshes grade (often very subtly) into transitional areas. *Spartina spartinae* apparently exists within a relatively broad range of elevations and moisture levels. Although 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. Expanses of *Spartina spartinae* were occasion-

Generally, this map unit was applied to areas in which *Taxodium distichum* occurs such as in certain areas of the Trinity River valley (pi. V). Among other species that may be present are *Cephalanthus occidentals*, and *Planera aquatica*, (Rice Center for Community Design and Research, 1974), and *Salix* spp. This map unit may also locally include hardwoods listed in table 17 under woodlands in fluvial areas and poorly drained depressions.

Woodlands in Fluvial Areas and in Poorly Drained Depressions

Areas along the floodplains of streams (excluding swamps) that undergo flooding frequently enough to support assemblages of water-tolerant trees and shrubs were delineated as fluvial woodlands (fig. 45). These fluvial woodlands areas are often distinguishable on aerial photographs by slight color variations, which indicate wetter conditions in the fluvial woodlands than in the 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 *Fraxinus* spp., *Salix nigra*, *Ulmus* spp., *Celtis* spp., *Carya illinoensis*, *Carya aquatica*, *Cephalanthus occidentals*, *Ilex vomitoria*, *Liquidambar styraciflua*, *Sepium sebiferum*, *Populus deltoides*, *Planera aquatica*, *Quercus* spp., *Acacia* sp., *Tamarix* sp., and others (table 17). Included in this assemblage in many areas is the pine tree *Pinus taeda*.

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 and in table 17. Moisture that sustains the woodland assemblages in these poorly drained depressions comes from precipitation runoff and ground water. The depressions include abandoned stream channels and meander scars. Woodlands associated with man-made ponds, reservoirs and stock tanks also are shown on the map.

closely-spaced man-made ponds and upland areas that were mapped together for cartographic simplicity. Overall, this map unit has a limited distribution in the Galveston-Houston map area.

Transitional Areas

Transitional areas 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- and brackish-water marshes. No attempt was made to differentiate fresh-water transitional areas from brackish-water transitional areas. Representative species are listed in table 17. Scattered shrubs include *Sesbania* sp., and *Baccharis halimifolia*.

In recent years, above normal precipitation (figs. 6 and 7) has maintained barrier-island water tables at higher than normal levels. Accordingly, much of the area on the barrier islands and barrier peninsulas not covered by wetlands, or by dunes (mapped by Fisher and others, 1972) (pl. V), fits the definition of transitional areas. Transitional areas were not mapped on barrier islands or barrier peninsulas, however, primarily because of the complexity of showing them in conjunction with wetlands at a scale of 1:125,000.

On the Coastal Plain, transitional areas occur along streams where moisture conditions or frequency of flooding are sufficient to maintain a distinct vegetation assemblage. This transitional assemblage can be distinguished from higher, drier assemblages that are less frequently flooded.

Swamps

Swamps as defined and mapped in this report are woodlands or forested areas, which during much of the year, contain saturated soils or are inundated with surface water.

Descriptions of Major Wetland Areas in Relation to Depositional Systems, Faults, and Geographic Location

Wetlands Associated with Modern Fluvial-Deltaic Systems

Modern fluvial-deltaic systems that transect the coastal plain in the Galveston-Houston area are associated with three major rivers, the Trinity, San Jacinto, and Brazes. The Trinity and San Jacinto Rivers discharge into the bay-estuary-lagoon system. The Brazes River, although discharging into the Gulf to the southwest, crosses the northeast corner of the map area (pi. V). Numerous smaller streams (bayous and creeks) discharge into various bays in the Galveston-Houston area (fig. 4). After downcutting of the river valleys during lower stands of sea level, the valleys were flooded during a rise in sea level, and filled (Brazes River) or partly filled (Trinity and San Jacinto Rivers) by Modern-Holocene fluvial-deltaic progradation (fig. 46, Fisher and others, 1972). Within these valleys occur wetlands in and along stream channels, point-bar deposits, levees, crevasse splays, abandoned channels, floodbasins, distributary and tidal channels, interdistributary flats, and delta-margin environments.

Trinity River

In the Trinity fluvial-deltaic area, units were delineated primarily through photographic interpretation along with a limited number of field surveys, but also by referring to maps and reports published by Fisher and others (1972), Rice Center for Community Design and Research (1974), Adams and Tingley (1977), Benton and others (1978), and U.S. Fish and Wildlife Service National Wetlands Inventory Maps (1982).

At the head of Trinity Bay is a modern bay-head-delta-marsh complex dissected by numerous distributary and tidal channels. Several natural lakes and man-made reservoirs occur within the Trinity River Valley inland from the delta margin (pi. V). Salinities are generally low (less than 5 parts per thousand; Texas Department of Water Resources, 1981) at the head of Trinity Bay because of fresh-water inflows from the Trinity River and because the nearest tidal

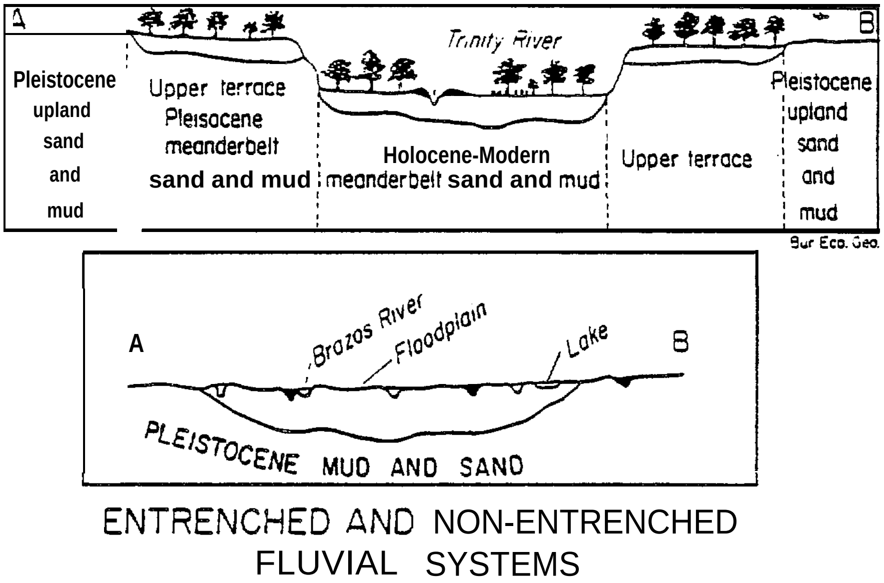


Figure 46. Cross sections of the Trinity and Brazes Rivers (after Fisher and others, 1972).

inlet, Bolivar Roads, is over 30 mi (48 km) away. Marsh vegetation is characterized by fresh- to brackish-water species extending from the bay margin inland to Interstate Highway 10 (PL V). Vegetation in these fresh to brackish reaches of the delta include *Alternanthera philoxeroides*, *Spartina patens*, *Spartina spartinae*, *Phragmites australis*, *Aster subulatus*, *Paspalum lividum*, *Paspalum vaginatum*, *Scirpus maritimus*, *Scirpus* spp., *Cyperus articulates*, *Eleocharis parvula*, *Lycium carolinianum*, *Echinochloa* spp., *Typha* spp., *Bacopa monnieri*, *Vigna luteola*, *Iva* spp., *Sesbania drummondii*, *Solidago* sp., *Zizaniopsus* sp., *Panicum* sp., *Setaria* sp., *Ammannia coccinea*, *Sagittaria* spp., *Eichhornia crassipes*, and *Spartina alterniflora*. *Spartina alterniflora*, while present in a few stands along the bay margin, apparently is not a significant component of the marsh system.

The fresh- to brackish-water marsh unit has been differentiated into high and low marshes through photographic analysis (pl. V). High marshes generally coincide with depositional highs such as natural levees that parallel distributary channels, and beach ridges or storm berms and ramps that occur in bay-margin areas. These latter bay-margin features characterize much of the southwest margin of the delta. In this area, distributaries that in the past prograded the delta are now inactive. Bay waves and currents, particularly effective during storms, have straightened the shoreline and formed storm berms or shell ramps on which the higher marshes have developed. Lower marshes are more typical in interdistributary areas and along the bay margin where active distributaries are prograding the delta bayward. Along the banks of the Trinity River west of Lake Anahuac, levees provide higher elevations on which a woodland assemblage predominates. Many of the species listed under woodlands in table 17 occur.

Farther inland along the Trinity River valley salinities decrease and fresh- to brackish-water marshes grade into fresh-water marshes. For mapping purposes the changeover to fresh-water marshes was placed along Interstate Highway 10. Fresh-water species inland from the Highway include many of those listed under fresh-water marshes in table 17.

Within the entrenched Trinity River valley around Lake Charles and inland from Lost Lake are swamps composed predominantly of *Taxodium distichum* (pi. V). Farther up the valley, the swamps occupy meander scars which grade into higher and dryer levees and point-bar-sand deposits where water-tolerant hardwoods compose a fluvial woodlands assemblage (table 17). The fluvial woodlands grade up the valley walls into upland mixed pine and hardwood forests mapped by Fisher and others (1972), but not shown on maps accompanying this report.

San Jacinto River

The San Jacinto River, like the Trinity River although much smaller, lies within an entrenched valley. The lower (gulfward) part of the valley, which is connected to Galveston Bay through a chain of smaller bays, has been affected by subsidence in the Houston area and has become permanently inundated. Water is the predominant map unit in bayward part of the valley (pi. V). Woodland-vegetated islands mark the position of natural levees that formed along the river before valley submergence. Inland, the valley is characterized by water-tolerant trees that are mapped as fluvial woodlands. Many of the woodland species are listed in table 17. More limited in distribution are fresh- to brackish-water marshes, fresh-water marshes, and a few semi-permanently-wet depressions mapped as swamps. Vegetation composition of fresh- to brackish-water marshes in some areas includes *Scirpus* sp., *Typha* sp., *Bacopa monnieri, Sagittaria* sp., possible *Alternanthera philoxeroides*, and others (table 17). Such species indicate relatively low salinities which places these marshlands at the fresh end of the fresh- to brackish-water marsh spectrum. Farther up the valley, away from estuarine water intrusion, the marshes were mapped as fresh-water marshes. Much of the lower portion of the San Jacinto River valley, including marsh areas, is characterized by dead trees that have succumbed to valley submergence. Changes in wetland distribution that have occurred between 1956 and 1979 in the lower part of the valley are presented in a later section.

DRAFT

Brazes River

The Brazes River, which flows across the northwest corner of the Galveston-Houston map area, discharges into the Gulf to the southwest. Unlike the Trinity and San Jacinto Rivers, which lie within entrenched valleys, the Brazes has essentially filled its incised valley with Modern-Holocene fluvial sediments (fig. 46, Fisher and others, 1972). A transect across the fluvial system reveals, in addition to the Brazes River and associated floodplain, numerous abandoned streams, oxbow lakes, and mud-filled channels.

Fluvial woodlands composed primarily of water-tolerant hardwoods (table 17) cover much of the floodplain (pi. V). Locally, abandoned channels or other depressions contain water, or are wet enough to support fresh-water marsh assemblages. Many of the areas of open water are covered with floating leaf aquatic plants such as Eichhornia crassipes. Other areas that are less frequently inundated support a transitional community (mapped as transitional areas) or upland-prairie grasses and associated vegetation (unmapped upland areas). Woodlands occurring in abandoned channels, sloughs, or other depressions that appear to be frequently flooded are mapped separately from woodlands that appear to be less frequently flooded (pi. V). The straight boundaries marking the edges of many woodland areas along the Brazes fluvial system are the result of clearing to produce rangeland and cropland.

Smaller Streams or Bayous

Several streams smaller than the Brazes, Trinity, and San Jacinto Rivers drain into the bay-estuary-lagoon system (fig. 4). These bayous and creeks have many similar characteristics. Fluvial woodlands are common along “much of their lengths, and many support fresh- to brackish-water marshes near their mouths. Upstream away from tidal input, fresh-water marshes may occur. Transitional areas are also mapped at some locations, usually above high marshes (pi. V).

Subsidence in the Houston area has had an effect on many streams. As subsidence occurs, the stream vane y is gradually flooded, and as exemplified by Clear Creek (and associated Clear

Lake), marshes and woodlands become permanently inundated and eventually are replaced by open water (fig. 47). Other changes in wetlands caused by subsidence are discussed in a later section.

Fluvial woodlands and marshes occurring along the bayous and creeks are characterized by species listed in table 17. Several of the bayous, for example Buffalo, Chocolate, and Bastrop Bayous, have been modified by dredged channels. Buffalo Bayou, which has been dredged to form part of the Houston Ship Channel, isintensively industrialized and is the most extensively modified of all the bayous in the map area. It has several tributaries along which fluvial woodlands occur, but because of the intense development along the bayou itself, there are few fluvial woodlands. Mixed pine and hardwood forests mapped by Fisher and others (1972) along Buffalo Bayou were not mapped in this study.

Barrier-Strandplain System

The modern barrier system in the Galveston-Houston area is composed of Bolivar Peninsula, and Galveston and Follets Islands. The Pleistocene barrier strandplain system is limited in areal extent in the Galveston-Houston area. These ancient barrier-sand deposits occur in an east-northeast trending linear belt inland from East Bay, and in smaller patches adjacent to Chocolate Bay, and at the edge of Galveston Bay (fig. 9; refer to fig. 4 for bay locations).

Modern Barriers and Tidal Deltas

Environments associated with Bolivar Peninsula, Galveston and Follets Island have been mapped and described by Fisher and others (1972). Broad expanses of vegetated flats lying between the fore-island dunes and back-island tidal flats and marshes were mapped as vegetated barrier flats. In recent years (1977-1979) above normal precipitation has produced higher than normal water tables and soil moisture on the barriers. Accordingly, much of the vegetated barrier flat fits the definition of transitional area as defined in this report. However, transitional areas were not mapped nor are they shown on plate V, primarily because of the complexity of showing them in conjunction with wetlands at the mapping scale used.

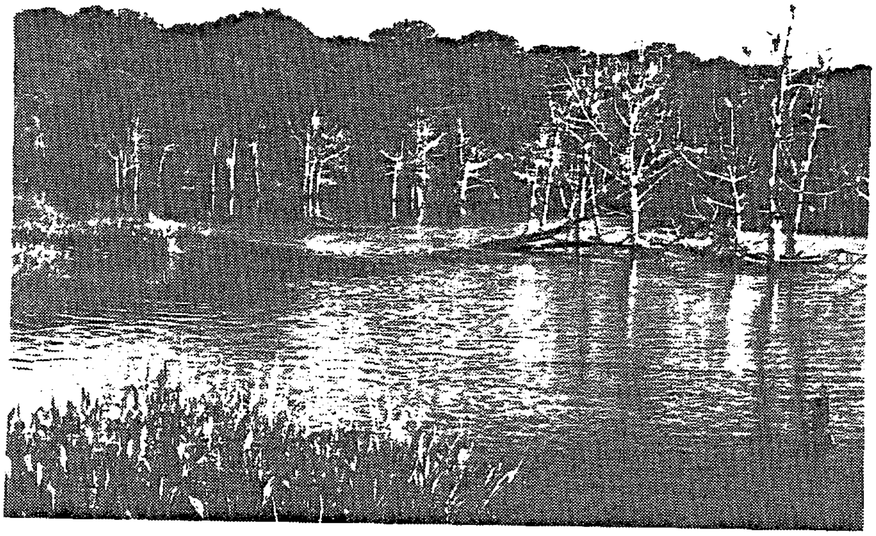


Figure 47. Effects of subsidence along a portion of Clear Creek.

Bolivar Peninsula.--Relatively extensive proximal and distal salt-water marshes occur on the back side of Bolivar Peninsula and in conjunction with two major fan deposits apparently formed in part by past storm washover processes (pl. V). These proximal and distal salt-water marshes have vegetation communities that generally include many of the species listed in table 17. *Spartina alterniflora* occurs in the proximal marsh along with other species such as *Batis maritima*, *Salicornia* spp., and locally *Juncus roemerianus*. *Spartina patens* and *Spartina spartinae* are generally more common at higher elevations such as in the distal marsh but there is an overlap of species. The two large fans in back-island areas are separated from the main body of Bolivar Peninsula by the Intracoastal Waterway. An upland ridge created by spoil disposal parallels the channel along its inland margin.

Active growth faults have substantially affected wetlands on the fans as well as the main body of the peninsula. The eastward-most fan, the largest of the two, is crossed by an arcuate growth fault that strikes northeast-southwest across the fan and the peninsula. The fault curves southeastward along its northern half and crosses the peninsula just west of Rollover Bay (fig. 48, pl. V). Land subsidence profiles constructed from benchmark releveling data provided by the National Geodetic Survey, confirm that this fault is active (Charles W. Kreitler, personal communication, 1983). The level lines show abrupt increases in subsidence on the downthrown side of the fault. Wetland units on the downthrown, gulf ward, side of the fault include proximal marsh, tidal flats with scattered marsh vegetation and open water. On the "upthrown" side of the fault slightly higher elevations provide a slightly drier substrate on which distal marshes, vegetated in large part by *Spartina patens* and *Spartina spartinae*, occur. Because the downthrown side lies gulfward of the fault line, the proximal marsh is gulf ward of the distal marsh. This relationship is the reverse of that occurring in other back-island areas of Bolivar Peninsula, where the progression is normally from distal salt-water marsh to proximal salt-water marsh in a bayward direction (pl. V).

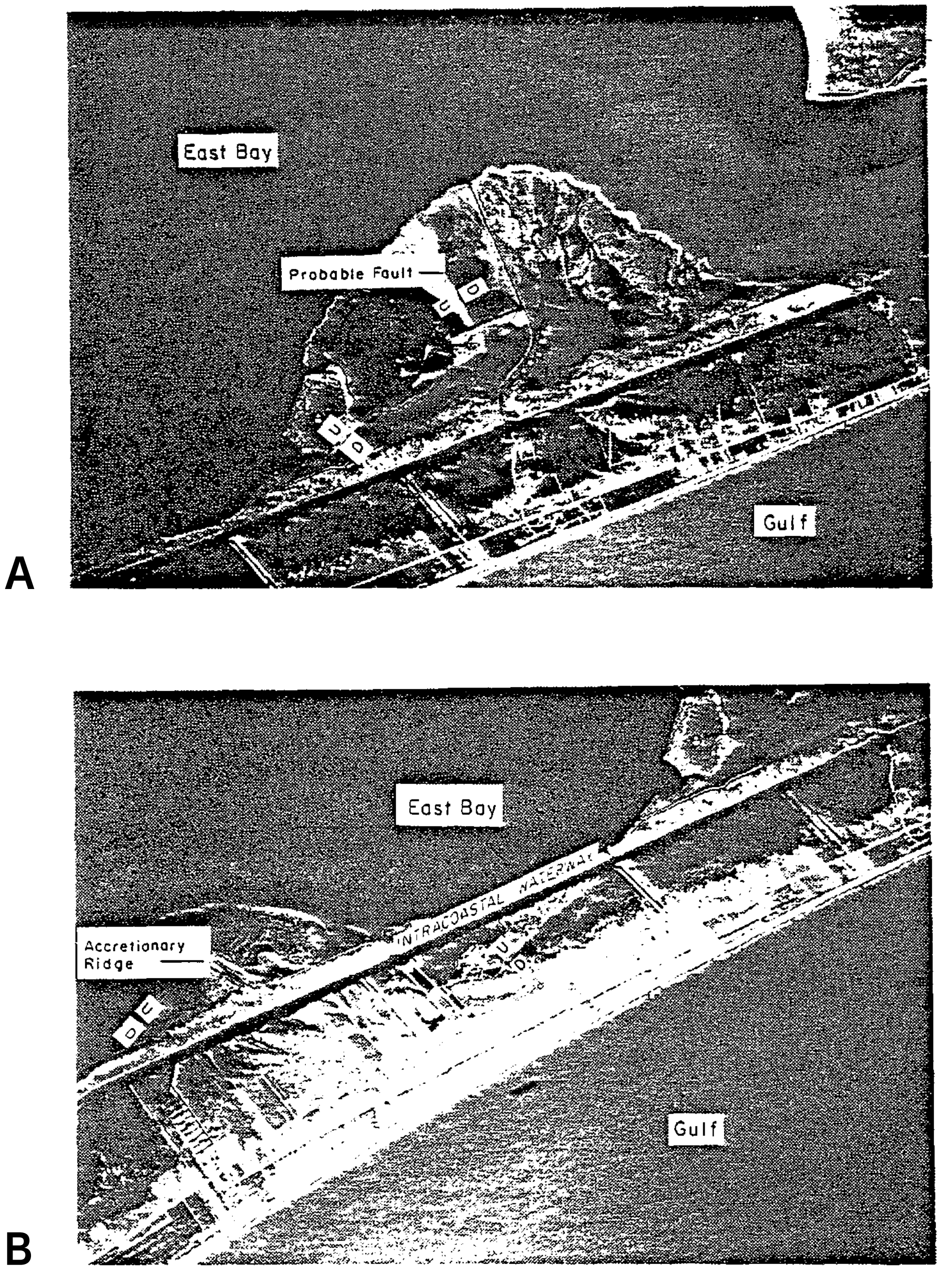


Figure 48A and B. Faults on Boliver Peninsula (D = downthrown side, U = upthrown side).

In the area where the fault crosses the large back-island fan, shallow subaqueous flats or open water occur on the downthrown side of the fault and distal salt-water marshes on the upthrown side. Striking northeast, approximately perpendicular to this fault, and subequally dividing the fan, is a second linear feature, also probably a fault, along which wetland map units abruptly change from distal marsh on the west side to open water on the east side.

The smaller washover fan to the west is also intersected by a fault along which an area of open water occurs on the downthrown northeast side (fig. 48B, Pl. V). Relict arcuate spit accretion ridges, documenting the westward growth direction of Bolivar Peninsula, also extend into this smaller fan. In the swales between the accretionary ridges, proximal marshes occur and grade upward on the ridge into distal marshes and uplands.

At the western end of Bolivar Peninsula, ridge and swale topography characterizing the accretionary origin of the peninsula, provides a depositional setting in which marshes have developed. The ridges curve Gulfward and proximal salt-water marshes occur in the swales or troughs near the tip of the peninsula. The proximal marshes, vegetated primarily with *Spartina alterniflora* in the intertidal areas, grade into tidal flats and zones of *Batis maritima*, *Distichlis spicata*, *Salicornia* spp., *Juncus roemerianus*, *Monanthochloe littoralis*, *Borrichia frutescens*, *Spartina patens*, *Spartina spartinae* and other species. Bayward of Highway 87, swales at the western end near the center of the peninsula, contain proximal marshes and open water that grade northeastward into an area of high fresh- to brackish-water marshes. Much of this fresh- to brackish-water marsh, especially that part located northeast of the road that crosses it, is a “borderline” wetland in that it might be more appropriately classified as a transitional area or an area of wetlands, uplands undifferentiated. As explained previously, however, transitional areas were not delineated or mapped on barriers.

Along swales in the central portion of the Peninsula are high fresh- to brackish-water marshes and, less commonly, low marshes and water. Marsh species include *Scirpus* spp., *Juncus* sp., *Typha* sp., *Sesbania* sp., scattered *Salix* sp. and others (table 17).

Galveston Island.--Galveston Island, flanked by West Bay to the northwest and the Gulf of Mexico to the southeast, is an accretionary barrier island with well-preserved ridge and swale topography along its wide northeastern half (fig. 49). Toward its southwestern end, the island becomes much more narrow and the relict accretionary beach ridges disappear. The orientation of the ridges and interlying swales that contain wetlands, is roughly parallel to the present island shoreline marked by the Gulf beach. This northeast-southwest orientation is almost normal to that of several broad, relict, washover channels filled with water that cut the ridges and swales and connect to back-island salt-water marshes and West Bay (PI. V).

From the margins of West Bay, proximal salt-water marshes of predominantly Spartina alterniflora (fig. 39) grade islandward into wind-tidal flats or distal salt-water marshes (pi. V). Also common along much of the bayward side of the island are shallow subaqueous flats that contain scattered clumps of Spartina alterniflora. These mixed areas of open water and marsh vegetation were mapped together as an undifferentiated map unit--proximal marsh and open water, undifferentiated (pi. V; table 17). In addition to Spartina alterniflora, salt-water marsh species occurring in the proximal marsh and grading into higher distal marshes include Batis maritima, Salicornia sp., Distichlis spicata, Borrichia frutescent, Monanthochloe littorals, Juncus roemerianus, Spartina patens, and Spartina spartinae among others listed in table 17.

Swales between the relict beach ridges on Galveston Island provide the topographic setting for many wetlands in central to back-island areas along the southeastern half of the island. Marsh vegetation is variable in these depressions depending on their connection to bay waters. Those that are somewhat protected from bay- and marine-water inundation (except perhaps during storms), are characterized by brackish- and fresh-water conditions and were mapped as fresh- to brackish-water marshes. The marshes become fresher toward the central part of the island in areas removed from tidal channels that connect to West Bay. Vegetation in these fresher areas include Scirpus californicus, Scirpus sp., Typha sp., Paspalum sp., Bacopa monnieri, Cyperus sp., Juncus sp., Spartina spartinae, Phragmites australis, Sesbania sp. and others (table 17). This type of' vegetation characterizes the fresh end of the fresh- to brackish-water salinity spectrum, and many of these marshes could have been mapped as fresh-water marshes. At the. other extreme--the brackish end of the spectrum--species such as Distichlis spicata, Borrichia frutescent, Spartina patens, Juncus roemerianus, and scattered Batis maritima and Salicornia spp. may occur.

High and low (fig. 42) fresh- to brackish-water marshes occur in the swales as do water bodies and, locally, woodlands. Undifferentiated map units locally include mixed areas of (1) tidal flats and marshes, and (2) miscellaneous wetlands and surrounding uplands. In back-island areas, distal salt-water marshes grade into high fresh- to brackish-water marshes. Fresh- to brackish-water marshes in back-island areas along the western half of Galveston Island reflect the orientation or alignment of relict storm washover channels in which the marshes have developed.

Follets Island.--Follets Island is a small barrier lying gulfward of Christmas and Drum Bays (pi. V). Separated from Galveston Island by San Luis Pass to the northeast, Follets Island is connected by wetlands to Pleistocene and Holocene fluvial-deltaic headlands to the southwest. Most of the island is composed of salt-water marshes. A narrow band of uplands and transitional areas (m appeal with uplands) stretches down the gulf ward margin of the island.

A relatively continuous band of proximal salt-water marshes has developed on coalescing washover fans along the island's hayward half. These marshes grade islandward into barren wind-tidal flats or wind-tidal flats with scattered marsh vegetation (sand or mud flats and marshes, undifferentiated; pl. V). Salt-water marsh vegetation is similar to that on Galveston Island. Spartina alterniflora in intertidal areas grades into areas of Batis maritima, Salicornia sp., Distichlis spicata, Borrichia frutescent, Monanthochloe littoralis, Juncus roemerianus, Spartina patens, Spartina spartinae, and other species listed in table 17. Fresh- to brackish-water marshes have a limited distribution. The largest fresh- to brackish-water marsh occurs gulfward of the island highway near the northeast end of the island. Vegetation in this area, in

DRAFT

1981, included *Typha* sp., *Scirpus americanus, Juncus* sp., and *Spartina patens*. Bayward, across the highway from this site, *Spartina patens* in distal marsh areas graded toward Christmas Bay into *Batis maritima* and other salt-water marsh species. At the southwest end of the Island, an area of distal salt-water marsh composed of *Monanthochloe littorals, Salicornia* sp., *Batis maritima, Borrichia frutescent,* and *Spartina patens,* grades almost imperceptibly into proximal salt-water marshes (fig. 40; pi. V).

Pelican Island.--Pelican Island is an extensively modified flood-tidal delta located at the bayward end of the tidal-inlet, Bolivar Roads (pl. V). Most of the island as depicted on plate V, is man-made land (Fisher and others, 1972). Mid 1800% topographic maps show the island to consist of a relatively small area of marshland located at the bayward tip of the island as it exists today. Wetlands on the bayward half of the island (as interpreted from 1979 photographs and shown on plate V) consist of rather extensive wind-tidal flats with scattered patches of marsh vegetation bounded along bayward margins by proximal salt-water marshes. At higher elevations, the sparsely vegetated flats grade into patches of barren wind-tidal flats, distal salt-water marshes, and uplands. The gulfward half of the island is complex. Dredged-spoil mounds are common in upland areas where scattered depressions are the sites of fresh- to brackish-water marshes. In some areas wetlands and uplands form a complex spatial and gradational relationship, and were mapped together as wetland/upland areas, undifferentiated. Vegetation in the marshes is characterized by those species listed in table 17. Future dredged spoil disposal on Harbor Island will change the distribution of map units as shown on plate V.

Mud, Moodys, and Bird Islands .--These islands are part of a flood-tidal-delta complex inland from San Luis Pass. Unlike Pelican Island, human modifications have been minimal. Wetlands are composed predominantly of proximal salt-water marshes (pi. V). Less extensive are sparsely vegetated wind-tidal flats, distal marshes, and scattered uplands. Tidal channels separate the islands.

Pleistocene Barrier-Strandplain

Pleistocene barrier-strandplain deposits, although limited in areal extent compared to the Corpus Christi area, provide a geomorphic setting for scattered wetlands. The largest area of barrier-strandplain sand occurs in a northeast-southwest trending belt between Trinity and East Bays. Other smaller areas are near Chocolate Bay and Galveston Bay (fig. 9). In some areas, wetlands, which include fresh-water marshes, fresh- to brackish-water marshes, and ponds, have developed in depressions between relict beach ridges that mark the depositional grain or framework of these ancient accretionary barriers. In the area between Trinity and East Bays, small circular wetlands form a belt that extends from near Smith Point northeastward to the edge of the map area (pi. V). The barrier sands overall form topographic highs. In the Smith Point area this sand ridge is bordered along much of its length by fresh- to brackish-water marshes and transitional areas that extend to the edge of Trinity Bay to the northwest and to East Bay to the southeast. Southwest of Chocolate Bay the Pleistocene barrier sand is bounded by water on its gulfward side and fresh- to brackish-water-marsh-filled tidal creeks on its landward side (pi. V, fig. 9).

These Pleistocene barriers are characterized by abundant circular sand mounds, known as pimple mounds, which in many areas produce a closely spaced grid of uplands separated by narrow wetlands that form in the depressions (where moisture is sufficient) between and around the mounds. The size and complexity of these tightly knit upland and wetland areas precluded mapping them separately. In some areas, for example on the barrier sands southwest of Chocolate Bay, they are mapped as wetland and upland areas, undifferentiated. In other areas where moisture and vegetation types indicated a transitional community, characterized by mixed upland and wetland vegetation, the transitional-map unit was applied.

Bay Margin and Associated Mainland Areas

Among the most extensive wetlands in the Galveston-Houston area are those that occur along and extend inland from the margins of East Bay, West Bay, Chocolate Bay, anc

DRAFT

Christmas/Drum Bays (pi. V). The wetlands have formed primarily on the margins of Pleistocene fluvial-delta plain, delta front, and barrier-strandplain deposits (Fisher and others, 1972) that slope gently gulf ward into the modern bay system. These areas contain extensive marshlands, lakes and embayments, and tidal channels. The wetlands are affected in some areas by growth faults in which the downthrown side of the fault is lower in elevation than the upthrown side resulting in a change in moisture conditions and vegetation communities across the faults.

East Bay Area

Inland from East Bay the wetlands are characterized by extensive fresh- to brackish-water marshes, transitional areas, and water bodies of various sizes (pi. V). Accretionary bay-margin deposits composed in part of storm berms and shell ramps separate inland marshes from East Bay. These slightly elevated bay-margin deposits, mapped as upland and transitional areas, partially block, or dam up, fresh-water runoff from inland areas, and also limit tidal inundation from estuarine waters of East Bay. The results are the extensive fresh- to brackish-water marshes that extend from the bay margin inland, approximately 4 mi (6.5 km) in some areas, to the margin of the Pleistocene barrier-strandplain sand body. Near the edge of the map area fresh-to brackish-water marshes compose much of Anahuac National Wildlife Refuge (pl. V). In these areas topographic lows contain standing water and low marshes which grade toward higher elevations into high marshes, transitional areas, and uplands. Marsh vegetation includes *Spartina patens*, *Spartina spartinae*, *Distichlis spicata*, *Scirpus olneyi*, *Paspalum* sp., *Borrichia frutescens*, Iva sp., *Phragmites australis*, and many others (table 17). Some areas, for example around Robinson Lake, have been modified, by dredged channels and associated spoil, which forms dikes or upland ridges along the channel margins. An area in the Anahuac National Wildlife Refuge is completely enclosed with dikes and a fresh-water marsh vegetated extensively with *Typha* sp. has developed. Many of the more inland marshes are at the fresh end of the fresh- to brackish-water salinity spectrum.

The marshes near Lake Stephenson are hydrologically interconnected to marshes to the northwest located across the Pleistocene barrier strandplain sand and extending to the edge of Trinity Bay (pl. V). This marsh system, known as Gordy Marsh, has relatively good tidal connections with Trinity Bay. It was mapped as a fresh- to brackish-water marsh rather than a salt marsh principally because (1) salinities in Trinity Bay in this area are generally between 5 to 15 ppt (Texas Department of Water Resources, 1981), (2) photo analysis indicates the vegetation includes *Spartina spartinae*, *Spartina patens*, and stands of *Typha* sp. among other species (some *Spartina alterniflora*, however, has been reported in this area; Benton and others, 1978), and (3) salinities are probably lowered by fresh-water inflows from upland areas and by ground-water discharge from adjacent topographically higher Pleistocene barrier-strandplain sands.

At least four faults intersect the surface and affect wetlands south and east of Robinson Lake. (Although independently identified on photographs during this research study, these faults are among six previously mapped and reported by Verbeek and Clanton, 1981.) The faults have a north-south strike, are parallel to each other, and extend inland from East Bay. The westernmost fault, which intersects the south margin of Robinson Lake, is downthrown to the east; the easternmost fault lies 2 mi (3.2 km) to the east and is downthrown to the west (fig. 50). The two faults in between are each downthrown to the east. Rather abrupt changes occur in wetland map units as the faults are crossed including changes from (1) transitional areas to high marshes, (2) high marshes to low marshes, and (3) low and high marshes to standing water (pl. V and fig. 50). A graben (depression produced by subsidence of a strip between normal faults; Suess, 1904), has produced a belt of lower, wetter wetland units relative to the flanking higher, drier units (pl. V; fig. 50).

West Bay Area

Wetlands inland from West Bay include extensive areas of open water, proximal salt-water marshes, distal salt-water marshes, low and high fresh- to brackish-water marshes, flats and

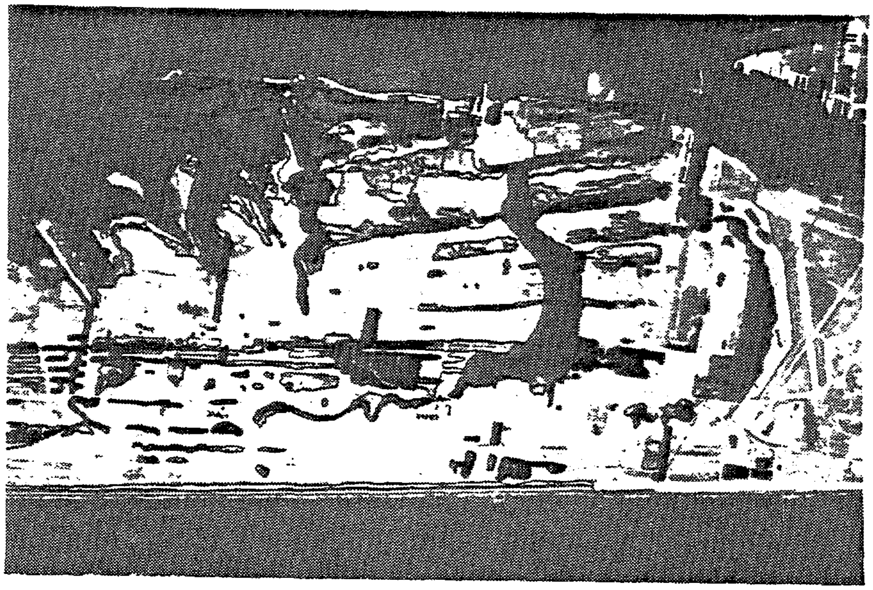


Figure 49. Aerial photograph of ridge and swale topography on Galveston Island.

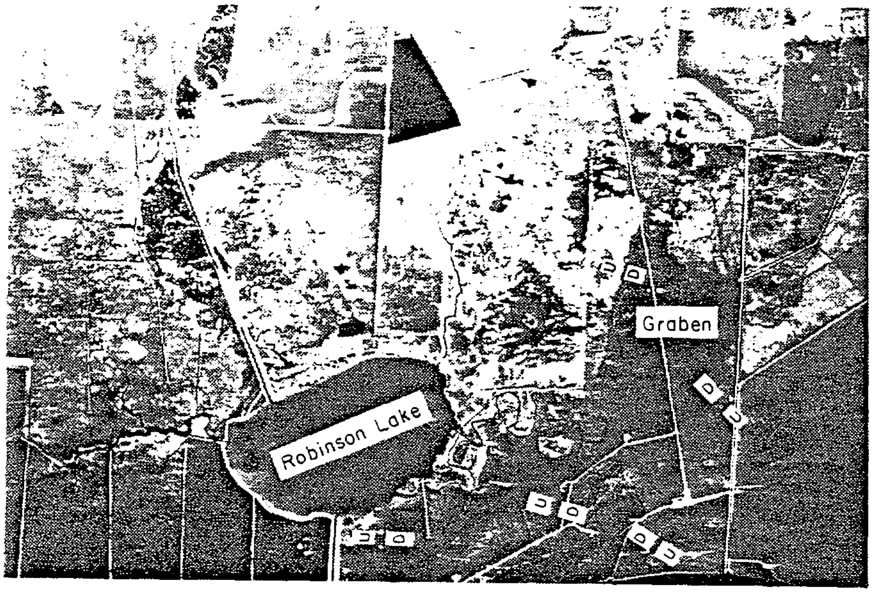


Figure 50. Faults near Robinson Lake. Three faults can be seen in this photograph. Note wetter conditions on downthrown sides of faults (D = downthrown side, U = upthrown side).

open water with scattered vegetation, and transitional areas that grade inland into uplands (pi. V). From near Jones Bay to Carancahua Lake, proximal marshes and areas of open water are extensive; distal marshes occur locally at slightly higher elevations. Vegetation includes *Spartina alterniflora*, *Batis maritima*, *Salicornia* sp., *Distichlis spicata*, *Monanthochloe littoralis*, scattered *Juncus roemerianus*, *Spartina patens*, *Spartina spartinae*, *Borrichia frutescens*, and others (table 17). In some areas, for example between Greens and Carancahua Lakes, *Spartina alterniflora* is mixed with such species as *Batis maritima*, *Salicornia* sp., and *Distichlis spicata*. Subsidence has had a significant effect on the wetlands in this area near Texas City; these effects are discussed in the section on changes in wetland distribution.

Between Carancahua and Halls Lake, dredged spoil ridges marking the inland edge of the Intracoastal and numerous dikes, limit salt-water inundation from West Bay and Chocolate Bay. Accordingly, except for a few areas where *Spartina alterniflora* appears dominant and was mapped as salt marsh, this area was mapped as fresh- to brackish-water marsh. Although *Typha* sp. is present locally in diked ponds, most of the vegetation appears to reflect the brackish end of the fresh- to brackish-water salinity spectrum, bordering on salt marsh. Around Halls Lake and along the east side of Chocolate Bay proximal salt-water marsh composed of *Spartina alterniflora* is predominant. These marshes grade toward higher elevations into distal marshes, high fresh- to brackish-water marshes, and transitional areas.

The marsh system inland from West Bay is characterized along much of its inland margin by a complex network of mud-filled tidal creeks (Fisher and others, 1972). The creeks provide a drainage network for inland areas and connect to the bayward lying marshes. Vegetation types along these topographic lows include *Spartina spartinae* and, depending on moisture levels, were mapped as high fresh- to brackish-water marshes or transitional areas (Pl. V).

Inland from Greens Lake, there are at least two growth faults, which intersect the surface and have modified or controlled the configuration of some marshes and transitional areas. Both faults cut across the network of tidal creeks and produce wetter conditions on the downthrown gulfward sides of the faults (fig. 51). A probable fault inland from Carancahua Lake strikes approximately east-west and separates an area of water and low marsh located on the landward side from high marsh on the gulfward side (pl. V).

Christmas-Bastrop-Drum Bay Area

Wetlands inland from the Christmas-Bastrop-Drum Bay complex, and southwest of Chocolate Bay, are among the most extensive in the Galveston-Houston map area. This modern wetland complex has apparently developed on Pleistocene fluvial-deltaic flood basin and interdistributary muds, and distributary channel and barrier-strandplain sands. Also, it has developed along the eastern margin of the Brazes-Colorado River Holocene fluvial-delta plain (Fisher and others, 1972; Morton, 1977). In addition, a salt dome (Hoskins Mound) and several faults occur in the area. These features and their relationships help explain the complexity and general configuration of this wetland system composed of numerous small bays, lakes, salt-, brackish-, and fresh-water marshes, transitional areas, active and abandoned streams, levees, oxbow lakes, tidal creeks, and dredged channels (pl. V).

The general relationship of marshes in this area is one in which proximal salt-water marshes were mapped principally gulfward of the Intracoastal Waterway, whereas extensive fresh- to brackish-water marshes were mapped landward of the Intracoastal. Among the reasons for classifying the marshes around Drum, Christmas, and Bastrop Bays as salt-water marshes were (1) vegetation assemblages, which near the Intracoastal Waterway north of Bastrop Bay included abundant *Batis maritima*, *Spartina alterniflora*, and other salt-water marsh species (table 17), and (2) salinity measurements, which between 1973 and 1978 in Drum Bay, and 1970 and 1978 in Christmas Bay averaged between 22 and 25 ppt with maximum values in excess of 30 ppt (Texas Department of Water Resources, unpublished data).

Fresh- to brackish-water marshes inland from the Intracoastal Waterway include extensive areas of high and low marshes and open water. The marsh system is divided by natural levees, mapped as uplands, along Big Slough (pl. V). Much of the marsh area mapped as fresh-to brackish-water marsh south of Big Slough is in the Brazoria National Wildlife Refuge. Vegetation is dominated by Spartina patens, and Distichlis spicata, with species including Spartina spartinae, Scirpus olneyi, Scirpus maritima, Paspalum vaginatum, Paspalum lividum, Phragmites australis, and Aster sp. (Fleetwood, undated). Fresh-water marshes occur in some areas such as in Big Slough and adjacent oxbow lakes; vegetation includes Typha sp., Scirpus californicus, Paspalum lividum, and other fresher water species (Fleetwood, undated). At least two growth faults occur in the area of the Brazoria National Wildlife Refuge, one is a major one occurring along the inland margin of Salt Lake. This particular fault, downthrown on the gulfward side and with a northeast-southwest strike, produces a definite linear feature on the map (fig. 52, pl. V). High fresh- to brackish-water marshes and uplands on the upthrown side of the fault change abruptly across the fault to low marshes, water, and barren flats (pl. V). The fault curves southeastward as it approaches Big Slough from the west and crosses the southern half of Cox Bay and extends into the south lobe of Lost Lake. Another fault, southwest of this one, has had a less dramatic effect.

North of Big Slough, fresh- to brackish-water marshes include many of the species listed above in the Brazoria Wildlife Refuge including Spartina patens, Distichlis spicata, Scirpus maritimus, Juncus roemerianus, Borrichia frutescens, Monanthochloe littoralis, patches of Phragmites australis, and scattered Batis maritima and Salicornia spp. Inland, high fresh- to brackish-water marshes grade into transitional areas and, locally, high fresh-water marshes. The transitional areas and fresh-water marshes may both contain abundant Spartina spartinae in this area, among other species (table 17). Farther to the northeast, a complex network of abandoned tidal creeks, some of which have courses diverging around Hoskins Mound, are mapped as high fresh- to brackish-water marshes and transitional areas.

The area around Hoskins Mound has been affected by several faults that strike toward this dome. The largest one is visible at the surface from the edge of Chocolate Bay and extends toward the center of Hoskins Mound to the southwest. The fault is downthrown to the north-

Figure 51. Faults inland from Greens Lake along West Bay (D = downthrown side, U = upthrown side).

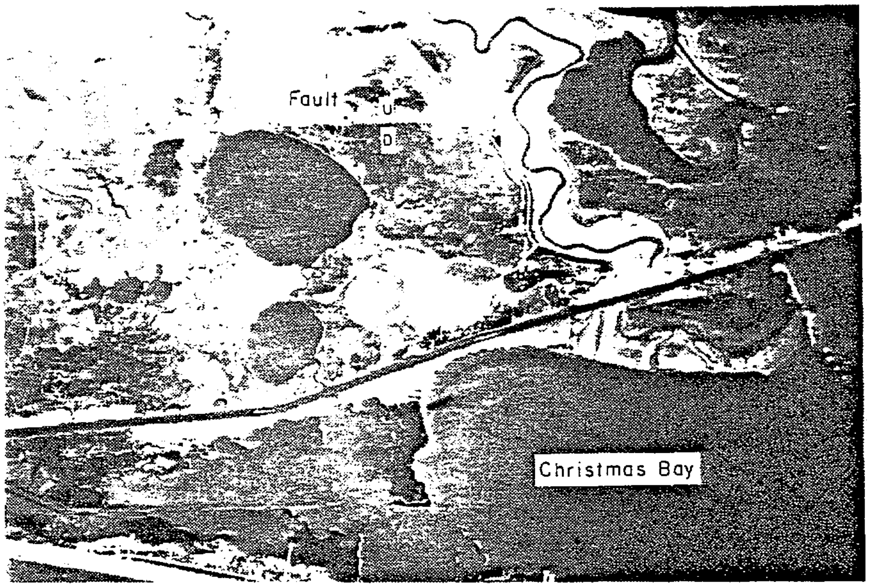


Figure 52. Fault in the Brazoria National Wildlife Refuge inland from Drum Bay (D = downthrown side, U = upthrown side).

west or inland and, therefore, the fault scarp has deflected tidal creeks draining from upland areas at near right angles (fig. 53). With the fault scarp acting as a barrier and the topographically lower, downthrown side retaining more moisture, the fresh- to brackish-water marshes are more extensive along the inland side of the fault. Another fault, also with the downthrown block on the inland side, lies just inland from this one, also striking toward Hoskins Mound at an angle of about 10° with the first fault. There is some evidence that the small water body along the Gulfward margin of the Pleistocene barrier-strandplain sand body in this area is fault controlled (fig. 53). The shorelines that mark the long dimension of the lake converge at about a 10° angle toward the southern margin of the salt dome, Hoskins Mound. Another fault, with a strike of approximately northwest-southeast, extends gulfward from Hoskins Mound and intercepts the eastern margin of Alligator Lake. The downthrown side, southwest of the fault line, supports low marshes. Several of the faults around Hoskins Mound, visible on photographs, appear to coincide with faults mapped in the subsurface by Bebout and others (1978).

Scattered Wetlands in Inland Areas

In inland areas of the Galveston-Houston atlas, numerous small wetlands are scattered across the coastal plain (pl. V). Collectively, these small, upland-surrounded marshes, ponds, transitional areas, and woodlands, comprise a significant component of the wetlands in the Galveston-Houston area. In many areas they follow certain trends or corridors across the coastal plain. Many have formed in abandoned, mud-filled channels and courses that are part of an extensive Pleistocene fluvial and distributary channel network (Fisher and others, 1972). In many areas, wetlands, particularly ponds and reservoirs, are the result of human activities.

Changes in Wetland Distribution, 1956-57 to 1979

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--Galveston-Houston Sheet (Fisher and others, 1972). Most of the aerial photographs used in the

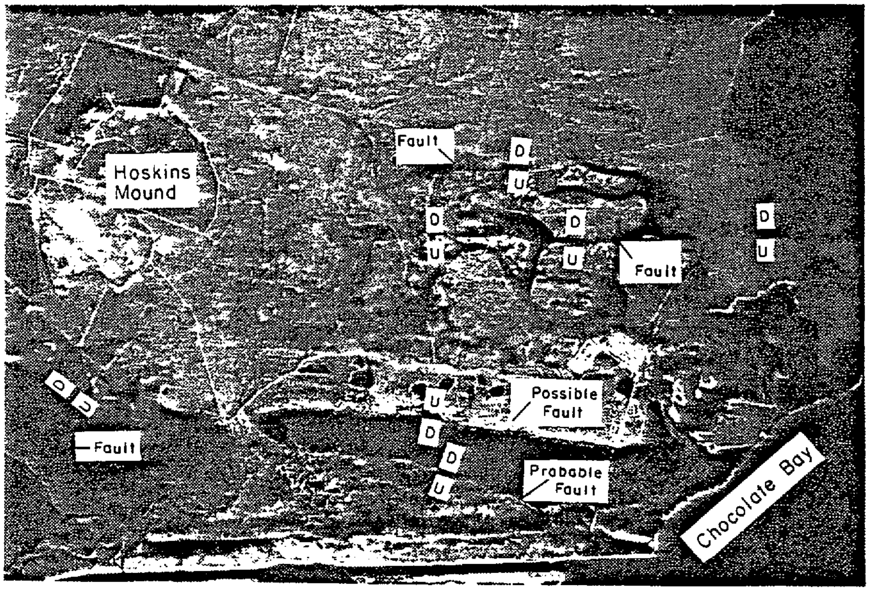


Figure 53. Faults in the vicinity of Hoskin's Mound (D = downthrown side, U = upthrown side).

earlier coastal atlas project were taken in 1956 and 1957 and for the submerged lands project (pi. V), in 1979 (for a small area in the northeast corner, 1982 photographs were used). Changes in natural environments, then, reflect this 22- to 23-year period. Caution must be used in making comparisons, however, for the following reasons: (1) wetland map units defined and mapped in this report , although similar to those defined and mapped in the coastal atlas, are not identical to them (table 16), (2) moisture and tidal conditions were at higher levels during 1979, which had above normal precipitation, than during 1956, which had lower than normal precipitation (drought conditions), (3) photographic interpreters were able to make more refined judgments concerning wetland distribution using the 1979, high-quality, color-infrared photographs, and (4) wetland mapping criteria probably varied, to some degree, between the two mapping projects. 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.

Modern Barrier - Tidal-Delta System

Among the changes in wetlands on the modern barriers (Bolivar Peninsula, Galveston Island, and Follets Island) is a decrease in the areal distribution of wind-tidal flats due to the expansion of salt-water marshes into these areas. This trend is particularly apparent in back-island areas of Bolivar Peninsula and Follets Island, but also on Galveston Island. In many areas there has apparently been an encroachment of salt-marsh vegetation into areas previously mapped as tidal flats. The more extensive flats in 1956 appear to owe their existence, in part, to a severe drought in 1956 which manifested itself in (1) increased evaporation and concentration of salts thereby inhibiting colonization of the flats by plants such as Spartina alterniflora, and Spartina patens, among others (Webb, 1983), and (2) lower sea-level (Morton and Pieper, 1977) resulting in more extensive flats as the shoreline moved bayward. The reduction in the areal extent of the flats by 1979 and corresponding increase in marshes can probably be attributed to (1) the recent rise in sea level (Hicks and Crosby, 1975), (2) natural compactional

DRAFT

subsidence (Swanson and Thurlow, 1973), (3) man-induced subsidence (Gabrysch and Bonnet, 1975), and (4) above normal precipitation during the late 1970's (fig. 6). These factors would tend to raise water levels (tidal and ground water) in 1979 thereby decreasing the width of the flats and leadingto more extensive and frequent inundation which would favor the establishment of marsh vegetation. The gradual submergence of wind-tidal flats from compactional subsidence and relative sea-level rise is a scenario similar to that reported by White and others (1978) for Mustang Island in the Corpus Christi area.

On the backside of Galveston Island and Follets Island, extensive marine grassflats shown on the Environmental Geologic Atlas maps are absent on plate V. Although some grassflats may have been present and not discernible on 1979 photographs, their areal distribution in 1979 is undoubtedly much less than that in 1956.

Some changes in wetlands on Bolivar Peninsula appear to be related to active faults. As mentioned in a previous section, land subsidence profiles using benchmark releveling data indicate that at least one fault (fig. 48) in the area is active. Approximately 0.3 ft (9 cm) of subsidence occurred on the downthrown side of the fault between 1936 and 1958 (Charles Kreitler, personal communication, 1984). Areas on the downthrown side of the fault, which crosses the back side of Bolivar Peninsula, changed from salt-water marsh to open water. Similar changes occurred along a suspected fault also crossing this large fan (fig. 48A, pl. V).

Some changes in wetlands on the back side of the modern barriers, especially Galveston Island, are related to human recreational/community development. The dredged channel networks and associated uplands on the bayward side of Galveston Island shown on plate V, generally have replaced tidal-flats, salt-water marshes, and vegetated barrier flats.

Bay Margin and Associated Mainland Areas

The extensive wetland areas along the inland margins of East Bay, West Bay, and Christmas Bay, have undergone significant changes between 1956 and 1979 in some areas. The most dramatic changes are inland from West Bay. Extensive areas of salt-water marsh inland from Jones Bay have been converted to shallow subaqueous flats, or areas of open water (pl. V; fig. 54). In addition much of thearea around Greens and Carancahua Lakes, mapped as fresh-to brackish-water marshes on the Environmental Geologic Atlas, were mapped as proximal, salt-water marshes on plate V. These changes from salt-marsh to open water, and brackish marsh to salt marsh are related to subsidence and subsequent inundation of the area by bay waters, There has been an encroachment of *Spartina alterniflora* into this area (Robert Bass, personal com munication, 1%34). These wetlands are in the peripheral areas of subsidence bowls centered on nearby Texas City and more distant Pasadena (fig. 55). Similar changes have occurred in the Swan Lake area near Texas City (pi. V). Locally, for example inland between Jones Bay and Carancahua Lake, marshes have encroached into areas previously mapped as barren, abandoned tidal creeks (Fisher and others, 1972). In the area of Jones Lake, residential developments, identifiable on plate V by intricate patterns of dredged channels and fringing uplands, have replaced fairly extensive salt marshes that occupied these areas in 1956 (Fisher and others, 1972).

An increase in fresh- to brackish-water marshes between Carancahua Lake and Halls Lake is related to dikes or levees and spoil ridges that appear to have reduced bay water inundation into this area. Although *Typha* sp., which is indicative of fresh- to brackish-salinity conditions! occurs in association with diked ponds in this area, the change from salt-water marsh to fresh- to brackish-water marsh may be more interpretational than real. Certainly, if the dikes or spoil ridges were breached by Hurricane Alicia in 1983, then the area will likely revert to salt-water marshes.

Inland from Christmas, Bastrop and Drum Bays, changes in wetlands reflect a trend toward expansion of fresh- to brackish-water marshes into inland areas previously mapped as prairie grasslands or inter distributary muds (Fisher and others, 1972). Also, transitional areas were mapped along much of the inland margins of these expanding marshes (pl. V). Some of the marsh expansion may be due to changes in mapping criteria and interpretation, but compac-

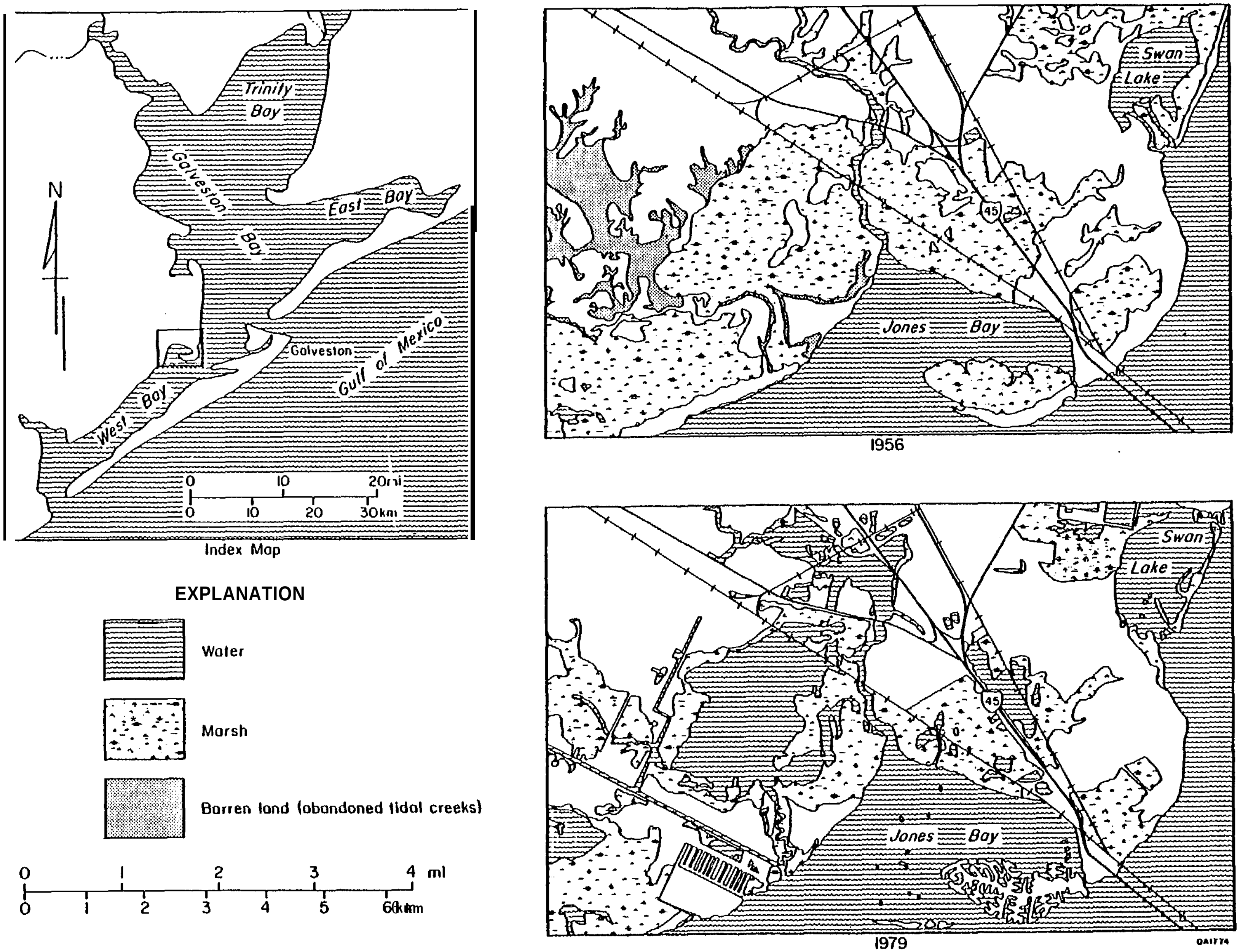


Figure 54. Changes in the distribution of wetlands between 1956 and 1979, in the vicinity of Jones Bay and Swan Lake. Note the increase in open water in 1979.

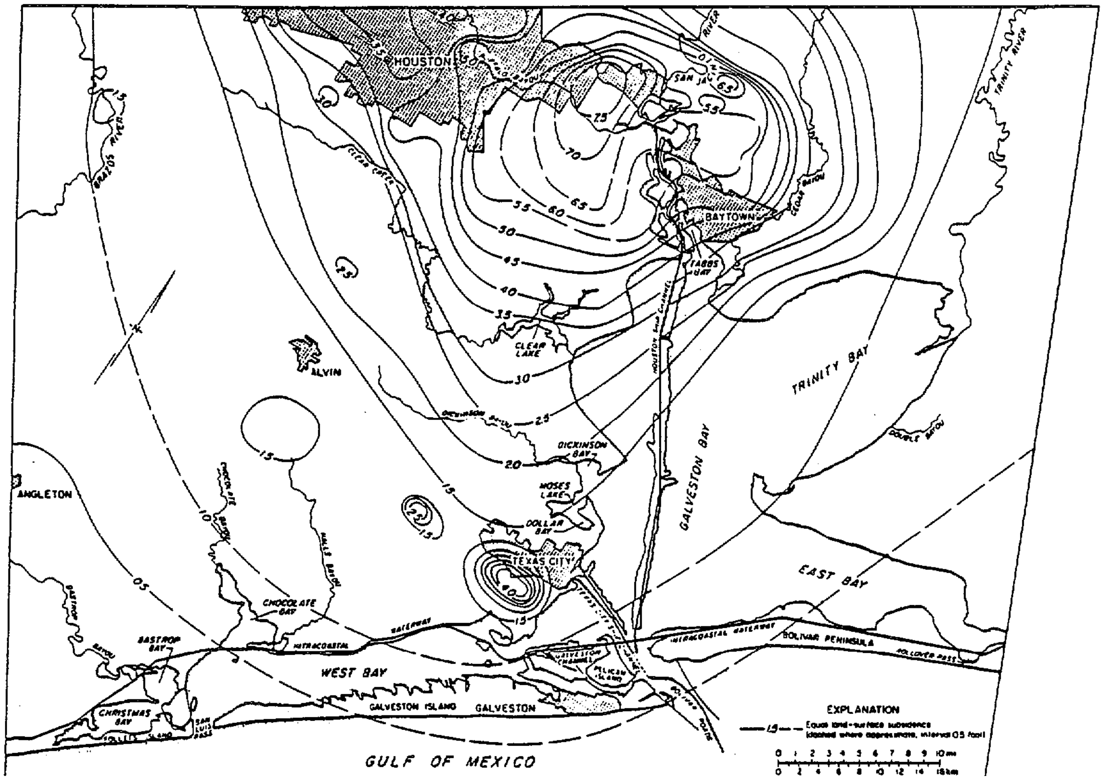


Figure 55. Subsidence of the Land Surface, 1943-1973 (modified from Gabrysch and Bonner, 1975).

tional subsidence and relative sea-level rise are processes that would contribute to the changes described.

Inland from East Bay, salt-water marshes shown on the Environmental Geologic Atlas in the area of Gordy Marsh and extending along the margin of East Bay from the Anahuac National Wildlife Refuge, were mapped as fresh- to brackish-water marshes on plate V. These changes are based primarily on photo interpretation and more recent vegetation and salinity data (refer to descriptions on major wetland areas). These marshes, however, are at the brackish end of the fresh- to brackish-water salinity spectrum. A local change inland from East Bay in the area southeast of Robinson Lake is associated with the series of parallel faults discussed in a previous section. A graben that has developed between two of the faults has produced slightly lower elevations and higher moisture conditions than the adjacent areas. This narrow corridor extends inland and was mapped as a high marsh (flanked by transitional areas), whereas it was previously mapped as an upland accretionary bay-margin unit.

Modern-Holocene Fluvial-Deltaic System

Among the most extensive changes of wetlands in the map area are those occurring along the valleys of the modern rivers and streams as a result of land-surface subsidence and valley submergence. The San Jacinto River is the most dramatic example of this effect. The lower reaches of the San Jacinto River in the area near its confluence with Buffalo Bayou, are near the center of subsidence (fig. 55) produced mostly from ground-water withdrawal (Gabrysch and Bonnet, 1975). By 1973 the lower part of the river had undergone between 3 and 6 ft (1 and 2 m) of subsidence. As subsidence occurs, submergence and resulting changes in wetland environments progress inland along the incised valley axis (fig. 56). The effect of the valley submergence on wetland environments from 1956 through 1979 is shown in figure 57. The most significant net change is “the encroachment of open water into the valley and the corresponding displacement. of fluvial woodlands and swamps. It should be noted that extensive areas of swamp shown on Environmental Geologic Atlas maps (Fisher and others, 1972) up the San

DRAFT

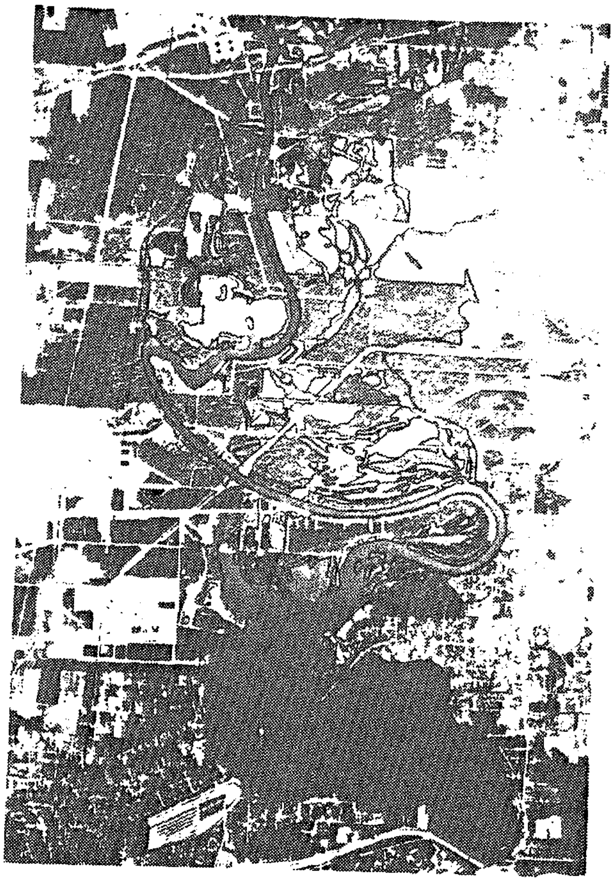
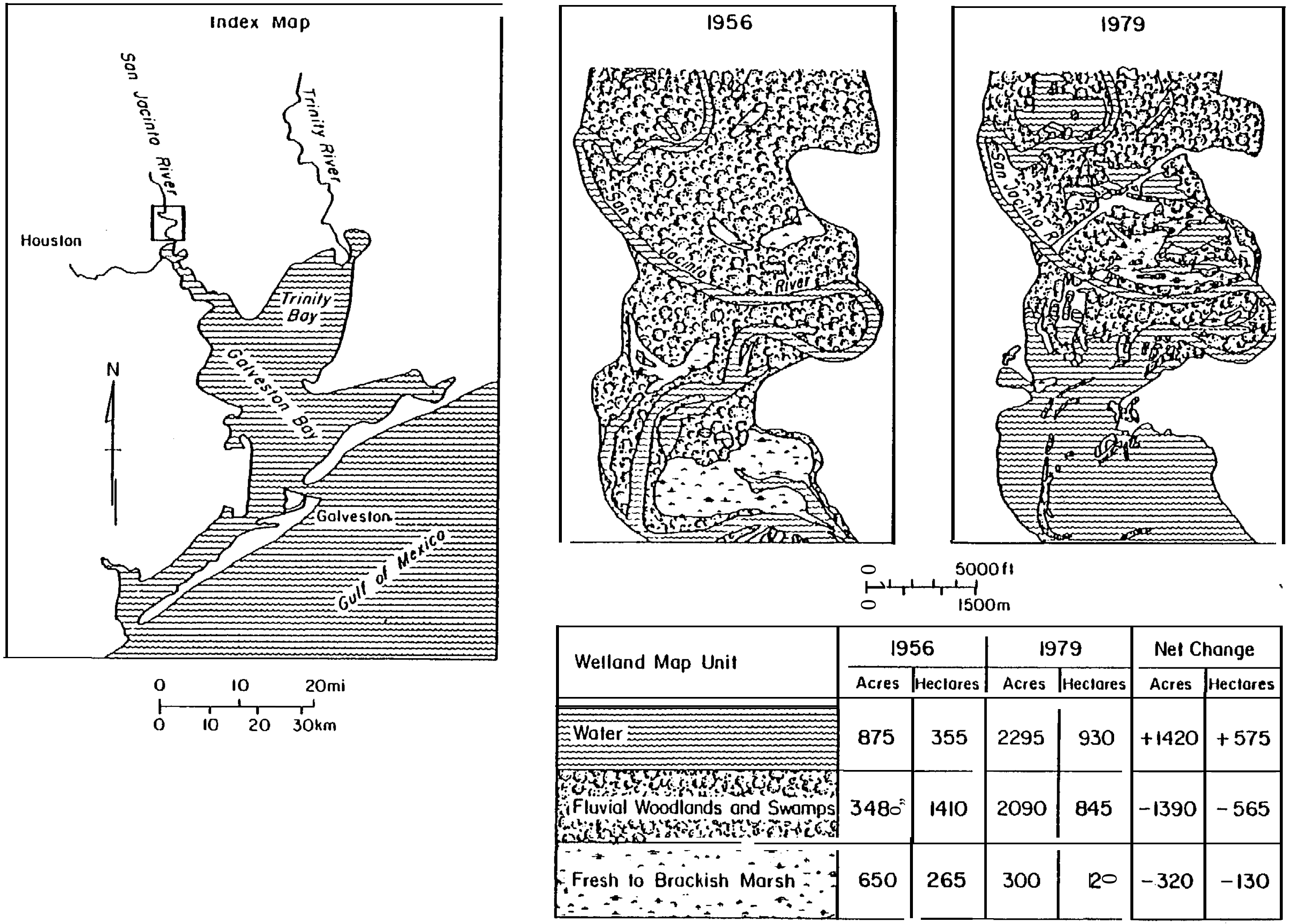


Figure 56. Aerial photograph, taken in 1979, of the lower reaches of the San Jacinto River.

DRAFT

HOUSTON AREA

Changes in the Distribution of Wetlands between 1956 and 1979 for a Segment of the San Jacinto River tha has undergone Subsidence



Wetland Map Unit	1956		1979		Net Change	
	Acres	Hectares	Acres	Hectares	Acres	Hectares
Water	875	355	2295	930	+1420	+575
Fluvial Woodlands and Swamps	3480	1410	2090	845	-1390	-565
Fresh to Brackish Marsh	650	265	300	120	-320	-130

Figure 57. Changes in the distribution of wetlands between 1956 and 1979 for a segment of the San Jacinto River near Houston, Texas (after White and others, in press).

Jacinto River valley, were mapped primarily as fluvial woodlands on plate V. This change is based more on mapping criteria than on actual changes in woodland species or moisture conditions.

The change in wetlands along the lower San Jacinto River valley is pronounced because of the proximity of the valley to the center of subsidence. Still, wetlands associated with other streams and valleys located around the Trinity and Galveston Bay System (fig. 4), are also experiencing change as a result of subsidence, both natural and human-induced, and relative sea-level rise. Changes in the lower valleys of bayous and creeks, such as Cedar Bayou, Clear Creek, and Dickinson Bayou located along the north and west sides of Galveston Bay, show some consistent trends. The trends reflect the following changes: (1) an increase in the extent of open water as water features become broader with respect to the valley axis and longer as the water encroaches farther up the valley, (2) a submergence and corresponding loss of marshes and woodlands in the valleys, and (3) the development, locally, of marshes along the valleys in more inland areas (pl. V, fig. 58).

The Trinity River valley is on the edge of the subsidence bowl; subsidence in this area between 1943 and 1973 was between 0.5 and 1.0 ft (0.15 to 0.3 m) (fig. 55). The combination of (1) man-induced subsidence, (2) natural compactional subsidence, and (3) relative sea-level rise, appear to be exceeding marsh sedimentation rates in many areas. This is reflected in a general increase in size of existing water features and the development of new ones. However, some of the most extensive increases in areas of open water in the Trinity River delta area are associated with human activities. For example, the large reservoir south of Cotton Lake (pl. V) was constructed as a cooling reservoir for a power plant located near Cedar Bayou. This reservoir replaced an area of fresh- to brackish-water marsh (Fisher and others, 1972). There are several other human modifications, such as the construction of dikes and levees, that have increased the extent of open water in the Trinity delta.

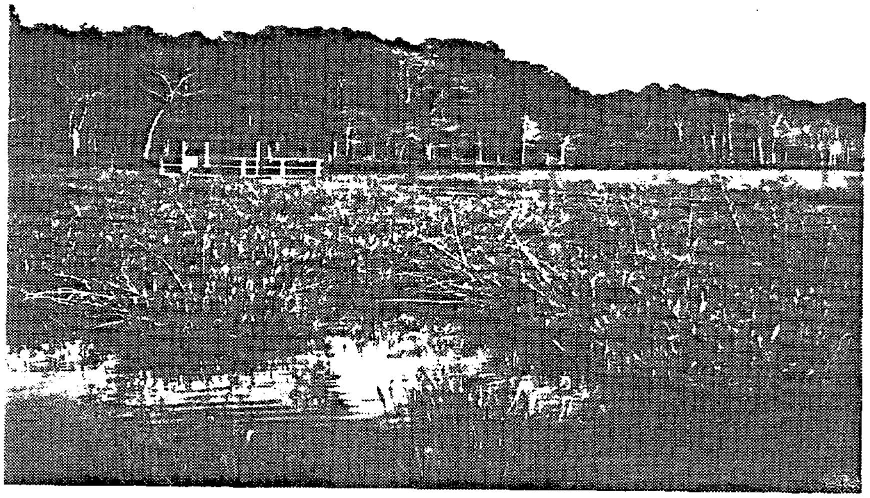


Figure 58. Inland fresh-water marsh along Clear Creek. Vegetation includes abundant *Sagittaria* sp.

Comparison of the Environmental Geologic Atlas map with plate V shows an extensive change from salt-water marshes to fresh- to brackish-water marshes along the margin of the delta adjacent to Trinity Bay. Although the drought that occurred in the mid 1950's (preceding the date of the earlier mapping photographs) may have produced more saline conditions in this area, the change to fresh- to brackish-water marshes (pl. V) is based on more recent vegetation surveys (for more information on species composition, refer to the section on descriptions of major wetland areas).

Changes along the Brazes River fluvial system, which crosses the northwest corner of the map, are in part the result of changes in mapping criteria. Although there has been a reduction in the areal distribution of woodlands between 1956 and 1979, the reduction is not as extensive as indicated on plate V. The fluvial woodland map unit used in the Environmental Geologic Atlas included areas of prairie grasslands, whereas only woodland areas are shown on plate V.

Summary of Changes

In summary, a general visual comparison of wetlands shown on maps from the Environmental Geologic Atlas (Fisher and others, 1972) with wetlands depicted on plate V of this report, reveals that among the changes that have occurred, at least locally, in the Galveston-Houston area are:

(1) the expansion of open water, or shallow subaqueous flats into areas previously occuped by marshes, woodlands, and uplands,

(2) the expansion of marshes along the back side of the modern barriers into areas previously characterized by wind-tidal flats,

(3) the formation of wetlands farther up the valleys of bayous and creeks,

(4) the expansion of existing marshes along their landward margins,

(5) the development of wetter conditions along the downthrown sides of faults especially in areas affected by tides,

DRAFT

(6) the reduction or elimination of marine grasses along the bayward margins of barrier islands,

(7) the reduction or modification of wetlands as a result of human activities.

Among the processes that are responsible for many of these changes are: (1) man-induced subsidence, (2) natural compactional subsidence, and (3) a rise in sea level. Under these conditions, many of the changes noted above would be expected, such as submergence of marshlands, woodlands, and uplands, and the spread of marshes into more landward areas. In contrast to the trend of expansion of marshes along their landward margins is the retreat of marshes along their bayward margins. Historical monitoring of bay shoreline changes in the Galveston-Houston area indicate, overall, that unprotected bay shorelines, which include extensive marshes, are undergoing erosion at rates of up to 10 ft/yr (3 m/yr), locally (Paine and Morton, in preparation).

It should be restated that some changes in wetlands as delineated on 1956 photographs (Fisher and others, 1972) and 1979 photographs (pl. V), can be attributed to contrasting climatic conditions manifested by a drought in 1956 and above normal precipitation in 1979. In addition, changes in the distribution and types of wetlands in some areas are the result of changes in map units, mapping criteria, photographic quality, and available field data. Some changes are associated with human development of the region (Finley, 1978).

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 Galveston-Houston area.

ACKNOWLEDGMENTS

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

Financial assistance was provided in part by (1) the General Land Office of Texas with funds in accordance with section 305 of the Coastal Zone Management Act for Coastal Zone Management Program (CZMP), (2) the Governor's Budget and Planning Office with grants in accordance with section 308 of the same act for the Coastal Energy Impact Program (CEIP), CZMP and CEIP funding are administered by the National Oceanic and Atmospheric Administration of the U. S. Department of Commerce, and (3) the Minerals Management Service of the U. S. Department of Interior. Contract numbers with the General Land Office were IAC(80-81)- 1201, IAC(78-79)- 1910, IAC(78-79)-0539, IAC(76-77)-1244, and IAC (76-77)-0833. Contract numbers with the Governor's Budget and Planning Office were CZ80M935019, IAC(80- 81)-0865, and IAC(78- 79)-1210. The contract number with the Minerals Management Service is 14-12-0001-30070.

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, 3. 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, 3. 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 Christianson, 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, Ken y 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, David H. LeComte, and Jeffrey Paine, under the supervision of William A. White, R. A. Morton, and 3. 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.

Several individuals and agencies assisted in benthic macroinvertebrate identification. These included Marian H. Pettibone, Kristian Fauchald, Meredith L. Jones, Stephen L. Gardiner, and Joseph Rosewater, Smithsonian Institution; Joan Uebelacker and Paul G. Johnson, Barry

DRAFT

Vittor and Associates, Inc., Mobile, Alabama; Nancy N. Rabalais, Steve Rabalais, and Mark Poff, The University of Texas Marine Science Institute, Port Aransas; Robert Robertson, Academy of Natural Science, Philadelphia, Pennsylvania; Thomas H. Perkins, Florida Department of Natural Resources, St. Petersburg, Florida; Eric Powell, Texas A&M University, Department of Oceanography; Larry D. McKinney and Donald E. Harper, Jr., Texas A&M University Marine Laboratory, Galveston, Texas; Harold W. Harry, Bellaire, Texas; and Granville Treece, St. Croix, U.S. Virgin Islands.

Computer programs for benthic macroinvertebrate distribution analyses were provided by Bill Longley, General Land Office of Texas; Scott Holt, The University of Texas Marine Science Institute, Port Aransas; and Rod Harwood, The University of Texas at Austin, Department of Geological Sciences.

Many individuals within the Bureau of Economic Geology assisted in production of the report. Directoral support was provided by L. F. Brown, Jr., and E. G. Wermund.

Manuscript word processing was by Dorothy C. Johnson, and typesetting was by Fannie M. Sellingsloh, under the direction of Lucille C. Harrell. Proofreading was by Diane L. Hall, Mary E. Johansen, and Susan H. Shaw, under the supervision of Susann V. Doenges, Editor-in-Charge.

Cartography of plates was by Barbara M. Hartmann (pls. V and VI). Drafting of text figures was by Mark T. Bentley, Margaret L. Evans, Jeffrey Horowitz, Jamie McClelland, and Richard M. Platt under the direction of Richard L. Dillon, Chief Cartographer. Text illustration camerawork was by James A. Morgan. Design and layout were by Jamie S. Haynes.

Computer data processing was by Elizabeth D. Orr, Audie L. Dobbs, Richard W. Ozment, and Mark E. McClelland, under the supervision of Michael P. Roberts. Field vehicles and equipment support were provided by Tommy Glimp and George Donaldson.

During the sampling and analysis phases, the Submerged Lands of Texas Project was fully integrated with U.S. Geological Survey and Bureau of Land Management studies of the Federal

Outer Continental Shelf of South Texas. H. L. Berryhill, Jr., L. E. Garrison, and Charles W. Holmes helped coordinate the U.S. Geological Survey cooperative effort.

C. M. Woodruff, Jr., of the Bureau of Economic Geology deserves special mention for convincing State and Federal planners that firm knowledge of substrate, processes, and biota on the inner continental shelf (that is, the offshore State-owned submerged lands) is essential for making decisions on environmental issues related to both production and transportation of petroleum found on the Outer Continental Shelf.

DRAFT

REFERENCES

Adams, D. B., and Tingley, C. A., 1977, A study of the hydrological and nutrient exchange processes in the Trinity River delta, Texas, Part II, Marsh habitats and primary production in the Trinity River delta: report prepared for Texas Department of Water Resources by Espey, Huston and Associates, Inc., Document no. 77-103, Job no. 0216, 20 p.

Allan, P. F., 1950, Ecological bases for land use planning in Gulf coast marshlands: Journal of Soil and Water Conservation, v. 5, p. 57-62 and 85.

Andrews, P. B., 1970, Facies and genesis of a hurricane-washover fan, St. Joseph Island, central Texas coast: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 67, 147 p.

Armstrong, Howard W., Fucik, Ken, Anderson, Jack W., and Neff, Jerry M., 1979, Effects of oilfield brine effluent on sediments and benthic organisms in Trinity Bay, Texas, in Cowell, E. B., and Anderson, J. W., eds., Marine Environmental Research: Applied Science Publishers LTD, Ripple Road, Essex, England, p. 55-69.

Aston, S. R., 1978, Estuarine chemistry, in Riley, J. P., and Chester, R., eds., Chemical oceanography, 2d cd., v. 7: New York, Academic Press, p. 361-440.

Bebout, D. G., Loucks, R. G., and Gregory, A. R., 1978, Frio sandstone reservoirs in the deep. subsurface along the Texas Gulf Coast, their potential for production of geopressured geothermal energy: The University of Texas at Austin, Bureau of Economic Geology, Report of Investigations No. 91, 93 p.

Bechtel, T. J., and Copeland, B. J., 1970, Fish species diversity indices as indicators of pollution in Galveston Bay, Texas: Contributions in Marine Science, v. 15, p. 103-132.

Benton, A. R., Jr., Snell, W. W., and Clark, C. A., 1979, Monitoring and mapping of Texas coastal wetlands, Galveston Bay and Sabine Lake areas, 1978 growing season: College Station, Texas A&M University, Remote Sensing Center, Technical Report R.SC- 102, 123 p.

Bernard, H. A., Major, C. F., Jr., and Parrott, B. S., 1959, The Galveston Island and environs: a model for predicting reservoir occurrence and trend: Gulf Coast Association Geological Societies Transactions, v. 9, p. 221-224.

Bernard, H. A., Major, C. F., Jr., Parrott, B. S., and LeBlanc, R. J., Sr., 1970, Recent sediments of southeast Texas, a field guide to the Brazes Alluvial and deltaic plains and the Galveston barrier island complex: The University of Texas at Austin, Bureau of Economic Geology Guidebook 11, 236 p.

Berryhill, H. L., Jr., 1975, Sediment characteristics of the inner shelf environmental geologic map, Port Aransas area, Texas: preliminary results: U.S. Geological Survey Open-File Report 75-218, 31 p.

Blevins, A. L., and Novak, W. J., 1975, Regional environmental analysis of the Houston-Galveston region: Texas Parks and Wildlife Department, Texas Outdoor Recreation Plan, 236 p.

Bodine, B. R., 1969, Hurricane surge frequency estimated for the Gulf Coast of Texas: U.S. Army Corps of Engineers, Coastal Engineer Research Center Technical Memorandum 26, 32 p.

Boesch, D. F., 1972, Species diversity of marine macrobenthos in the Virginia area: Chesapeake Science, v. 13, no. 3, p. 205-211.

________ 1977, Application of numerical classification in ecological investigations of water pollution: Virginia Institute of Marine Science, special scientific report no. 77, 112 p.

Brown, L. F., Jr., project coordinator, 1972-1980, Environmental Geologic Atlas of the Texas Coastal Zone: The University of Texas at Austin, Bureau of Economic Geology, 7 atlases.

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

Bullard, F. M., 1942, Source of beach and river sands on Gulf Coast of Texas: Geological Society of America Bulletin, v. 53, no. 7, p. 1021-1043.

Bryan, G. W., and Ward, A. E., 1965, The absorption and loss of radioactive and non-radioactive manganese by the lobster, Homarus vulgaris: Journal of the Marine Biological Association of the United Kingdom, v. 45, no. 1, p. 65-95.

Chabreck, R. H., 1972, Vegetation, water, and soil characteristics of the Louisiana coastal region: Louisiana State University and Agricultural and Mechanical College, Bulletin no. 664, 72 p.

Cliff oral, H. T., and Stephenson, W., 1975, An introduction to numerical classification: New York, Academic Press, 220 p.

Correll, D. S., and Correll, H. B., 1975, Aquatic and wetland plants of southwestern United States: Stanf oral, California, Stanford University Press, 2 volumes, 1777 p.

Cowardin, L. M., Carter, V., Golet, F. C., and LaRoe, E. T., 1979, Classification of wetlands and deep-water habitats of the United States: Washington, D.C., U.S. Department of the Interior, Fish and Wildlife Service Office of Biological Services, FWS/OBS-79/31, 103 p.

Cowardin, L. M., Golet, F. C., and LaRoe, E. T., 1977, Classification of wetlands and deep-water habitats of the United States (an operational draft): Washington, D.C., U.S. Department of the Interior, Fish and Wildlife Service, 100 p.

Defenbaugh, Richard E., 1976, A study of the benthic macroinvertebrates of the continental shelf of the northern Gulf of Mexico: Texas A&M University, Ph.D. dissertation, 476 p.

de Groot, A. J., Salomons, W., and Allersma, E., 1976, Processes affecting heavy metals in estuarine sediments, in Burton, 3. D., and Liss, P. S., eds., Estuarine chemistry: New York, Academic Press, p. 131-157.

Diener, R. A., 1975, Cooperative Gulf of Mexico estuarine inventory and study--Texas: area description: National Oceanic and Atmospheric Administration, Technical Report, National Marine Fisheries Service Circular 393, 129 p.

Finley, R. J., 1978, Evaluating the environmental geologic map, Environmental Geologic Atlas of the Texas Coastal Zone: The University of Texas at Austin, Bureau of Economic Geology Research Note 11, 26 p.

Fisher, W. L., McGowen, J. H., Brown, L. F., Jr., and Groat, C. G., 1972, Environmental Geologic Atlas of the Texas Coastal Zone–Galveston-Houston Area: The University of Texas at Austin, Bureau of Economic Geology, 9 maps, 91 p.

Fleetwood, R. J., undated, Plants of Brazoria/San Bernard National Wildlife Refuges, Brazoria County, Texas: U.S. Department of the Interior Fish and Wildlife Service, 61 p.

Folk, Robert L., 1974, Petrology of sedimentary rocks: Austin, Texas, Hemphill Publishing Company, p. 16-24.

Förstner, U., Müller, G., and Stoffers, P., 1978, Heavy metal contamination in estuarine and coastal sediments: sources, chemical association and diagenetic effects, in Biogeochemistry of estuarine sediments: proceedings of UNESCO/SCOR workshop, Paris, p. 49-69.

Förstner, U., and Wittman, G. T. W., 1981, Metal pollution in the aquatic environment, 2nd cd., New York, Springer-Verlag, 486 p.

Gabrysch, R. K., and Bonnet, C. W., 1975, Land-surface subsidence in the Houston-Galveston region, Texas: Texas Water Development Board, Report 188, 19 p.

Gillard, Robert M., 1974, Distribution, abundance, and species diversity of macrobenthic and meiobenthic invertebrates in relation to Houston Ship Channel pollution in upper Galveston Bay and Tabbs Bay, Texas: Texas A&M University, Ph.D. dissertation, 186 p.

Gilmore, Gil, and Trent, Lee, 1974, Abundance of benthic macroinvertebrates in natural and altered estuarine areas: U.S. Dept. of Commerce NOAA technical report NMFS SSRF-677, 13 p.

Goldberg, E. D., 1954, Marine geochemistry, 1. Chemical scavengers of the sea: Journal of Geology, v. 62, p. 249-265.

DRAFT

Grimes, D. J., and Marranzino, A. P., 1968, Direct current arc and alternating current spark emission spectrographic field methods for the semi quantitative analysis of geologic materials: U.S. Geological Survey Circular 591, 6 p.

Guy, R. D., and Chakrabarti, C. L., 1975, Distribution of metal ions between soluble and particulate forms (abs.): International Conference on heavy metals environment , Toronto, Canada, p. D-29-30.

Harper, Donald E., Jr., 1970, Ecological studies of selected level-bottom macroinvertebrates off Galveston, Texas: Texas A&M University, Ph.D. dissertation, 314 p.

Harry, H. W., 1976, Correlation of benthic mollusca with substrate composition in lower Galveston Bay, Texas: Veliger, v. 19, no. 2, p. 135-152.

Hayes, M. O., 1967, Hurricanes as geological agents: case studies of Hurricanes Carla, 1961, and Cindy, 1963: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 61, 56 p.

Henry, Clyde Allan, 1976, A study of offshore benthic communities in natural areas and in areas affected by dredging and dredged material disposal: Texas A&M University, [Master's thesis, 186 p.

Herber, J. P., 1981, Holocene sediments under Laguna Madre, Cameron County, Texas: The University of Texas at Austin, Master's thesis, 664 p.

Hicks, S. D., and Crosby, 3. E., 1975, An average, long period, sea-level series for the United States: National Oceanic and Atmospheric Administration Technical Memoir NOS 15, 6 p.

Holland, 3. S., Maciolek, N. J., Kalke, R. D., and Oppenheimer, C. H., 1975, A benthos and plankton study of the Corpus Christi, Copano, and Aransas Bay systems: report on data collected during the period July 1974-May 1975 and summary of the three-year project: The University of Texas at Port Aransas Marine Science Institute, Final report to the Texas Water Development Board, 171 p.

Holland, J. S., Maciolek, N. 3., and Oppenheimer, C. H., 1973, Galveston Bay benthic community structure as an indicator of water quality: The University of Texas, Institute of Marine Science Publications, v. 17, p. 169-188.

Holmes, C. W., 1974, Maps showing distribution of selected elements in surface-bottom sediment of Corpus Christi and Baffin Bays, Texas: U.S. Geological Survey Miscellaneous Field Studies 571, 2 p.

——— 1977, Effects of dredged channels on trace-metal migration in an estuary: U.S. Geological Survey Journal of Research, v. 5, no. 2, p. 243-251.

——— 1982, Geochemical indices of fine sediment transport, northwest Gulf of Mexico: Journal of Sedimentary Petrology, v. 52, no. 1, p. 307-321.

Holmes, C. W., Slade, E. A., and McLerran, C. J., 1974, Migration and redistribution of zinc and cadmium in marine estuarine systems, Environmental Science and Technology, v. 8, no. 3, p. 255-259.

Hopkins, S. H., Anderson, J. W., and Horvath, K., 1973, The brackish water clam *Rangia cuneata* as indicator of ecological effects of salinity changes in coastal waters: Vicksburg, Mississippi, U.S. Army Engineer Waterways Experiment Station, by Texas A&M University Department of Biology, Research Foundation, Contract No. DACW 39-71-C-007, Contract Report H-73- 1, 250 p.

Ingram, R. L., 1971, Sieve analysis, *in* Carver, R. E., ed., Procedures in sedimentary petrology: New York, Wiley-Interscience, p. 49-67.

Jackson, M. L., 1958, Soil chemical analysis: New York, Prentice-Hall, 498 p.

Jenne, E. A., 1968, Controls on Mn, Fe, Co, Ni, Cu, and Zn concentrations in soils and waters: the significant role of hydrous Mn and Fe oxides, *in* Gould, R. F., cd., Trace inorganic in water: American Chemical Society Advances in Chemistry Series 73, p. 337-387.

Johnson, Ralph Gordon, 1971, Animal-sediment relations in shallow water benthic communities: Marine Geol., v. 11, p. 93-104.

Keith, M. L., and Degens, E. T., 1959, Geochemical indicators of marine and fresh-water sediments, in Cronin, L. E., ed., Estuarine research, v. I, Chemistry, biology, and the estuarine system: New York, Academic Press, New York, p. 38-61.

Kinsman, D. J. J., 1969, Modes of formation, sedimentary associations, and diagnostic features of shallow-water and supratidal evaporates: American Association of Petroleum Geologists Bulletin, v. 53, no. 4, p. 830-840.

Krauskopf, K. B., 1956, Factors controlling the concentration of thirteen rare metals in sea water: Geochimica et Cosmochimica Acts, v. 9, p. 1-328.

Krumbein, W. C., 1934, Size frequency distributions of sediments: Journal of Sedimentary Petrology, v. 4, p. 65-77.

Krumbein, W. C., and Pettijohn, F. J., 1938, Manual of sedimentary petrography: New York, D. Appleton-Century Co., p. 43-75.

Mackin, J. G., 1971, A study of the ef feet of oil field brine effluents on biotic communities in Texas estuaries: Texas A&M University Research Foundation Project 735, 73 p.

Martinez, A. R., 1973, Coastal hydrographic and meteorological study, coastal fisheries project report, Texas: Texas Parks and Wildlife Department, p. 111-172.

__________ 1974, Coastal hydrographic and meteorological study, coastal fisheries project report, Texas: Texas Parks and Wildlife Department, p. 61- 108.

__________ 1975, Coastal hydrographic and meteorological study, coastal fisheries project report, Texas: Texas Parks and Wildlife Department, p. 100-157.

McAtee, J. W., 1976, Autecological aspects of Gulf cordgrass [Spartina spartinae (Trin.) Hitchc. 1 communities of the Texas coastal prairie, in Range ecological and management research on the coastal prairie, progress report of cooperative studies: Welder Wildlife Foundation, Sinton, Texas, and Texas A&M University, Texas Agricultural Experiment Station, College Station, p. 2-12.

DRAFT

McBee, 3am es Terrell, Jr., 1975, Species composition, distribution, and abundance of macrobenthic organisms in the intake and discharge areas before and after the construction and operation of the Cedar Bayou electric power station: Texas A&M University, Master's thesis, 220 p.

McGowen, 3. H., Byrne, 3. R., and Wilkinson, B. H., 1979, Geochemistry of bottom sediments, Matagorda Bay system, Texas: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 79-2, 64 p.

McGowen, J. H., Groat, C. G., Brown, L. F., Jr., Fisher, W. L., and Scott, A. J., 1970, Effects of Hurricane Celia--a f ecus on environmental geologic problems of the Texas Coastal Zone: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 70-3, 35 p.

McGowen, J. H., and Morton, R. A., 1979, Sediment distribution, bathymetry, faults, and salt diapirs, submerged lands of Texas: The University of Texas at Austin, Bureau of Economic Geology, 31 p., 7 maps.

McGowen, J. H., and Morton, R. A., 1979, Surface sediment distribution maps, Texas submerged lands, Corpus Christi and Port Lavaca sheets: The University of Texas at Austin, Bureau of Economic Geology, scale 1:125,000.

McIntosh, R. P., 1967, An index of diversity and the relation of certain concepts to diversity: Ecology, V. 48, p. 392-404.

Moffett, A. W., 1975, The hydrography and macro-biota of the Chocolate Bayou estuary, Brazoria County, Texas (1969- 1971} Texas Parks and Wildlife Department Technical Series No. 14, 72 p.

Morton, R. A., 1977, Historical shoreline changes and their causes, Texas Gulf Coast: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 77-6, p. 352-364.

__________ 1981, Formation of storm deposits by wind-forced currents in the Gulf of Mexico and the North Sea: International Association of Sedimentologists, Special Publication no. 5, p. 385-396.

Morton, R. A., and Nummedal, D., 1982, Regional geology of the northwest Gulf Coastal Plain, in Sedimentary processes and environments along the Louisiana-Texas coast: Geological Society of America, annual meeting field trip guidebook, p. 3-25.

Morton, R. A., and Pieper, M. J., 1977, Shoreline changes along Mustang and north Padre Islands (Aransas Pass to Mansfield Channel} The University of Texas at Austin, Bureau of Economic Geology Geological Circular 77-1.

Morton, R. A., and Winker, C. D., 1979, Distribution and significance of coarse biogenic and elastic deposits on the Texas inner shelf: Gulf Coast Association of (Geological Societies Transactions, v. 29, p. 136-146.

Nance, H. S., 1982, Textural analyses of marine benthic sediments, Texas Coastal Zone: The University of Texas at Austin, Bureau of Economic Geology Open-File Report No. OF-BR-1982-1, 16 p.

Nissenbaum, A., and Swaine, D. 3., 1976, Organic matter-metal interactions in Recent sediments: the role of humic substances: Geochimica et Cosmochimica Acts, v. 40, p. 809-816.

Paine, J. G., and Morton, R. A., in preparation, Historical shoreline changes in the Galveston Bay system, Texas Gulf Coast: The University of Texas at Austin, Bureau of Economic Geology Geological Circular.

Parker, P. L., 1962, Zinc in a Texas bay: University of Texas, Port Aransas, Publications of the Institute of Marine Science, v. 8, p. 75-79.

Parker, R. H., 1960, Ecology and distributional patterns of marine macro-invertebrates, northern Gulf of Mexico, in Shepard, F. P., Phleger, F. B., and van Andel, T. H., eds., Recent sediments northwest Gulf of Mexico: Tulsa, Oklahoma, American Association of Petroleum Geologists, p. 302-337.

penfound, W. T., and Hathaway, E. S., 1938, Plant communities in the marshlands of southeastern Louisiana: Ecological Monographs, v. 8, no. 1, 56 p.

Poff, Mark Jay, 1973, Species composition, distribution and abundance of macrobenthic organisms in the intake and discharge areas after construction and operation of the Cedar Bayou electric power station: Texas A&M University, Master's thesis, 300 p.

Potter, P. E., Shimp, N. F., and Witters, J., 1963, Trace elements in marine and fresh-water argillaceous sediments: Geochimica et Cosmochimica Acts, v. 27, p. 669-694.

Purdy, E. G., 1964, Sediments as substrates, in Imbrie, J., and Newell, N. D., eds., Approaches to paleoecology: New York, Wiley, 432 p.

Rashid, M. A., 1974, Absorption of metals on sedimentary and peat humic acids: Chemical Geology, v. 13, p. 115-123.

Rehkemper, L. F., 1969, Sedimentology of Holocene estuarine deposits, Galveston Bay, in Lankford, R. R., and Rogers, 3. J. W., eds., Holocene geology of the Galveston Bay area: Houston Geol. Sot., Delta Study Group, pp. 53-77.

Reid, George K., Jr., 1955, A summer study of the biology and ecology of East Bay, Texas: Texas Journal of Science, v. VII, no. 3, p. 316-343.

Rice Center for Community Design and Research, 1974, Environmental analysis for development planning, Chainhers County, Texas, An approach to natural environmental analysis, Technical Report, Volume one: Houston, Texas, Rice Center, 531 p.

Sanders, H. L., 1958, Benthic studies in Buzzards Bay. I. Animal-sediment relationships: Limnology and Oceanography, v. III, no. 3, p. 245-258.

__________ 1968, Marine benthic diversity: a comparative study: American Naturalist, v. 102, no. 925, p. 243-282.

Schlee, J., 1966, A modified Woods Hole rapid sediment analyzer: Journal of Sedimentary Petrology, v. 36, p. 403-413.

Shepard, F. P., 1960, Rise of sea level along northwest Gulf of Mexico, in Shepard, F. P., Phleger, F. B., and van Andel, T. I-1., eds., Recent sediments, northwest Gulf of Mexico: Tulsa, Oklahoma, American Association of Petroleum Geologists, p. 338-344.

Shepard, F. P., and Moore, D. G., 1955, Central Texas coast sedimentation: characteristics of sedimentary environment, recent history, and diagenesis: American Association of Petroleum Geologists Bulletin, v. 39, no. 8, p. 1463-1593.

________ 1960, Bays of central Texas coast, in Shepard, F. P., Phleger, F. B., and van Andel, T. H., eds., Recent sediments, northwest Gulf of Mexico: Tulsa, Oklahoma, American Association of Petroleum Geologists, p. 117-152.

Shew, D. M., Baumann, R. H., Fritts, T. H., and Dunn, L. S., 1981, Texas barrier island region ecological characterization: environmental synthesis papers: Washington, D.C., U.S. Department of, the Interior, Fish and Wildlife Service Office Of Biological Services, FWS/OBS-81/32, 413 p.

Shideler, G. L., 1976, A comparison of electronic particle counting and pipette techniques in routine mud analysis: Journal of Sedimentary Petrology, v. 46, p. 1017-1025.

Shimp, N. F., Leland, H. V., and White, W. A., 1970, Distribution of major, minor, and trace constituents in unconsolidated sediments from southern Lake Michigan: Illinois Geological Survey Environmental Geology Notes, No. 32, 19 p.

Shimp, N. F., Schleicher, J. A., Ruth, R. R., Heck, D. B., and Leland, H. V., 1971, Trace element and organic carbon accumulation in the most recent sediments of southern Lake Michigan: Illinois State Geological Survey Environmental Geology Notes, No. 41, 25 p.

Sholkovitz, E. R., 1976, Flocculation of dissolved organic and inorganic matter during the mixing of river water and seawater: Geochimica et Cosmochimica Acts, v. 40, p. 831-845.

Simpson, R. H., and Lawrence, M. B., 1971, Atlantic hurricane frequencies along the U.S. coastline: U.S. Department of Commerce, National Oceanic and Atmospheric Administration Technical Memorandum NWSSR-58, 14 p.

Suess, Eduard, 1904, Das Antlitz der Erde (The Face of the Earth), translated by Sollas, H. B.C.: Oxford, Clarendon Press, v.I, 126p.

Suter, 3. R., 1980, Concentration, distribution, and behavior of heavy metals in recent sediments, Corpus Christi Ship Channel Inner Harbor: The University of Texas at Austin, Master's thesis, 127 p.

Swanson, R. L., and Thurlow, C. I., 1973, Recent subsidence rates along the Texas and Louisiana coasts as determined from tide measurements: Journal of Geophysical Research, v. 78, no. 15, p. 2665-2671.

Texas Department of Water Resources, 1978, Hydrological and biological studies of the Trinity River Delta, Texas: Texas Department of Water Resources, LP-70, 176 p.

——————— 1981, Trinity-San Jacinto Estuary: a study of the influence of freshwater inflows: Texas Department of Water Resources, LP-113, 310 p.

Thorne, L. T., and Nickless, G., 1981, The relation between heavy metals and particle size fractions within the Severn Estuary (U.K.) inter-tidal sediments: The Science of the Total Environment, v. 19, p. 207-213.

Thornthwaite, C. W., 1948, An approach toward a rational classification of climate: Geographical Review, v. 38, no. 1, p. 55-94.

Thornthwaite, C. W., and Mather, J. R., 1957, Instructions and tables for computing potential evapotranspiration and the water balance: Publications in Climatology, Laboratory of Climatology, Centerton, New Jersey, v. X, no. 3.

Turekian, K. K., 1965, Some aspects of the geochemistry of marine sediments, in Riley, 3. P., and Skirrow, G., eds., Chemical Oceanography, v. 2, New York, Academic Press, p. 81-126.

Turekian, K. K., and Wedepohl, K. H., 1961, Distribution of elements in some major units of the Earth's crust: Geological Society of America Bulletin, v. 72, p. 175-192.

U.S. Army Corps “of Engineers, 1956, Wave statistics for the Gulf of Mexico off Caplan, Texas: Beach Erosion Board, Corps of Engineers, Technical Memorandum no. 86, 51 p.

__________ 1972, Texas Coast hurricane studv: Galveston District, Corps of Engineers.

U.S. Coast and Geodetic Survey, Nautical charts, 1938-1939: Rockville, Maryland, U.S. Department of Commerce, Environmental Science Services Administration, Coast and Geodetic Survey.

U.S. Department of Commerce, 1978, Tide Current Tables 1979, Atlantic coast of North America: National Oceanic and Atmospheric Administration, National Ocean Survey, 231 p.

U s . Environmental Protection Agency, 1974, Proposed guidelines for determining acceptability of dredged “sediments disposal in EPA Region VI: Dallas, Texas, unpublished, 4 p.

u..% Fish and Wildlife Service, 1982, National wetlands inventory draft maps: U.S. Department of the Interior.

Verbeek, E. R., and Clanton, U. 5., 1981, Historically active faults in the Houston Metropolitan area, Texas: in Etter, E. M., cd., Houston area environmental geology: surface faulting, ground subsidence, hazard liability: Houston Geological Society, p. 28-68.

Vinogradov, A. P., 1962, Average contents of chemical elements in the principal types of igneous rocks of the earth’s crust: Geochemistry, no. 7, p. 641-664.

Warshaw, S., 1976, Metals concentrations in water and sediment of Texas: Texas Water Quality Board (Texas Department of Water Resources) Special Report No. 4, 71 p.

Webb, 3. W ., 1983, Soil water salinity variations and their effects on Spartina alternif lora: Contributions in Marine Science, v. 26, p. 1-13.

Wedepohl, K. H., 1960, Spurenanal y Tische Untersuchungen an Tiefseetonen aus dem Atlantik: Geochimica et Cosmochimica Acts, v. 18, p. 200-231.

Wentworth, C. K., 1922, A scale of grade and class terms for elastic sediments: Journal of Geology, v. 30, p. 377-392.

White, W. A., Calnan, T. R., Morton, R. A., Kimble, R. S., Littleton, T. G., McGowen, J. H., Nance, H. S., and Schmedes, K. E., 1983, Submerged lands of Texas, Corpus Christi area: sediments,. geochemistry, benthic macroinvertebrates, and associated wetlands: The University of Texas at Austin, Bureau of Economic Geology, p. 154, 6 maps.

White, W. A., McGraw, M., and Gustavson, T. C., 1977, Preliminary environmental analysis of a geopressured-geothermal test well in Brazoria County, Texas: University of Southwestern Louisiana, Lafayette, Louisiana, Third Geopressured-Geothermal Energy Conference Proceedings, v. 2, p. E-109 - E-208.

White, W. A., Morton, R. A., Kerr, R. S., Kuenzi, W. D., and Brogden, W. B., 1978, Land and water resources, historical changes, and dune criticality, Mustang and north Padre Islands, Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 92, 46 p.

Williams, S. C., Simpson, H. J., Olsen, C. R., and Bopp, R. F., 1978, Sources of heavy metals in sediments of the Hudson River Estuary: Marine Chemistry, v. 6, p. 195-213.

Williams, S. J., Prins, D. A., and Meisburger, E. P., 1979, Sediment distribution, sand resources, and geologic character of the inner continental shelf off Galveston County, Texas: U.S. Army Corps of Engineers, Coastal Engineering Research Center, Misc. Rept. 79-4, 159 p.

Windom, H. L., 1975, Heavy metal fluxes through salt-marsh estuaries, in Cronin, L. E., ed., Estuarine research, v. f, Chemistry, biology and the estuarine system: New York, Academic Press, p. 137-152.

DRAFT

APPENDIX A: TEXTURAL ANALYSIS OF BENTHIC SEDIMENTS

Textural analysis involved the handling of approximately 3,700 benthic samples (for the entire coast) by the Sedimentology Laboratory of the Bureau of Economic Geology. Most aspects of the basic sample preparation and particle-size analysis techniques used by that laboratory have been treated by Krumbein and Pettijohn (1938), Ingram (1971), and Folk (1974), among others. In addition to determination of gravel-sand-mud ratios, particle-size distribution within the sand fraction (-1 .0ϕ to 4ϕ) was determined using a Rapid Sediment Analyzer and included sand-sized shell material. Most of the shell material was broken and apparently transported. Size distribution within the mud fraction (4.0ϕ to 10.62ϕ) was determined with a Coulter TA II electronic suspended particle counter.

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

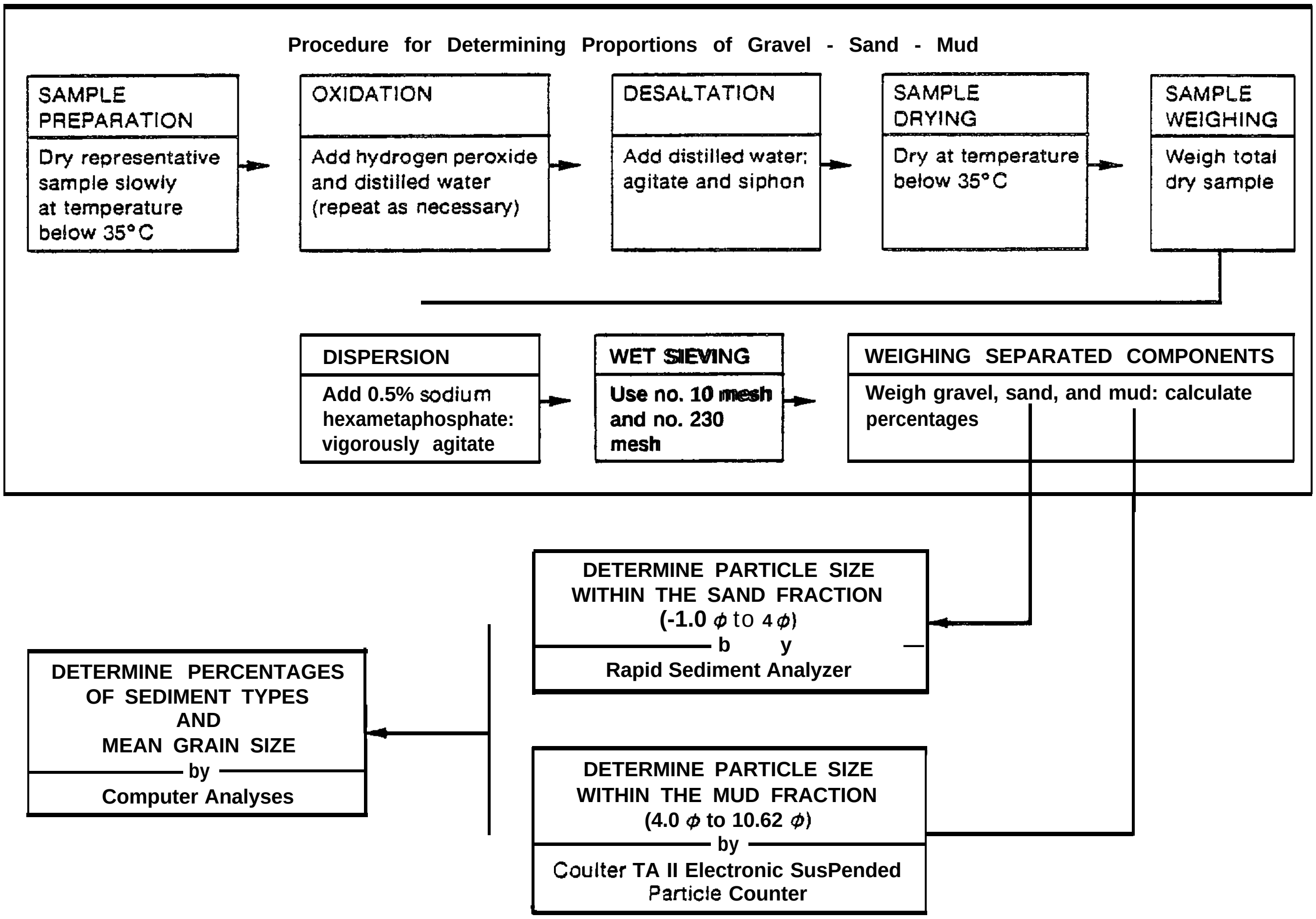


Figure A1. Flow diagram of general textural analysis procedures.

APPENDIX B: TEXTURAL AND GEOCHEMICAL DATA, GALVESTON-HOUSTON AREA

BOLIVAR PENINSULA INTRACOASTAL

	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
1							1.5											
2	733	6941	1638	688	23.26	3.64	0.5											
3							1.3											
4	1.55	7939	13.87	5.18	19.05	344	0.2	38	220	0.63	4.9	41	0.40	190	<4.6	<Io	57	<22
5	0.17	9319	512	154	664	316	0 4											
6							0 4	63	240	1.2	31	13	1.1	260	10	11	63	<22
7	035	8612	949	4.04	13.53	346	0 4											
8							0 7	62	280	051	23	9.8	1.2	180	10	<10	61	<22
9	0.90	70.21	21.36	750	26.89	408	0.6											
10							0 5	50	220	1.1	42	26	1 5	300	16	28	56	40
11							0.4											
12	0 00	45.63	3947	1490	5437	515	0.9	47	300	0.88	24	14	1.3	340	14	12	64	25
13							0 7											
14	0.40	5524	3505	931	44.35	466	0 6	54	370	0.62	33	7.6	11	280	8.9	<Io	110	<22
15							1 2											
16	000	892	6656	2452	91.06	642	2.1	67	440	0.48	39	17	1.9	980	16	17	110	51
17							1.7											
18							1 0	58	370	0.92	38	13	1.6	550	16	14	88	<22
19	0.00	6.94	64.36	2868	93.06	678	2 0											
20							1 8	75	330	0.72	43	18	2.1	920	19	19	90	26
21	0.00	61.13	28.49	10.38	36.67	4.69	0.6											
22							17	64	360	096	59	18	2.7	650	23	26	110	63
23	000	496	7197	2305	95.02	656	17											

CEDAR BAYOU

	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
1	0.80	1055	67,36	21.29	88.65	6.22	2 0											
2							1.7											
3	0.00	996	74.19	1585	90.04	567	1.9											
4							1.6											
5[a]	000	356	55.12	41.32	96.44	7.42	1.8		424	1.33	99.9	19.9	3.96	267	78,3	<40.0	115	123
6							1.5											
7							1.1											
8[a]	000	10.27	72.25	17.48	69.73	5.95	1.8		472	1.20	69.9	22.5	2.83	250	66.4	<40.0	92.7	149

‘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.)

“indicates that the result is near the detection limit and must be Interpreted accordingly,

		Textural Analysis											Geochemistry					
Sample No.’	Gravel %	Sand %	%	Clay %	Mud %	mean φ	TOC %	B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb pprn	Sr	Zn ppm
CLEAR LAKE																		
1[a]	094	1269	5560	3078	8636	669	2.1		464	2.26	596	80.1	3.57	275	40.4	<40.0	150	131
2							1 8											
3							1.4											
4							21											
5							0 6											
6’	000	531	5905	35.64	94.69	6.87			403	0.937	39.1	72,3	3.81	315	20. lb	<40.0	131	276
7							2 2											
8							2 0											
9“	000	000	71 14	2686	1000	656	19		664	0669	47.6	63.7	3.63	260	113	<40.0	102	103
10	000	46,60	45.46	7.74	53.20	462	0.6											
11							1 6											
12[a]							0.6		130	31.3	<4.00	4.77’	0.859	649	<10.0	<40.0	1020	30.3
DICKENSON BAYOU																		
1	329	24,21	5777	1473	7250	554	14											
2“	062	1629	61,54	21.55	8309	608	2.3		648	0593	25.1	16.4	2.55	241	10.4”	<40.0	106	90.1
3							2.3											
4“							2.4		616	0.510	11.4	12.2	2.33	212	<10.0	<40.0	110	86.7
5	0.00	1243	6265	2491	8757	6.37	2 3											
DOLLAR BAY																		
1[a]	166	536	6478	28.20	92.96	675	14		293	8.32	673	15.3	2.59	242	29.3	<40.0	366	137
2							0.4											
3[a]	021	8285	1310	384	16.94	357	0 5		232	0.229	245	12.3	1.00	143	16.8[b]	<40.0	45.6	59.1
4[a]	1.19	4655	4275	951	5227	472	0.5		264	3.24	46.8	12.0	1.37	162	24. 1[b]	<40.0	165	71.9
GALVESTON, TRINITY, AND EAST BAYS																		
1							0 3	2 4	310	4.8	14	6.6	0.85	200	7.7	11	140	<22
2	1660	71 11	753	276	10.29	319	0 3											
3							0 4	32	170	4 6	19	12	085	340	8.0	14	96	35
4	000	6652	2466	881	3348	437	0 3	43	240	058	23	18	1.2	230	11	14	46	<22
5							01											
6	0.17	6825	968	198	11.56	3.30	0 4											
7							0 9	23	140	7.5	23	6.1	.77	340	8.7	< l o	220	29
8	055	3380	4459	2106	65.65	5.75	0 7											
9							0 5	36	180	5.3	21	16	1.3	370	12	16	170	45
10	9.99	81.36	7.59	1.07	8.66	3.41	0 3											
11							0.3	27	150	2.2	41	7.4	0.39	190	5.5	16	48	<22
12	2458	3680	24.93	11.58	3652	5.15	1.2											
13							0.8											
14	0.01	86.02	11.40	2.57	13.97	3.15	0 2	22	200	0.48	11	fill	0.72	130	78	< m	54	23

GALVESTON, TRINITY, AND EAST BAYS, cont. 1

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
15							0 6											
16	042	6023	2966	946	3935	4.36	0 5											
17	001	9631	302	066	368	305	0 1	29	240	1.3	17	10	0.74	360	7.7	18	76	30
18	513	2646	4783	2059	6641	5.72	1 0											
19B							0 3	25	220	5 6	13	4.2	040	290	<4.6	< l o	470	29
20							0 5											
200	035	9769	1.01	095	1.96	296	0 1											
21	005	9753	1.41	101	242	315	0 1	19	300	1.7	5.5	3.5	048	330	5.2	10	95	<22
22	3.82	1964	6226	1429	76.55	559	1 0											
28	045	4246	3904	1605	57.10	537	1 2											
29							0 1	15	170	7.3	6.7	3.7	058	460	6.1	< l o	420	44
30	209	9478	252	061	3.12	352	0 2											
31	000	30.51	4662	22.86	69.49	589	0 6											
32	1 78	9671	082	069	151	309	01	33	220	1.6	29	4.0	0.33	150	<4.6	< l o	92	<22
33							0 2											
34							0 9											
35							0 2											
36	109	97.79	080	033	1.12	2.93	<0 1	12	220	0.41	1.7	2.6	0.35	220	<4.6	< l o	33	<22
37							0 4											
38	016	6455	2628	7.01	3529	4.26	0 3	42	260	0.74	23	13	091	210	8.8	11	55	<22
39							0 8											
40							0 5											
41	039	5665	3650	6.46	42.96	431	0 5											
42							0.9	72	600	1.5	83	19	2.1	470	22	28	96	43
43	184	8915	651	250	9.01	3.19	0 3											
44	66.16	3074	235	075	3.10	218	0 2											
45	3122	6103	465	290	7.75	2.35	0 2											
46							0 2	36	220	2.7	43	16	0.93	260	11	27	43	49
48	150	8138	1065	627	17.12	364	0 6											
49							0.2											
50	14.29	8076	349	146	4.95	323	0 2	34	390	1.9	11	3.9	0.66	310	6.8	12	110	<22
51	008	6566	11.41	2.83	14.24	3.3a	0 2											
52	000	3641	4850	1518	63.69	534	0 7											
53							0 5											
54	0.00	9463	3.80	1.58	5.37	339	0.1	49	240	0.40	27	4.2	0.33	160	<4.6	<10	27	<22
55							0 3											
56	0.00	83.23	12.29	448	16.77	315	0 3											
57							0 8											
58	000	52.64	36.68	1066	47.36	4.56	0 5	64	260	1.9	44	18	2.0	570	19	<20	72	33
59	239	42,83	3626	16.52	5478	525	1 0											
60							0.6											
61	0.13	6013	29.48	1026	39.74	464	0 6											
62							0.5	58	500	093	33	8.9	1.6	400	14	15	120	<22
63	003	91.39	458	401	8.58	315	0.3											
64	000	97.67	1.11	1.22	2.33	3.18	0.3											
65							0.7											
66	014	493	72.26	22.67	94.63	6.48	1.2	110	420	0.90	48	27	2.4	570	20	32	72	65
67							1.1											
68	0.03	52.10	35,33	12.54	47,87	4.87	0.6	67	360	1.1	33	13	2.0	420	16	16	110	32
69							0.5											
7n	5.35	48.65	32.71	13.29	46.00	4.95	[illegible]	“c	31	[illegible]	24	[illegible]	[illegible]	..,1	[illegible]	[illegible]	[illegible]	[illegible]

GALVESTON, TRINITY, AND EAST BAYS, cont. 2

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 pprn	Pb ppm	Sr ppm	Zn ppm
71	0.00	66,83	26,65	6.52	33.77	430	0 9											
72							0 6	61	290	0.80	47	14	1.5	240	14	17	60	<22
73							0.3											
74	0.00	97.29	1.54	1.18	2.71	324	0.1	22	100	0.22	16	3.2	0.16	54	<4.6	<lo	16	<22
75	0.55	69.45	2130	670	30.00	4.35	0 3											
76							0 4											
77	0.17	73.52	1970	6.61	26.31	3.91	0 5											
78							0 6	61	360	063	30	12	1.3	260	13	16	81	<22
79	6669	2350	5.69	1.92	7.61	373	0 2											
80							0 6											
81	0.05	4720	38.47	14.29	52.75	5.10	0 9											
82							11	72	410	10	42	18	2 0	3s0	19	21	93	32
83							1.3											
84	0 0B	2215	4804	29.73	77.77	636	1.9											
85							1.3	62	230	0.54	36	16	1.9	320	16	21	30	32
86	0.04	8642	965	3.89	13.54	335	0 5											
87	000	74.89	2179	332	25.11	3.84	0.3											
88	000	1472	4964	3564	85.28	678	1 2											
89							1.5											
90							12	51	240	0.65	29	17	1.4	310	13	20	37	27
91							0 5											
92	0.32	4419	3737	17.71	55.48	5.32	1 0											
93							0 9											
94	022	5254	3294	1430	4724	500	0 7	60	680	1.7	44	15	1.7	330	16	17	120	<22
95							0 6											
96							0 9											
97							0 8											
98							0 3	46	240	0.55	22	6.9	0.66	210	7.4	13	35	<22
99	000	6910	25.77	5.13	30.90	406	0.4											
100	023	17.82	63.16	1878	81.95	586	0 9											
101	1.32	25.39	5881	1449	73.20	5.42	0 6	20	260	2.0	6 9	4.4	0.52	220	6.0	10	180	<Z?
101B							0 2											
102							0 5	66	240	0.96	25	16	1.1	200	11	15	50	<22
103	0.27	26.06	67,12	4.55	71.67	458	0.5											
104	005	4999	4640	555	51.95	4.39	0 3	44	220	0.63	25	B.2	0.71	140	7.6	12	44	<22
105							0.3											
106	21.83	6317	1138	362	15.00	367	0 5											
107							0.3											
108	044	9440	404	1.12	5.16	349	0 3											
109							0.8	80	290	2.1	40	17	2.2	320	18	18	140	31
110	079	5163	33.38	14.01	47.39	5.09	1.0											
111							1.0	61	440	1.0	41	17	2 0	330	18	19	100	24
112							1.7											
113	015	4057	5366	5.62	59.28	4.21	0,9	58	310	1.6	40	12	1.7	290	15	13	110	<22
114							1.4											
115							1 2											
116							1.5											
117	5951	3059	621	3.70	990	3.45	0.3	3.6	53	17	7.2	4.0	0.40	520	<4.6	<lo	730	<22
118							0.5											

GALVESTON, TRINITY, AND EAST BAYS, cont. 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
120							0 4											
121							0 5	38	190	1.4	17	4.2	.73	200	7.1	12	85	<22
122	000	67.19	2436	842	32.81	427	0 6											
123							0 7											
124							15											
125	2336	1945	3830	1889	5719	572	1.3	40	390	5.6	32	11	1.3	450	12	15	250	40
126	6846	2592	327	235	561	2.14	0 2											
127							16											
128	493	19.48	5289	2271	7559	613	1.2											
129							15											
130	000	1445	4669	3687	8555	709	0 8	57	410	0.80	42	17	1.8	300	19	27	86	36
131							1.1											
132	336	2015	4571	30.78	7849	655	1.4											
133							1 2	53	460	21	37	13	1.6	370	16	17	140	<22
135							0 6											
136	29.39	5941	838	2.83	11.20	311	0 3											
137							01	55	360	2.5	42	10	0.93	230	10	13	100	<22
138	002	81.06	1200	692	1692	372	0 2											
139							0 3	45	180	9.8	8.5	6.0	0.48	260	7.5	14	290	<22
140							0.2											
141	686	3064	4197	2053	6250	577	0 5											
142	4032	2636	2055	1277	33.32	499	0 4	6	220	29	15	19	0.48	580	5.5	47	1000	220
143	9364	425	1.47	064	2.11	334	0 3											
144	9187	479	239	095	3.34	373	0.3											
145							1.2											
146	0.19	2941	50.15	2026	70.41	579	1 2											
147							0.6	85	280	0.81	62	18	2.4	410	19	26	78	44
148	024	16.88	58 81	24.06	82.88	6.14	1 3											
149							0 2	3 4	1 50	27	9	4.1	0.42	1100	5.3	<10	1100	<22
150	062	1455	45.28	3955	84.63	695	0.7											
151							1 5											
152	731	2400	44.43	2426	68.69	620	1.3											
153							14	94	460	2.5	69	20	3.1	620	27	35	160	72
154	012	51.20	2521	2347	46.68	545	0 9											
155							0 7											
156	0.13	4771	3555	1661	52.16	526	0 6	94	480	2.9	92	17	2.7	430	21	29	170	42
157							0.3											
158	020	6317	3325	3.37	36.62	413	0 3											
159							1.0											
160	0 08	49.47	252B	25.18	50.45	562	0 7	83	410	1.6	48	15	2.3	440	18	23	140	37
161							0 9											
162	1655	24.98	3333	25.14	5847	6.31	1.2											
163							1.3											
164							1 2	120	450	1.6	78	21	3.9	540	30	36	130	69
165							1.7											
166	000	489	57.25	3785	95.11	7.29	1 8											
167							1.4											
168	020	1680	50.50	32.49	8299	663	1.1											
169							0 9	93	380	2.1	74	19	3.0	490	22	27	120	55
170							1 2											

GALVESTON, TRINITY, AND EAST BAYS, cont. 4

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
171							1 5											
172	5787	3287	600	326	926	267	0 1	10	200	29	16	6 2	0.72	1200	8.5	13	1100	190
173							1.5											
174							0 7											
175	22.28	43.06	22.51	12.15	3466	4.51	<0.1											
176	25.10	2798	2760	1932	4692	524	0 9											
177							1 0											
178	000	6246	2960	792	37.52	430	0 6	74	460	0.49	27	13	1.2	280	12	16	49	<22
179							12											
180	002	13.79	7442	11.76	86.19	5.39	0 9	95	360	1.4	76	60	2.1	280	21	25	88	31
181	0.00	7660	2072	268	23.40	369	0 2											
162	152	8836	928	084	1012	2.94	0 3											
183							0 9											
184	005	538	5839	36.19	94.53	7.08	1.2	96	400	1.4	60	24	2.7	400	24	35	100	55
185							0 6											
186	000	3364	41.12	25.23	66.36	6.11	1 0											
187							15											
188							1 8	84	490	3.1	78	18	2.4	450	20	25	160	32
189	001	92.49	623	127	7.50	381	01											
190	000	626	5831	3544	9374	6.99	1 0	93	600	3 1	56	19	2.7	490	23	31	170	53
193							12											
194	034	2846	4652	24.68	71.20	598	0 8	120	360	072	86	22	4 0	360	28	52	130	100
195							0 3											
196							0 1											
196B							01											
197	002	8024	16.77	297	19.74	388	0 2											
198							12	110	1600	1.6	56	21	3 8	590	25	37	130	79
199	002	291	4885	4821	9707	78a	14											
200	6049	2984	847	3,20	9.67	2.57	0 3	5.6	110	26	11	4.3	0.53	1 400	5.6	<10	1200	<22
201	148	2014	4370	3468	7838	668	1 2											
202							13	93	300	0.85	58	17	2.3	350	22	33	110	69
203	000	635	5723	3642	9365	7 15	0 8											
204							1.2											
205	56.45	3259	6.71	425	10.96	296	0 4	4	250	29	8 8	3.9	0.43	1 100	6.8	<lo	1400	<22
206	000	56.76	3397	928	4324	465	0 4											
207							1.4	78	470	0.88	39	9.5	1.7	270	16	16	140	50
208	009	723	6150	31 17	926$	692	1.5											
209	002	7892	1676	430	21 06	374	14											
209B							10											
210							1 3											
211	000	144	6337	3519	9856	721	18	93	360	2.2	66	23	2 6	450	24	28	110	37
212	000	1316	65.38	2146	8684	607	1 6											
213							1.3											
215	000	3404	5452	1144	65.96	509	0 6	95	400	0.74	44	11	1.8	260	15	20	130	76
216							0 6											
217							0 4	78	320	4.7	61	6.3	1.3	280	10	15	290	60
218							1.8											
219	001	3265	4754	1980	67.34	5.72	1.0	99	380	0.70	59	17	2.7	400	20	32	110	37
220							0 5											
221							0 3											

GALVESTON TRINITY, AND EAST BAYS, cont. 5

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
222							0 3											
223							0 5	82	470	0.63	120	12	2 0	330	17	23	110	24
224	000	1928	5732	2339	80.72	611	0 8											
225							1.4											
226							0 8											
227							0 4	35	260	0.36	26	3.2	0.17	41	<4.6	13	33	<22
228	0.02	3171	4948	18.79	68.27	571	0 9											
229							12											
230	000	15.73	54.72	2956	84.27	653	13											
231	000	2007	5712	2281	7993	619	13	100	450	0.94	71	19	3.2	860	26	33	120	54
232	000	8149	1532	3.19	18.51	379	0 1											
233							0.1											
234	43.89	5373	160	058	2.38	287	0 2											
235							14											
236	0.05	390	5799	38.06	9605	7.37	1.2											
237							0 5											
238	2.53	2360	52.80	2108	7387	596	1.0											
239							1.2											
240	3972	4071	15.27	429	1956	327	0 3											
241							11											
242	020	12.82	5299	3399	8698	677	1 5											
243	0.01	1604	5905	2489	8394	6.27	12	90	270	074	50	21	2.3	380	22	33	77	56
244							1.7											
245	000	410	6392	3199	9560	695	18											
246							1.3											
247	000	9086	818	095	914	373	0 2	53	250	0.66	16	6 8	047	92	7.0	12	43	<22
248							0.2											
2480							1.0											
249	000	1319	7399	12.82	86.81	5543	1.1											
250							19	76	300	1.3	61	53	2.7	440	27	37	71	51
251	000	145	6560	32.95	98.55	710	1.4											
252							1 0											
253							1.4											
254	276	3036	4905	1782	66.87	557	0 9											
255							1.1	70	390	1.8	46	19	2.1	480	19	24	120	37
256	0.01	1184	66.19	2196	88.15	6.25	1.3											
257							1.4	66	560	2.4	46	19	2.2	360	22	25	170	42
258	061	440	61.31	3368	94.99	706	1.6											
259							2.0	50	220	041	31	18	1.9	350	16	24	32	45
260	000	15.22	5860	26.18	84.78	6.07	1.4											
261							1.4											
262	0.05	6845	1930	12.20	31.49	4.81	0.4											
263	000	9040	5.47	4.12	9.60	3.60	0.2	25	170	0.44	23	4.6	0.46	74	6.6	<10	27	<22
264							0 6											
265	335	10.52	5154	3459	86.13	6.99	1.2	46	330	5.4	17	130	1.1	350	9.5	140	46Q	270
266							1.4											
267	000	1.81	6677	31.42	98.19	7.12	1.9	62	400	0.67	47	19	1.9	380	19	27	40	46
268							1.9											
269	0.59	3.39	5800	3802	96.02	7.30	0 4											
270							1 7											

GALVESTON, TRINITY, AND EAST BAYS, cont. 6

			Textural Analysis															
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
271							1.4											
272							14											
273							0 6											
274	024	43.12	4610	10.54	56.64	476	0 9											
275							1 0	69	250	1.4	37	19	1.6	300	19	29	74	28
276	026	1256	7227	14.69	6715	5.66	0.9											
277							11											
278	001	3492	6065	442	65.07	4.44	0 4											
279							01	29	140	0.21	6.2	4.0	0.16	89	<4.6	< l o	26	<22
280	0.00	57.70	3683	3.47	42.30	4.12	0 3											
261							0 6											
282	098	3490	5196	12.16	64,12	522	0 6											
283							0 2											
284	074	643	6553	2531	90.83	671	1 0	74	380	2.3	53	18	2 0	360	20	22	100	32
265							1.5											
286							1 8											
287	009	356	5917	37.18	9635	730	1 9	100	700	1.8	85	29	4 1	660	29	35	140	67
288							1.9											
289	002	11.58	5236	3604	6a 40	701	1 9											
290							1 7											
291							1 6											
292							1 3											
293	012	4196	3200	2591	57.92	5.86	0 6											
294	001	8659	993	347	1340	370	0.7											
295	000	6663	935	202	11.37	361	0 2	68	160	036	22	38	034	61	< 4 6	13	25	<22
296							0 4											
297	000	3380	4459	21.61	66,20	587	1 0	75	350	0.98	69	18	3 1	430	26	28	93	49
298							14											
299							18											
300	004	7.05	5499	3792	92.91	720	2 0											
301							1 9	100	460	1.2	69	27	3 8	500	30	34	110	60
302	012	301	4957	47.30	96.87	7.66	1 8											
303							1.8											
304	007	852	5462	3679	91.41	746	1.7	71	350	1.4	46	24	2.0	400	22	23	94	39
305							13											
306	003	1665	5968	2344	83.12	625	1.1											
307							0 9	98	430	3.5	73	25	3 0	470	25	31	140	54
306							0 3											
309	0.00	6656	25.96	546	31.44	409	0 5											
310							0 2											
311	001	63.16	1477	206	16,63	3.54	0 2	66	290	2.7	34	6.1	0.71	260	9.8	14	77	<22
312	0.72	3436	49.05	1586	64,91	539	1.1	49	280	1.8	35	15	1.3	370	17	18	89	<22
313							0 4											
314	000	054	62,44	37.02	99.46	7.53	0 4											
315							1.2	100	310	2.6	61	22	3 2	480	25	35	100	62
316							1.2											
317	004	21.72	4908	29.16	78.24	6.42	1 3											
318							1 6											
319	000	1.86	47.55	5059	98.14	7.69	1.9											
320																		

GALVESTON, TRINITY, AND EAST BAYS, cent 7

Sample No. *	Textural Analysis Gravel %	Sand %	Silt %	Ciay %	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
321	0.00	624	5449	3927	93.76	723	1 9											
322							16											
323							10	80	330	1.4	50	22	2.1	440	24	29	130	43
324							1.4											
325							0 9											
326	0.00	66 00	21.01	1099	32.00	4.58	0 7											
327							0 1	22	190	0.50	6.5	4.4	0.3s	98	6.0	13	28	<22
328							01											
329	0.00	5522	2899	15.79	4478	492	0 6											
330							10											
331	0.00	1017	5901	3082	69.83	685	15	92	580	1.1	71	20	3.3	520	28	33	110	53
332							15											
333	0.00	312	5404	4283	96.88	742	1.5											
334							17											
335	0.00	096	6329	3574	99.04	735	1 9	100	820	0.92	60	28	2.6	430	25	35	100	84
336							18											
337							1 7	64	500	0.72	36	16	1.7	350	19	24	42	60
338							1.7											
339							1 6	100	410	1.9	67	21	3.8	480	28	35	140	65
340	051	1839	5318	2792	81.10	6.47	16											
341							1.3											
342	017	078	8021	18.63	9904	652	0 4											
343							0 1	44	300	1.8	19	5.8	0.59	210	7.7	13	47	<22
344	000	592	5673	3535	94.06	710	1 2											
345							1 2											
346	006	2102	5554	2339	7892	599	0 7											
347							0.2	66	340	6 8	51	24	4 7	760	19	53	130	44
348	007	1301	5762	2929	8692	662	1 3											
349							0.7											
350	071	61.58	2941	829	37.70	420	0 3											
351							1 3	120	330	2 8	79	29	3 5	440	26	69	140	64
352	213	9566	176	023	1.99	315	0 1											
353	020	4351	44.40	11.88	5629	499	1 2											
354	005	508	6661	28.26	94.87	670	0 5											
355							0 7											
356	000	52,26	31.33	1838	47.72	496	0.6											
357							1.3											
358							1 6											
359	071	302	57.26	3901	96.27	739	1 5	100	430	1.9	96	30	4.3	400	34	48	120	71
360							1 3											
361	0.10	2.98	56.84	4007	9&92	745	1.9											
362							1.7											
363	0.63	5.65	57.89	35.83	93.71	7.12	1 5											
364							2 2											
365							2.1											
366							1.5											
367	0.71	14.34	57.92	2703	84.95	6.56	1.1	88	300	7.2	76	21	3.5	490	28	36	280	68
368							1.4											
369	17.55	61.25	13.53	767	21.19	4.25	0.3											

GALVESTON, TRINITY, AND EAST BAYS, cont. 8

Sample No.”	Textural Analysis Gravel %	 Sand %	 silt %	 Clay %	 Mud %	 mean φ	TOC %	Geochemistry B ppm	 Ba ppm	 Ca %	 Cr ppm	 Cu ppm	 Fe %	 Mn ppm	 Ni ppm	 Pb ppm	 Sr ppm	 Zn ppm
370							0 4											
371							10											
3 7 2	000	6663	2131	1206	3337	460	0 7	70	250	0.76	45	16	2.0	200	20	22	56	<22
373	0.00	4342	4089	15.69	56.58	529	10											
374							18											
375	016	382	5905	3696	96.01	7.38	1 9	110	500	2.0	75	22	3 3	530	30	3s	130	71
' 376							2 0											
377	022	164	5998	38.16	98.14	75a	2 3	56	360	11	53	19	2.4	350	23	27	86	45
37a							18											
379							16	91	360	4.8	60	19	3.3	470	26	31	210	7
380	0.25	32.04	40 35	27.36	67.71	617	15											
381							1 3											
382	0.05	5420	36.79	6.96	45.75	4.25	0 6											
383							0 2	63	160	0.28	8.3	4.5	0.39	84	8.2	< l o	22	<22
384	1027	56.12	2444	917	3361	4 18	0 8											
385							0 7	66	260	0.78	41	12	1.3	240	15	16	50	<22
386	004	74,46	2175	375	25.50	3.26	0 2											
387							0 9	74	590	1.8	59	16	2.2	410	20	27	160	30
388	047	14.76	6094	23.63	84.77	6.35	16											
389							17											
390”							14		357	1.68	102	16.0	344	293	60.1	<40.0	117	200
391							1.5											
392	0.24	2365	6208	1403	76.11	535	0.7											
393	049	576	68.51	25.24	93.75	6.57	1 6											
394[a]	053	1445	6267	2235	8502	618	1 3		312	1.53	584”	18.1	2.45	326	12.2[b]	< 4 0 0	86.9	98.7
395	002	9249	563	187	7.49	361	0 2											
396	6101	3383	327	189	516	279	0 3	4 3	85	14	15	4.3	029	420	5.2	< l o	750	<22
397	137	626	6308	29.29	92,37	6.91	19											
398							2 2											
399	029	417	5346	4208	95.53	7.49	2 0											
400							18	73	510	1.6	42	18	1.8	400	21	28	120	130
401							1.1											
402	047	554	57.03	36.98	9399	7.27	1 6											
403							1.2	48	370	0.88	52	16	1.9	260	20	22	70	<22
404	054	6581	2276	1069	33.65	4.50	0 5											
405							0 2											
406	026	3918	4374	1682	60.56	530	0 5											
407							1.1											
408	106	558	5580	37.56	93.36	7.35	1.7											
409							19	58	230	0.60	39	24	2.0	380	19	26	42	54
410	341	545	57.75	33.39	91.14	7.07	2 0											
411							1 8	100	430	1.8	72	27	3.4	390	27	34	120	83
412							2 0											
413	027	361	5090	4522	96.12	770	2 0											
414							1.5	70	360	1.2	54	18	2.4	380	24	25	99.	28
415	004	6135	2a 53	1008	38.61	463	0 5	72	270	0.98	44	17	2.0	380	17	24	71	40
416							0 2											
417	009	9177	5.84	2.30	8.14	362	01											
418							0 8											

GALVESTON, TRINITY, AND EAST BAYS, cont. 9

Sample No. "	Textural Analysis Gravel %	Sand %	Sill %	Ciay %	Mud %	φ	TOC %	B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
419	007	2915	5157	1922	70.79	571	11											
420							18											
421	094	669	6240	2998	92.37	704	18											
422							21											
423							2 0	95	380	0.80	66	19	3.2	370	25	33	93	59
424	000	1.23	6695	3182	9877	709	15											
425							14											
426	081	39 66	39.23	2031	5954	565	11											
427.							01											
428	001	90.32	7.96	172	967	306	01	28	200	0.24	8 6	4.4	0.49	S7	7.3	11	26	<22
429							0 8											
430	3163	3599	3028	210	32.38	371	0 5	18	200	11	17	5.8	o.%	440	7.8	<lo	460	59
431							17											
432	095	104	5972	3829	9801	753	2 4											
433							18	77	300	1.2	53	28	3 0	460	25	34	110	59
434	047	164	6141	3646	97.89	7.42	18											
435							19											
436	061	3626	5087	12.25	63.12	528	0 8											
437							0.1	25	190	0.36	13	4 4	030	70	7.9	<10	30	<22
438							01	87	350	15	64	27	3 6	430	29	32	120	55
440	1.11	2684	5713	1491	72.05	538	0 6											
441							16											
442	662	394	6900	2025	89.25	656	1.4											
443	200	1378	6033	2389	8422	646	1.1											
444	1757	794	5516	1933	7449	639	. 1.4											
445							0 6											
446	002	8822	991	185	11.76	311	0 1											
447							0 7											
448	000	3649	4260	2091	6351	581	15	·30	250	0.59	24	12	1.1	270	9.4	14	54	<22
449							14											
450	071	1566	6288	2072	8360	616	15											
451							1.2	46	510	1.2	38	16	1.7	310	13	17	77	<22
452	1.81	391	6859	2569	94.28	682	15											
453							0 9											
454	000	9576	365	058	4.24	358	0 1											
455							0.1	27	180	0.12	10	3.9	0.17	50	<4.6	<10	22	<22
456	002	4422	5123	454	5576	425	0 3											
457							12											
458	006	24.17	6661	894	7575	544	0 8											
459	000	1076	6206	7.18	89.24	512	0 8	59	320	0.38	35	7.8	069	150	9.6	14	65	<22
462	0.00	7823	2102	075	21.77	3.36	0 3											
463	000	1163	6319	518	88.37	4.81	0 8	35	260	0.34	25	10	0.s6	310	9.1	<10	59	<22
GA	2.68	8615	778	1.38	9.17	335	0 3											
GB	3954	5021	760	264	10.24	2.88	<0.1											
GC	0.12	9324	444	220	6.84	334	0 2											
GD							1.4											
GE	596	8796	361	2.47	6.08	3.10	0.3											
GBB							0 3											

Sample No.'	Textural Analysis						TOC %	Geochemistry										
	Gravel %	Sand %	Sill %	Clay %	Mud %	mean φ		B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
GALVESTON CHANNEL																		
1							57											
2	000	4425	3425	2150	55.75	566	1.4											
3							17	80	640	075	41	29	2 0	470	21	25	77	37
4	000	053	5427	4520	9947	770	18											
HOUSTON SHIP CHANNEL (BUFFALO BAYOU)																		
	0.05	1353	5831	2811	8642	652	16	59	290	0.59	51	20	1.8	410	18	31	53	29
2							12	55	290	2.1	43	17	1 8	310	17	25	67	22
3							1.7	78	330	1.6	57	21	2 4	a00	25	30	90	46
4							19	91	340	1.9	59	32	2 6	770	25	31	97	60
5	000	16.24	5318	3056	8376	655	16	51	250	1.4	34	19	1 6	510	16	19	63	<22
6							2 3	79	250	16	100	120	3 2	630	32	66	99	150
7							2 3	62	180	087	52	29	1 8	440	19	33	36	89
8	000	276	7043	2681	97.24	671	2 3	66	230	099	81	160	2 3	290	3a	55	65	52
9	000	449	5006	4545	9551	774	1 9	82	2ao	2.1	58	30	2 3	920	23	31	110	34
10	000	138	4898	4963	9862	795	2 0	71	240	15	50	33	2 2	750	21	45	76	66
11	000	035	4584	5381	99.65	811	2 2	67	170	081	5a	24	2.2	350	24	45	38	75
12							01	4 7	210	067	2.4	3 4	0.11	42	<4.6	11	15	<22
13	983	88.33	130	054	164	223	0 3	6.2	180	2 5	2.0	3.3	012	90	<4.6	<10	43	<22
14	0.71	8320	1036	573	16.09	254	0 8	16	140	029	6 2	6.9	0.29	66	<4.6	10	15	<22
15							11	33	260	3 3	22	5.1	0.93	300	8.2	11	200	<22
16	0.00	8 90	5624	3486	91 10	699	18	88	220	15	66	36	2.3	690	24	49	67	76
17							18	80	240	19	60	34	2.4	610	25	41	72	75
18							2 3	54	200	14	62	65	2.2	300	24	72	59	100
19	0.00	199	90.61	740	98.01	6,13	0 5	84	350	1.9	62	29	1 9	290	20	32	76	33
20							19	64	140	0.88	40	34	1 7	250	18	46	46	57
21	000	9635	257	109	365	339	01	17	95	0.17	3.1	3.7	013	27	<4.6	<10	13	<22
22	0.29	535	70.12	2423	94.35	683	10	74	200	099	43	19	2 2	220	22	28	46	25
23							2 2	69	330	1.5	76	59	2 4	310	27	93	94	150
24	006	3305	5536	1153	6689	513	11	45	260	1.7	46	25	11	280	12	37	51	68
25	004	1671	5063	3062	8125	647	19	52	590	1.6	95	60	2 0	270	25	97	69	130
26							2 3	49	270	18	59	60	1 8	270	20	120	46	160
27							3 6	51	220	13	75	8a	2 0	270	24	110	85	230
28	616	6971	1844	568	24.73	375	0 4	29	350	082	13	4 . 7	084	280	8.1	12	84	<22
29	000	3.22	6758	2920	9678	673	2 7	87	260	3 2	100	90	2.4	330	28	150	2ao	310
30							2 2	18	860	5 5	11	7.1	098	360	8.1	13	230	28
31	9641	062			097		01	<15	300	13	24	29	6 2	1800	17	84	430	110
32	000	1763	5781	2456	82.37	614	1.8	49	420	3 4	68	36	1.4	270	17	110	97	87
33	1463	5554	2040	944	29.83	382	19	40	270	20	72	60	1.1	240	17	160	75	170
34	0.00	4.33	6519	30.47	95.67	692	3 9	64	660	4 9	150	120	3.1	380	41	260	140	590
35	0.77	1287	6015	2822	86.36	6.55	3 2	39	440	41	74	86	5.0	610	21	210	44	460
36							18	31	200	063	21	17	070	180	8.3	82	25	73

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 p pm	Sr ppm	Zn ppm
OFFATT BAYOU																		
1							17											
3“	000	194	3226	6061	9806	817	4 0		373	0710	448	394	353	566	19.4”	<40.0	123	264
SAN JACINTO IRIVER																		
1	000	306	6022	3672	9594	726	16	55	270	1.1	60	30	2.0	330	24	37	59	56
2							2 3											
3	385	6823	550	262	8.12	ı 69	0 2	25	91	0.37	17	9.1	076	130	8.3	11	20	<22
4	000	549	5294	4157	9451	736	2 4	54	140	0.65	45	22	2 0	450	19	32	44	66
5	000	9720	4.40	265	724	245	01	3.3	190	014	3 3	3 0	0.11	22	<4.6	< 10	17	<22
6							0 7											
7	000	14.88	4654	3856	85.12	702	0 9											
8	000	9276	440	265	7.24	245	01											
WEST (GALVESTON) BAY																		
1	9.64	8844	136	056	193	2.83	0 2	30	210	2.9	14	3.9	0.28	170	<4.6	11	91	<22
2							0 8											
3“							0 8		341	1.06	470	14.8	1.54	180	<10.0	<40.0	90.9	51.6
4“	443	2089	5196	2271	74.69	618	0 9		426	183	33.1	12.4	243	356	11.3[b]	<40.0	114	86.9
5	000	23.85	5166	2428	7615	6’04	10											
6							1.1	75	250	1.4	43	18	2 0	330	17	22	75	28
7							0 3											
6							0 4											
9							0 9											
13							13											
14[a]	0.20	677	7523	1720	93.03	606	13		370	1.58	215	11.1	2.47	397	<10.0	<40.0	114	73.9
15	45.27	2990	1803	680	2483	419	0 6											
16	6610	16 18	974	398	1372	414	0 5											
17	0.50	7984	14.80	466	1968	353	0 6											
18							01											
19							0 3	58	270	4 0	20	6.5	1.1	250	9.7	12	110	<22
20							0 7											
21							0 3											
22	1.43	75,27	14.84	846	2320	433	0 6											
23	2834	3339	2427	1401	38.27	531	0 5											
24	0.57	6317	1176	449	16.25	358	0 3											
25	0.58	9611	231	100	3.31	315	0 2											
26							0.1	29	140	0.14	3.3	3.1	0.14	53	<4.6	< l o	25	<22
27							0 2											
28							0.5											
29							0 5	50	190	7.7	22	9.3	1.1	380	10	17	220	41
30							0 2											
31	005	9852	279	063	3.42	352	0.1											
32	1.77	7027	2064	7.32	27.96	4.34	0 3											
33	0.76	7299	17.25	901	26.25	4.34	0.5											
34	011	9286	4.96	2.05	7.03	335	0 2											
35	000	76.54	16.28	7.18	23.46	396	0 6											

WEST (GALVESTON) BAY, cont. 1

Sample No.'	Gravel %	Sand %	Silt %	clay %	Mud %	mean φ	TOC %	B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
	Textural Analysis							Geochemistry										
37							0 2											
38							0 4											
39							0 6											
40							0 2											
41	002	9357	541	100	6.41	343	01											
42	1481	6670	1101	548	16.49	332	0 4	27	130	12	13	6.1	069	550	8 0	13	380	73
43	001	6996	2086	916	3002	437	0 8											
44							01											
45							0 3											
46							0 7											
48							0 2											
49	6,59	32,07	51.76	9.58	6134	481	0 7	85	330	7.7	59	16	2.0	490	15	23	210	36
50	2.13	4031	3888	18.68	5756	555	10											
51	031	9795	1.15	0.59	174	320	0 3	61	360	0.69	41	5.9	12	270	10	12	110	<22
52							0 3											
53							10											
54							0 5											
55	004	9343	567	086	653	357	0 2											
56	056	3792	4103	2046	6151	576	0 7											
57	005	5207	3062	17.26	4768	512	0 7											
58	002	9813	145	041	1.86	336	01	14	150	0.22	17	3.1	0.15	64	< 4 6	<10	29	<22
59							01											
60							0 7											
61							0 6	81	320	1.5	46	14	2 0	420	17	19	96	26
62							0 2											
63	094	9372	458	076	5.34	345	0 2											
64	0.12	4154	3736	2098	58 34	561	0 6											
65	015	4293	3448	2243	5692	576	0 7											
66	000	3697	4586	1717	6303	556	12	86	210	066	43	30	1.9	430	17	18	59	24
67							01											
68							0 9											
69							0 6	73	350	094	62	13	1.8	310	21	16	82	<22
70							0 5											
71[a]	227	3693	4772	13.11	6063	524	0 6		383	0.680	661	158	201	233	32.6	<40.0	950	68.9
72	000	8143	1595	262	18.57	362	0 5											
73[a]	465	9408	086	041	127	306	0 3		111	6.73	59.1	4.61[b]	0370	130	18.9”	<40.0	192	123
74							0 7											
75[a]	023	6134	2652	1191	38.42	484	0 5		321	0.548	66.3	11.3	1.49	215	33.2	<40.0	79.4	84.8
76							0 5											
77	006	8885	956	152	1109	36a	0 2											
78							0 2											
79							0 2											
80	000	4488	4599	913	5512	461	0 7											
81[a]	2297	2951	2909	18.43	47.52	565	0 4		633	12.9	349	8.80”	2.35	345	11.8[b]	<40.0	472	104
82							18											
83[a]	003	1208	6192	2596	87.88	646	10		290	0.539	44.7	18.5	2.74	395	<10.0	<40.0	860	140
84							10											
85”	0.00	10 62	6380	2556	8938	640	0 6		320	1.04	148	13.8	2.76	247	14.8”	<40.0	888	186
86							0 6											
87							0 6											

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 ppnr
	Textural Analysis						Geochemistry											
							WEST (GALVESTON) BAY, cont. 2											
68	0.00	3831	38.77	2292	6169	583	1.6											
89							0 2											
90							0.2	11	250	1.8	4.5	3 0	044	310	<4.6	12	75	<22
91							10											
92	047	6288	2275	1390	3665	494	0.8											
93							0 4	70	200	0.83	23	8 3	1 2	240	11	12	61	<22
94							0 3											
95							0 3											
96	2.56	6613	1820	1311	31.32	484	0 5											
97							0 2											
96	000	99 00	055	045	1.00	336	01											
101							01											
102	237	8944	555	263	818	320	0 4											
103	000	9937	036	0,26	063	3.20	01											
104							01											
105							0 5	49	300	1.3	64	7.7	1.3	310	12	12	85	<22
106	001	9722	2.07	0.70	2.77	357	0 2											
107							0 2											
106	3391	6403	139	067	2.06	2.35	0 2											
109							01	44	190	0.63	I1O	3.1	0.46	150	<4.6	12	64	<22
110[a]	002	9869	079	0.50	129	324	01		252	0.658	<4.00	<4 00	0.3437	109	<10.0	<40.0	795	9.39’
111							0.2											
112	4711	4316	636	337	973	323	0 3											
114							0 2											
115[a]	1869	2977	3788	1366	51.54	547	0 7		265	12.4	30.1	<4 00	1.56	420	16.9[b]	<40.0	360	35.6
116							0 3											
117							1.2											
116	000	2026	6520	1385	7974	554	0.7											
119[a]	173	66.19	2316	892	32.06	436	0.3		355	0.339	174	8.02[b]	1.96	226	10.4[b]	<40.0	85.9	96.0
120							0.2											
121							0 7											
122’	6363	21.32	1206	298	15 05	360	0 2		44.2	35.7	<4.00	<4.00	0.217	367	<1 0 0	<40.0	659	52.8
123							0 2											
124”	0.14	8898	847	241	1088	365	0 3		438	0.695	50.5	5.43”	0.997	214	34.3	<40.0	117	789
125							04											
126							0 6											
127	034	37.96	4445	17.24	61.70	551	0 5											
128”	000	9423	5.17	0.61	5.?7	375	0 3		360	0317	54.8	6.19”	0.439	157	<25.0	<40.0	86.7	57.6
129							0 2											
130							0 9											
131”	2166	46.70	1963	1179	31.62	444	0 5		137	25.9	<4 0 0	<4.00	0.733	465	<10.0	<40.0	824	63.9
132”	1108	3783	3791	1320	51.11	522	0 5		356	5.81	72.6	16.0	1.38	297	40.2	<40.0	227	122
									SHELF									
23	1.67	9634	125	0.73	1.86	302	0.1											
24							0.2	46	390	1.0	34	4.9	0.67	300	6.9	13	120	<22
25	0.02	47.97	4669	3.31	52.00	4.24	0.3											
26							1.0	62	620	0.83	71	16	2.0	560	19	17	110	23

SHELF, cont. 1

Sample			Textural Analysis										Geochemistry					
Sample No. ”	Gravel %	Sand %	Silt %	Clay %	Mud %	φ	TOC %	B ppm	Ba ppm	Ca “10	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
27	000	9198	705	097	802	371	0.1	53	390	7.0	14	6.1	083	270	7.1	13	310	<22
2851							0 7	55	420	0.64	28	12	2.1	300	14	13	160	24
2852							0 8											
2853							0 8	73	550	12	40	15	2.7	330	17	18	210	45
2854	005	4626	3784	15.85	5369	4.79	0 5											
2855							0 9											
2856	000	2800	4884	2316	72 00	585	0 8											
2857							10											
2858	037	2240	51.74	2549	7723	619	11											
2859							12											
2860	000	359	7014	2628	9641	670	13											
2861							0 9											
2862	010	376	5552	40.62	9614	7.51	1 0											
2863							0 9											
2865							0 2	41	350	0.74	24	5.3	1.5	370	6.8	12	210	16
2866							15											
2867							0 6	58	390	1.1	30	16	2.6	490	16	13	190	38
2868							1 0											
2869							1 2	84	470	1.7	48	19	3.4	510	23	19	220	66
2870							11											
2871							1.3	80	510	0.93	48	2 5	3.2	450	20	22	210	56
2872							0 5											
2873							0 7	67	490	066	27	17	2.5	340	18	12	170	30
2874							0 6											
2875							0.4	60	410	065	23	12	2.2	330	13	14	210	23
2876	000	1879	5603	2519	8121	613	1.2											
2877							0 5											
2878	018	5449	31 19	1414	4534	481	0 6											
7879							1.0											
2860	000	747	4826	4428	92.53	7.22	1.3											
2881							1.0											
2862	000	1281	5938	2781	87.19	672	0 9											
2883							0.7											
2884	002	2383	5632	1983	76.15	587	0.6											
2885							0 6											
2686	0.02	9238	566	195	761	372	0 2											
2807							01	45	240	038	32	5.8	1.3	360	4 2	8.3	150	37
2888							0.9											
2889							0 7	80	490	1.1	37	20	2.7	480	20	17	240	52
2890							0 6											
2891							11	65	430	0.66	33	27	2.7	460	15	18	180	49
2692							10											
2893							0 9	85	490	077	44	<15	3.3	480	21	18	200	51
2894							1.0											
2895							0 8											
2896							0 8											
2897							0 7	69	450	0.95	58	16	2.5	390	15	19	220	59
2898	002	2038	4650	33.10	76.61	651	0 9											
2899							0 6											

SHELF, cont. 2

		Textural Analysis						Geochemistry										
Sample No. "	Gravel %	Sand %	Sill %	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
2900	0.48	4503	3584	1865	54.49	529	0 7											
2901							11											
2902	002	13.76	58 49	27 74	8622	6 60	10											
2903							10											
2904	000	3847	4337	1816	61.53	5.68	0 8											
2905							0.6											
2906	000	21.25	6050	1825	7875	588	0 7											
2907							0 7											
2908	0.00	52.70	3457	1260	47.25	4.78	0 3											
2909							0 9	35	320	057	33	5.9	1.2	340	4.4	12	190	20
2910							0 7											
2911							0 8	58	430	0.70	25	16	2 3	570	15	16	180	29
2912							0 7											
2913							0.7	65	520	0.81	45	23	2.6	400	23	16	200	47
2914							0.9											
2915							0.7	74	450	0.62	36	24	2 6	420	20	24	160	34
2916							0.7											
2917							0 6	57	410	0.72	48	13	2.2	360	15	20	200	35
2918							0 5											
2919	000	2639	6058	1303	7361	533	0 6	63	390	0.59	25	13	2.1	320	15	11	160	29
2920	005	5270	3457	1268	47.25	478	0 7											
2921							1 0											
2922	190	68.23	18.59	1128	2987	440	0 4											
2923							10											
2924	0.00	3639	3635	2526	6161	566	0 9											
2925							1.0											
2926	0.08	23.14	4865	2814	7676	624	0 9											
2927							0,8											
2928	041	3807	3965	2167	61.53	557	0.9											
2929							0.6											
2930	0.07	9308	494	191	6.85	367	0 1											
2931							0 3	45	270	0.72	66	4.7	1.3	400	4.8	11	170	3a
2932							0 4											
2933							0 8	45	380	0.79	19	8.3	1.9	300	12	13	200	28
2934							0.9											
2935							1.0	63	340	0.46	25	14	2 3	410	14	11	140	29
2936							11											
2937							0.8	80	550	0.88	46	21	3.0	440	21	21	200	47
2938							0.6											
2939							0,8	67	540	0.71	38	16	2.5	330	18	13	200	43
2940							0 6											
2941							0.6	61	450	0.61	29	12	2.1	320	14	13	170	30
2942	000	61,84	26.46	11.70	38.16	443	0.6											
2943							0.9											
2944	000	4091	39,70	1939	59.09	540	0 8											
2945							0.6											
2946	0.00	13.77	4637	3988	86.23	7.01	0.9											
2947							0.9											
2948	002	1262	6389	23.48	87.36	6.24	0 9											
2949							0 9											

SHELF, cont. 3

	Textural Analysis							Geochemistry										
Sample No.	Gravel %	Sand %	Sill %	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
2950	012	4121	3910	1957	5867	544	07											
2951							07											
2952	097	9136	493	274	767	353	0 2											
2953	005	9165	621	208	8.30	367	01	37	230	0.29	13	4.3	064	270	3	<6.8	110	21
2954							0 3											
2955	000	811	6595	2595	9189	628	0 8											
2956							11											
2957	000	616	5786	3596	93.84	696	10											
2958							11											
2959	000	22.77	4654	3174	78.27	625	10											
2960							0 5											
2961	0.11	48.80	2676	24.21	51 .00	541	09											
2962							0 6											
2963	003	61.12	2283	1602	36.85	495	0 5											
2964	0.00	32.S1	44.05	2314	67.19	565	0.7											
2965							0 5											
2966	003	55,22	27.26	16.97	4475	4.99	0 9											
2967							0 5											
2968	005	31.47	4098	27.50	66.48	6.11	0 8											
2969							1.0											
2970	0.13	1317	5772	28.98	86.70	637	0 9											
2971							0.7											
2972	007	2844	4262	2887	71.49	635	1.1											
2973							0 4											
2974							0 3											
2975							0 2											
2976	000	9016	911	0.73	984	354	0 2											
2977							0 6											
2976							0.8											
2979							0 6											
2980	000	879	7362	17.59	91.21	587	0 8											
2981							0 9	64	440	0.77	27	13	2 3	360	14	11	180	24
2982							0 6											
2983							0 8	62	460	0.s4	34	16	2.4	370	18	12	170	30
2984	0.00	47.43	3847	14.70	5257	498	0 5											
2985							0 6	45	390	0.68	19	7 9	1.6	260	8.7	9.3	160	26
2986	026	5497	2693	1587	4477	493	12											
2987							10											
2988	0.03	2456	52.25	2317	75.41	591	10											
2989							0 7											
2990	2.36	55.49	24.78	17.37	42.15	4.90	0 7											
2991							12											
2992	075	3317	4256	2352	6608	560	1.1											
2993							11											
2994	001	3613	4308	2079	63.86	546	0 9											
2995							0 4											
2996	000	9515	395	090	4.85	353	0 2											
2997							0 4	46	260	0.32	8.9	4.3	0.85	280	2.7	<6.S	120	17
2998							0 2											
2999							11	51	480	0.89	35	12	2.2	370	14	11	180	29

Sample	Textural Analysis							Geochemistry										
Sample No. “	Gravel %	Sand %	Sill %	Ciay %	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. 4

3000							0 8											
3001							2 0	51	390	0.75	29	12	2.1	340	15	11	160	26
3002							0 7											
3003							01	62	420	1.1	32	10	1 9	290	12	14	210	24
3004							14											
3005							0 6	54	410	0.66	24	11	2.2	320	13	8.7	170	20
3006							1.4											
3007	043	2753	5266	1918	72.04	572	0 9	69	460	0.81	36	14	2.5	340	17	23	190	36
3008	005	3058	4402	2536	69.37	5.91	1.2											
3009							0 7											
3010	021	4406	41.47	14.25	55.72	504	0 8											
3011							0 9											
3012	168	4341	3684	1806	5490	530	01											
3013							0 8											
3014	601	4877	2883	1639	4522	492	0 9											
3015							0 5											
3016	019	3747	4640	1594	62.34	526	0 4											
3017							0 2											
3018	001	6602	983	414	1397	340	01											
3019							0 2	55	370	0.64	42	5.9	1.4	510	6.2	17	200	43
3020							0 3											
3021							0.7	66	530	1.1	27	12	2.4	440	17	23	250	32
3022							0 7											
3023							0 3	60	380	1.3	19	9.3	1.7	340	10	14	230	20
3024							0 4											
3025							0 7	71	520	1.4	44	15	2.5	380	20	21	230	35
3026							’ 0 1											
3027							01	73	450	0.85	32	14	2.4	340	16	21	200	37
3028							0 8											
3029							0 4	59	440	095	29	13	2.3	310	17	20	220	31
3030	1 15	58.78	2878	1130	40.06	456	0 3											
3031							0 4											
3032	1.43	3216	4637	2005	66.41	563	0 4											
3033							0 2											
3034	11.92	5883	1863	10.62	29.25	4.38	<0.1											
3035							0.2											
3036	270	53.42	29.75	14.73	44.48	475	0.5											
3037							0.6											
3038	0.50	4685	37.43	15.42	52.85	5.12	0 7											
3039							0 8											
3040	001	92.32	5.90	1.77	767	373	0 3											
3041							04	71	440	0.78	50	7.1	1.7	370	8.3	15	190	18
3042							0.5											
3043							0 8	54	400	0.90	30	12	2.2	360	15	22	220	33
3044							0.7											
3045							0.7	46	340	1.1	58	9.6	2.0	380	11	15	200	20
3046							0.7											
3047							0 5	58	410	2.0	19	9.6	2.0	340	13	19	270	33
3048							0.3											

	Textural Analysis							Geochemistry										
Sample No."	Gravel %	Sand %	Sill %	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.			5						
3049							0 7	53	440	0.79	29	14	2.2	330	15	19	170	26
3050							0 7											
3051							0 6	60	550	1.6	26	9.6	1.8	300	13	14	230	23
3052	368	62.76	1945	1471	3356	466	0 4											
3053							12											
3054	048	3624	4190	2137	63.27	5.66	0 7											
3055							0 3											
3056	447	7786	10.77	689	1766	359	0.4											
3057							0 7											
3058	125	5245	2754	1676	43.30	499	0 6											
3059							10											
3060	013	7458	1530	9.99	25.29	4.33	0 7											
3061							0 7											
3062	003	8867	615	515	11.30	3.74	0 6											
3063							0 6	57	400	096	48	5.7	1.6	510	7.6	14	220	17
3064							10											
3065							0 8	46	410	084	51	9.1	1 8	310	11	15	210	33
3066							0 7											
3067							11	46	370	2.0	25	11	2.2	410	14	16	290	31
3068							1.0											
3069							0 6	61	400	2.1	18	7.3	1.7	340	9.2	13	250	26
3070							0 6											
3071							11	67	480	1.0	32	15	2.4	370	18	19	200	32
3072							10											
3073							10	67	500	1.1	42	15	2.6	380	17	22	220	39
3074	004	3000	4614	2382	69.96	587	10											
3075							0 6											
3076	169	3782	4068	1981	6049	557	10											
3077							0.5											
3078	471	7459	1202	868	20.70	367	0.8											
3079							0 7											
3060	345	4624	3106	1.925	5031	520	1.0											
3081							0.8											
3082	0.26	42.46	3839	1888	5727	533	0 8											
3083							0 8											
3084	0.08	9221	571	200	7.71	361	0.5											
3085							0 4	66	350	0.38	31	56	13	300	8.4	12	180	38
3086							1.0											
3087							0 8	61	530	1.2	36	16	2.3	430	16	19	240	43
3089							0 8	79	510	2.8	98	28	2.9	570	20	15	240	47
3090							0.8											
3091							10	29	260	12	13	7.4	1.3	700	5.1	8.8	910	110
3092							11											
3093							1.5	62	530	1.2	28	16	2.5	410	17	17	250	38
3094							11											
3095							1.3	79	450	093	37	28	2 6	420	18	20	210	30
3096	005	4259	3620	1916	57.36	5.41	0.8											
3097							0.8											
3098	043	44.72	3685	1599	54.84	517	0.9											
3099							1.0											

			Textural Analysis									Geochemistry						
Sample No.”	Gravel %	Sand %	silt %	Clay %	Mud %	mean φ	TOC %	B ppm .	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
									SHELF, cont.		6							
3100	1060	5221	2401	1319	3720	417	10											
3101							17											
3102	914	2337	4493	2256	67.49	593	15											
3103							14											
3104							11											
3105							0 6											
3106	291	5688	2835	11.87	4021	465	0 8											
3107							0 8	57	490	1.9	64	17	2 4	380	13	17	310	39
3108							0 5											
3109							10	49	460	1.1	24	14	2.3	420	14	13	230	30
3110							0 7											
3111							0 9	59	470	1.7	32	14	2.3	440	15	15	260	26
3112							0 6											
3113							0 6	11	340	28	13	5 6	1.1	690	5.1	<6.6	1900	<15
3114							0 6											
3115							0 9											
3116							0 9											
3117							0 6											
3118	048	4745	3147	2061	52.08	535	0 8											
3119							0 5											
3120	2.56	5681	25 60	1503	4063	489	0 6											
3121							0 6											
3122	4155	16 33	2515	1696	42.11	552	0 8											
3123							10											
3124							12											
3125							1.1											
3126	045	48.06	3270	1860	51.49	4 30	0 9											
3127							0 6											
3128	166	3570	4160	2096	6256	564	0 6											
3129	1 19	7628	1798	455	22.63	3.66	0 9	23	310	0.99	23	5.4	1.1	260	5.2	9.1	180	31
3130	8.30	5798	2179	1194	33.73	436	0 6											
3131							0 9	78	420	1.2	46	34	3.2	550	21	15	210	41
3132	549	5529	2792	1131	39.22	447	0.7											
3133	6.39	3451	3879	1977	5656	5.36	0 9	70	500	3.2	33	26	2.6	520	18	14	310	59
3134	0.55	551	5567	2837	9394	716	0.9											
3135	7.83	8359	484	374	8.58	236	0 4	31	370	9.5	14	6.5	1.6	420	7.7	11	660	72
3136	6.96	7814	444	1046	14.89	314	0 3											
3137							0 8	66	540	2.5	30	18	2.6	410	16	17	270	42
3138	2.96	5136	30.48	1520	45.s6	491	0 7											
3139							0.6	64	510	5.1	40	14	2.3	340	15	14	340	55
3140							0 8											
3141							0 7											
3142							0 7											
3143							0.2											
3144							0.8											
3145							10											
3146							0 7											
3147							12											
3148							1.1											
3149							1.1											

Sample No.'	Textural Analysis Gravel %	Sand %	Sill %	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. 7																		
3150							0.6											
3151	029	80.52	1511	409	19.20	375	0.7	42	450	1.3	11	3.5	1.3	630	0.2	<6.s	260	15
3152							10											
3153	102	12.26	6156	25.14	6670	626	10	62	560	1.3	39	16	2.9	690	26	16	250	86
3154							1.1											
3155	439	1444	55.77	2540	81.17	626	0 9	66	450	1.2	37	17	3.1	680	26	15	240	56
3156							0 9											
3157	033	746	6259	2960	92.19	661	14	74	490	0.87	49	22	3.5	690	34	21	210	69
3158							0.2											
3159	0.17	1568	5977	24.38	6415	612	1.3	71	550	095	46	16	2.6	600	24	15	220	47
3160							0 5											
3161	288	4096	43.83	1231	5613	505	0 6	51	460	3.6	24	11	2.0	530	17	11	360	40
3162							0 6											
3163							0 7											
3164							1.2											
3165							01											
3166							0 2											
3167							1.2											
3168							11											
3169							1.7											
3170							1.1											
3171							0 1											
3172							0 5											
3173	4.68	7280	1365	8.67	2252	439	0 4	33	420	2 9	12	4.3	11	450	8.1	7.1	420	14
3174							1.0											
3175	011	1123	5876	2989	8665	667	10	71	450	069	45	20	3.0	660	28	19	210	56
3176							0 9											
3177	0.54	28.03	5080	2063	71.43	569	0 6	79	500	1.2	34	15	3.0	640	24	15	230	55
3178							0 5											
3179	046	4036	4267	1651	59.16	517	0 7											
3160							0 4											
3181	001	3875	4897	1227	61,24	497	0 7	73	620	095	42	16	3 0	670	26	16	220	56
3182							1.1											
3163	001	5564	2868	1567	4455	508	0 7	70	570	091	38	14	2.8	560	24	13	230	51
3184							0 6											
3185							0 6											
3186							0 7											
3187							0 4											
3186							0 6											
3169							0 6											
3190							0 8											
3191							0.8											
3192							0 6											
3193							1 0											
3194							0 3											
3195	003	6999	900	0.97	998	360	0 2	36	390	0.47	19	1.7	063	440	3.6	< 6 8	150	23
3196							1.1											
3197	0.00	595	7246	21.57	94.05	6.25		68	570	0.98	50	22	3 7	630	31	20	230	75
3198							1.1											
3199	008	25643	5205	2219	74.24	561	0.9	70	560	1.2	51	19	2.9	780	25	16	230	46

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
								SHELF, cont.			8							
3200	165	4336	3647	1852	5489	524	0 7	56	460	1.0	36	12	2.4	520	18	11	180	34
3201							10											
3202	283	35.45	4190	1982	61.72	551	0 5	57	400	0.99	21	10	2.4	580	19	12	180	38
3203							0 6											
3204	0.46	3469	4773	1712	6485	544	0 7	62	470	094	31	11	2.6	56a	21	14	200	3a
3205	002	2577	6472	948	74.20	4sa	0 7											
3206							0 9											
3207							0.7											
3208							0 7											
3209							10											
3210							0 9											
3211							0 9											
3212							0.7											
3213							1.1											
3214							10											
3215							1.1											
3216							0 1											
3217	033	91.81	679	108	768	364	0 1	59	320	0.50	50	1.7	0.78	590	4.6	<6.8	140	<lo
3216							0 6											
3219	002	621	6638	25.39	91.77	644	0 6	54	490	0.68	33	17	2.6	680	23	13	160	38
3220							10											
3221	000	501	6240	3259	94.89	693	10	70	500	0.87	58	22	3.1	780	30	22	170	63
3222							1.0											
3223	000	973	8362	2665	90.27	643	10	68	500	1.0	48	17	3 0	710	29	19	190	51
3224							0 8											
3225	000	1498	6049	2453	85.02	627	1.0	77	470	0.93	50	17	3.2	700	27	17	180	48
3226							11											
3227	000	2154	5757	2089	76.46	591	1.0	83	530	1.1	49	19	3.2	590	27	16	200	48
3228							0 6											
3229							11											
3230	032	5560	2825	1583	44.06	4s0	0.9											
3231							11											
3232							1 2											
3233							1.2											
3234							11											
3235							1.1											
3236							1.1											
3237							0 9											
3238							0.1											
3239	1.20	9048	5.65	266	831	363	0 2	60	400	1.4	16	1.7	1.1	540	6.4	<6.8	220	<lo
3240							0.6											
3241	0.00	17.77	55.78	26.45	8223	634	0.9	80	430	0.70	25	11	2.8	830	19	11	170	44
3242							1.1											
3243	0.03	723	64.71	28.03	92.73	667	1.1	68	720	1.0	57	21	3.1	830	29	20	190	57
3244							0.9											
3245	000	1206	62.49	25.46	67.94	630	0.7	75	550	0.89	53	21	3.4	720	32	16	190	48
3246							0 9											
3247	0.04	28.08	4502	2685	71.88	5.97	0.9	76	500	0.95	42	20	3.5	680	29	17	200	83
3246							0.7											
3249	000	26.78	53.78	19.45	73.22	5.69	0.7	65	460	0.62	49	12	2.7	480	22	11	190	41

SHELF, cont. 9

Sample No.'	Gravel %	Sand %	Textural Analysis Sill %	Clay. %	Mud %	mean φ	TO C %	Geochemistry B ppm	Ba ppm	Ca %	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
3250							10											
3251							0.7											
3252	000	10.74	5248	3677	8926	693	0 9											
3253							0 8											
3254							0 9											
3255							10											
3256							10											
3257							11											
3258							10											
3259							0 6											
3260							0.1											
3261	0.32	9415	418	1.35	553	360	01	49	320	058	18	1.5	0.86	530	4.3	<8.8	140	<lo
3262							0 5											
3263	002	2857	5163	1977	71.40	579	0 6	66	500	0.82	45	21	3.2	860	28	22	150	52
3264							0 9											
3265	002	8.50	6142	30.08	91.48	674	0 8	71	540	082	47	16	3.1	860	28	17	150	43
3266							0 6											
3267	000	436	6630	2934	95.64	674	0 9	79	570	0.96	52	21	3.3	810	33	24	170	49
3268							0 9											
3269	000	1625	5902	24.73	83.75	624	0 7	80	520	091	51	20	3.6	750	31	19	200	69
3270							0 5											
3271	000	4683	3959	13 58	53.17	498	0 5	57	470	080	43	12	2.4	460	23	14	170	46
3272							0 8											
3273							0 9											
3274							10											
3275							0 9											
3276							10											
3277							1.0											
3278							11											
3279							0 9											
3280							0 6											
3281							0.3											
3262							0.3											
3283	0.23	9558	284	136	4.79	355	0 5	20	310	042	5.9	1.6	0.70	370	3 6	<6.8	130	<lo
3264							0 3											
3285	002	7092	2457	446	29.06	392	0 5	46	520	1.0	19	3.7	1.5	460	9.0	11	200	<10
3286							10											
3287	0.00	493	6984	25.22	95.07	662	0 6	74	620	0.94	51	18	3.6	1000	33	23	190	75
3286							11											
3289	000	073	6580	3337	99.27	7.12	1.2	67	480	0.62	44	21	3.1	820	30	19	170	68
3290							10											
3291	007	16.40	5216	2937	81.53	632	10	63	550	0.98	53	17	2 9	730	32	18	200	48
3293	000	1516	5365	31 19	8484	6.63	0 9	59	610	0.94	45	16	2.8	590	30	18	210	51
3294							0 6											
3295							10											
3296							0 9											
3298							10											
3299							1.0											
3300							0.9											
3301							0.6											

			Textural Analysis									Geochemistry						
Sample No. ”	Gravel %	Sand %	sill %	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.		10							
3302							01											
3303							0.1											
3304							0 2											
3306							0 3											
3307	040	9698	170	092	261	301	0 3	31	340	0.81	5.6	1.5	0.61	36a	3.4	< 6 8	120	15
330a							0 6											
3309	012	4064	4061	18 44	5905	547	0.8	53	560	1.1	36	17	2.6	820	22	18	210	49
3310							12											
3311	008	1023	6066	2902	89.69	665	11	73	640	1.1	61	22	3.1	a20	34	23	220	60
3312							0 7											
3313	452	5045	2792	17.11	4503	4.90	0 6	49	530	0.79	2a	9.1	2.0	430	20	12	200	27
3314							1.1											
3315	026	3029	51.66	17.60	69.46	555	0.9											
3316							0 7											
3317							0.3											
3318							0 7											
3319							0.8											
3320							0 8											
3321							07											
3322							07											
3323							01											
3324							0 3											
3325							01											
3326							0 2											
3327	26.36	7047	1.81	1.33	3.15	241	0.1											
3326	000	2347	4366	3267	76.53	647	0 6	63	600	1.1	53	22	3.2	1300	31	24	200	49
3329	0.00	1583	47.57	3660	84.17	663	0 4											
3330	1.00	89 60	709	230	9.40	373	01	2a	350	1.6	18	4.0	1.2	490	8.2	9.2	200	<10
3331	1.85	92.81	4.51	0 84	5.34	3.19	o											
3332	031	5704	2384	18.81	42.65	4.97	0.4	49	500	1.1	25	12	2.3	730	19	15	170	27
3333	0.00	2011	41.55	3834	79.69	672	01											
3334	0.62	56.25	2202	1912	41.14	4.94	04	51	470	1.3	42	11	2.3	640	19	15	210	33
3335	1395	28,84	45.63	1157	57.21	505	0.5											
3336	261	4539	3608	1592	52.00	505	0 2	52	570	1.2	74	11	2.4	580	23	18	220	50
3337	0.29	4944	3839	11.88	5027	4.78	0 2											
3338							0 2											
3339							0 2											
3340							0 2											
3341							0 2											
3342							0.9											
3343							0.8											
3344							0.5											
3345							0.6											
3346							0.5											
3347	036	594	80.40	1330	93.70	5.64	0.8	66	540	1.1	40	12	2.4	770	21	18	210	29
3348							0.6											
3349	1518	35.56	2664	20.63	49.27	5.43	0 5	44	440	9.1	25	12	2.4	1300	20	20	530	79
3350							0 3											
3351	001	71,79	17.72	10.47	28.19	4.29	0.7	33	420	0.75	26	4.5	1.5	5543	10	11	140	11
3352							0.8											

Sample No.*	Textural Analysis						Geochemistry											
	Gravel %	Sand %	Sill %	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. 11																		
3353	010	1735	4418	38.37	8255	683	0.9	66	590	095	49	20	3.0	860	30	23	200	61
3354							0 4											
3355	14.02	2846	4654	10.98	5752	5.02	0 2	68	340	073	26	91	1.9	370	12	11	150	16
3356							0 4											
3357							0.3											
3358							0.4											
3359							0.6											
3360							0 8											
3361							0 8											
3362							0 8											
3363							10											
3364							0 8											
3365							1 0											
3366							0 8											
3367							0 9											
3368	002	856	7621	1521	91.42	575	0 8	72	560	067	31	12	1.6	700	10	17	190	38
3369							0 7											
3370	0.31	2724	5221	2024	7245	566	0.8	72	620	1.1	36	17	3 3	790	25	21	230	47
3371							0 9											
3372	006	4405	4251	1338	5589	512	0 7	66	460	0S0	27	13	2.9	660	19	15	190	37
3373							0 8											
3374	000	1086	5422	35.12	8934	6,94	1.0	78	580	0.76	36	16	3 5	790	27	23	210	57
3375							0 8											
3376	005	5477	3528	989	4518	438	0.5	86	510	0.74	32	13	3.3	580	23	19	200	46
3377							0.5											
3378	1.45	5599	2845	1411	42 56	471	0 6	50	440	0.68	31	8.6	1.9	400	15	10	140	19
3379							0 4											
3380							0 4											
3381							0 9											
3382							0.7											
3383							0 7											
3384							1 0											
3385	000	2727	51.64	21.09	72.73	563	0 8											
3386							1.0											
3387	019	2586	5548	1646	7395	569	0 6											
3386							0 7											
3389							0 7											
3390	0.25	3692	5195	1088	6283	528	0 7	63	560	1.3	26	12	2.6	7cKr	19	16	240	36
3391							0 9											
3392	071	48.18	3955	11.55	51 10	4.84	0 7	65	600	1.4	47	11	2.7	620	24	14	240	39
3393							1.0											
3394	011	32 60	4644	2085	67.30	5.83	0.8	78	470	1.2	49	19	3.4	690	27	20	230	63
3395							0.7											
3396	0.14	4719	36.46	1621	52.68	5.15	0.7	60	490	1.2	34	16	2.6	6343	24	19	230	48
3397							0.6											
3398	0.53	4070	4075	1802	5077	5.36	0 6	69	510	1.7	50	12	2.9	680	23	17	240	50
3399							0.5											
3400	0.92	4460	3840	16.07	54.48	511	0.5	62	490	1.1	25	11	1.6	470	19	14	220	38
3401							0.4											
3402							0.4											

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.				12						
3403							0 6											
3404							0 6											
3405							0 6											
3406							0 5											
3407							0 5											
3408							0 6											
3409							0 9											
3410							0 9											
3411							0 7											
3412	0.s1	4546	4520	853	53.73	4 8 5	0 8	58	500	1.1	26	9.5	2.0	630	20	16	210	25
3413							0 7											
3414	0.85	4467	3552	1896	54.48	5.19	0 5	55	790	1.4	26	11	2.7	580	22	13	230	38
3415							0.5											
3416	1.59	57.07	2865	1449	41.34	4 7 4	0 6	58	460	1.0	21	8.5	1.6	520	16	14	230	42
3417							0 6											
3418	044	4615	3648	1695	5341	5 1 7	0 6	62	530	1.1	25	10	1.6	500	20	15	220	42
3419							0 6											
3420	072	3762	4534	16.12	6146	5 2 8	0 6	73	540	1.1	28	9.8	3.0	480	20	14	230	42
3421							0 6											
3422	027	4357	4114	1501	5616	5 0 8	0 6	58	440	0.87	29	9.8	2.0	460	18	13	190	36
3423	000	3396	5066	1518	6604	5 3 a	0 6											
3424							0 7											
3425							0 6											
3426							0 7											
3427							0 6											
3428							0 5											
3429							0 6											
3430																		
3431	016	2597	5240	2148	7346	5 8 7	0 7											
3432							0 6											
3433							0 8											
3434	1.01	3366	5015	14.98	65.12	5 4 3	0 7	69	600	1.0	35	12	2.8	670	22	16	200	37
3435							0 7											
3436	022	2605	4924	2449	73.73	6 0 3	0 7	79	570	1.0	50	19	3.4	840	30	21	210	57
3437							0 9											
3438	3.49	50.16	27.85	18.49	4634	4 9 5	0.5	50	530	1.6	28	11	2.6	570	21	16	240	44
3439							0.7											
3440	1.25	52.52	2658	19.65	46.23	5.12	0 5	56	450	1.2	29	11	2.6	580	21	14	230	48
3441							0.6											
3442	1.12	4563	3424	1681	53.05	5.26	0.5	69	540	1.1	50	10	3.0	670	24	15	250	50
3443							0 5											
3444	1.77	3393	41.43	22.88	64.30	5.77	0 7	66	550	1.1	36	13	2.9	580	24	16	230	51
3445							0 6											
3446							0.7											
3447							0.7											
3448							0.6											
3449							0.5											
3450							0.6											
3451							0.5											
3452							0.6											

SHELF, cont. 13

Sample No."	Textural Analysis							Geochemistry										
	Gravel %	Sand %	Sill %	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
3453							07											
3454							07											
3455							09											
3456	004	2091	6601	1304	7905	551	05	57	500	076	23	10	2.7	730	18	16	170	28
3457							07											
3458	003	3589	4288	21 19	6407	577	07	65	470	0.83	28	14	2.9	860	21	18	200	62
3459							08											
3460	058	4698	31.18	21.26	5243	535	06	45	590	1.3	30	10	2.5	600	20	13	240	36
3461							07											
3462	141	5478	2920	1461	4381	4.72	04	54	470	1.7	35	10	2.6	700	20	14	250	46
3463							05											
3464	033	5184	32.65	1518	4783	496	06	48	670	1.3	33	9.8	2.3	450	19	13	240	41
3465							06											
3466	015	3736	48.49	1400	62.49	483	07	60	490	10	30	10	1.9	480	20	15	230	44
3487							06											
3468							07											
3469							08											
3470							04											
3471							07											
3472							07											
3473							06											
3474							07											
3475							07											
3476							09											
3477							07											
3478	1389	5231	2344	10 3s	33 80	433	04	49	550	3 7	43	5.5	1.6	750	13	8.2	390	44
3479							07											
3480	030	3070	4366	2534	69 00	4.s3	07	69	470	1.1	38	15	3.1	600	24	19	220	47
3481							09											
3482	1.60	4192	3530	21 19	5646	5,45	08	67	540	1.2	28	12	3.0	720	23	17	250	55
3483							07											
3484	4.58	4774	3021	1747	4766	500	06	45	550	2.1	27	9.4	2.7	580	19	14	300	59
3485							05											
3486	2.48	5223	3107	14.73	45 30	4.85	06	62	1300	1.1	45	11	2.6	520	21	13	370	40
3487							0.7											
3488	0.10	4754	3345	18.91	5236	526	05	54	620	1.6	39	10	2.7	490	22	15	240	41
3489							07											
3490							08											
3491							08											
3492							09											
3493							07											
3494							07											
3495							08											
3496							09											
3497							08											
3498							04											
3499	000	4442	4037	15.21	55.5s	505	03											
3500	0.36	2579	5430	1955	7364	570	03	76	560	1.0	41	18	3.3	840	27	21	210	66
3501							03											
3502	0.53	42.11	3782	1953	57.36	5.41	07	56	510	1.0	29	13	2.7	650	23	17	230	53

SHELF, cont. 14

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
3503							0.7											
3504	0.86	46.59	3426	18.29	5265	5 2 0	09	58	630	1.5	37	12	2.9	730	22	18	250	43
3505							06											
3506	104	50.78	3066	17.52	4818	492	07	72	550	1.s	35	12	3.2	590	23	14	270	68
3507							04											
3508	0.40	58.75	2727	1358	40.85	467	06	43	530	1.2	25	7.5	1.9	430	16	12	240	29
3509							0.6											
3510	7.36	5146	3006	1112	41.18	461	05	50	570	1.3	36	9.7	1.9	460	19	14	230	33
3511	674	3818	41.71	13.37	55.08	502	07											
3512							o?											
3513							06											
3514							05											
3515							05											
3516							0.7											
3517							07											
3518							08											
3519							08											
3520							06											
3521							05											

Appendix C: Distribution of Molluscan Species in the Galveston-Houston Area

	G	T	E	w	CL	s	Total
Phylum Mollusca							
Class Gastropoda Cuvier, 1797							
Family Fissurellidae Fleming, 1822							
Diodora cayenensis (Lamarck, 1822)						D	
Lucapinella limatula (Reeve, 1850)						D	
Family Hydrobiidae Stimpson, 1865							
Hydrobia sp.	D	D	D				
Family Littoridinidae Thiele, 1929							
Texadina barretti (Morrison, 1965)	7	15	7	6	D		35
Texadina sphinctostoma (Abbott and Ladd, 1951)	7	12	7	D	D	D	26
Family Stenothyridae Fischer, 1885							
Probythinella louisianae (Morrison, 1965)		13				D	13
Family Vitrinellidae Bush, 1897							
Vitrinella floridana Pilsbry and McGinty, 1946	D		D	D		71	71
Cyclostremiscus pentagonus (Gabb, 1873)	D			D		43	43
Cylostremiscus suppressus (Dan, 1889)	D			D			
Anticlimax pilsbryi McGinty, 1945						D	
Solariorbis blakei Rehder, 1944	D						
Solariorbis infracarinata Gabb, 1881						2	2
Solariorbis cf. *mooreana* (Vanatta, 1903)						D	
Teinostoma biscaynense Pilsbry and McGinty, 1945	D					2	2

	G	T	E	W	CL	S	Total
Teinostoma lerema Pilsbry and McGinty, 1945				D			
Teinostoma parvicallum Pilsbry and McGinty, 1945						D	
Teinostoma sp.				D			
Family Caecidae Gray, 1850							
Caecum johnsoni Winkley, 1908				D		6	6
Caecum nitidum Stimpson, 1851							
Caecum pulchellum Stimpson, 1851				1			1
Family Turritellidae Clark, 1851							
Vermicularia fargoi Olsson, 1951			D				
Family Architectonicidae Gray, 1850							
Architectonic nobilis Röding, 1798						D	
Family Modulidae Fischer, 1884							
Modulus modulus (Linné, 175'8)						D	
Family Cerithiidae Fleming, 1822							
Bittium varium (Pfeiffer, 1840)	D		D	D		D	
Alabina cerithidioides Dan, 1881						D	
Cerithiopsis emersoni (C. B. Adams, 1838)						D	
Cerithiopsis greeni (C. B. Adams, 1839)				D		D	
Seila adamsi (H. C. Lea, 1845)	D			D		D	
Litiopa melanostoma Rang, 1829						D	
Family Triphoridae Gray, 1847							
Triphora nigrocincta (C. B. Adams, 1839)						D	
Family Epitoniidae S. S. Berry, 1910							
Epitonium albidum (Orbigny, 1842)					D		
Epitonium angulatum (Say, 1830)						D	

	G	T	E	W	CL	s	Total
Epitonium apiculatum (Dan, 1889)	D		D			4	4
Epitonium humphreysi (Kiener, 1838)			D				
Epitonium multistriatum (Say, 1826)	1			D		1	2
Epitonium novangliae (Couthouy, 1838)						D	
Epitonium rupicola (Kurtz, 1860)	D					D	
Family Eulimidae Risso, 1826							
Eulima bilineata (Alder, 1848)						7	7
Eulima hemphilli Dan, 1884						D	
Balcis arcuata (C. B. Adams, 1850)						D	
Balcis jamaicensis (C. B. Adams, 1845)						D	
Balcis sp.						D	
Niso aeglees Bush, 1885						D	
Family Aclididae G. O. Sars, 1878							
Henrya goldmani Bartsch, 1947						D	
Family Calyptraeidae Blainville, 1824							
Crepidula convexa Say, 1822	D		D	D		1	1
Crepidula fornicata (Linné, 1758)	D		D	D		D	
Crepidula plana Say, 1822	4	D	D	3		D	7
Family Naticidae Gray, 1840							
Natica pusilla Say, 1822	1		D	D		82	83
Polinices duplicates (Say, 1822)	4		D	2		7	13
Sinum perspectivum (Say, 1831)						D	
Family Muricidae da Costa, 1776							
Thais haemastoma (Linné, 1767)	D					D	

	G	T	E	W	CL	S	Total
Family Columbellidae Swainson, 1840							
Costoanachis cf. *avara* (Say, 1822)						D	
Costoanachis lafresnayi (Fischer and Bernardi, 1856)						D	
Cosmioconcha calliglypta (Dan and Simpson, 1901)						D	
Suturoglypta iontha (Ravened, 1861)						D	
Parvanachis obesa (C. B. Adams, 1845)	3		D	1		73	77
Parvanachis ostreicola (Melvill, 1881)	D			D		1	1
Mitrella lunata (Say, 1826)	D			D		D	
Family Buccinidae Rafinesque, 1815							
Cantharus cancellarius (Conrad, 1846)						D	
Family Melongenidae Gill, 1867							
Busycon perversum (Linné, 1758)						D	
Busycon spiratum (Lamarck, 1816)						D	
Family Nassariidae Iredale, 1916							
Nassarius acutus (Say, 1822)	7		D	D		98	105
Nassarius vibex (Say, 1822)	D			1			1
Family Olividae Latreille, 1825							
Oliva sayana Ravenel, 1834						D	
Olivella dealbata (Reeve, 1850)						6	6
Olivella minuta (Link, 1807)						4	4
Family Terebridae H. and A. Adams, 1854							
Terebra concava Say, 1827						D	
Terebra protexta Conrad, 1845						2	2

	G	T	E	w	CL	s	Total
Family Turridae Swainson, 1840							
Kurtziella rubella (Kurtz and Stimpson, 1851)						D	
Kurtziella sp. A						D	
Kurtziella sp. C						2	2
Kurtziella sp. D	D					D	
Kurtziella sp. E	D					2	2
Nannodiella vespuciana (Orbigny, 1842)						D	
Pyrgocythara plicosa (C. B. Adams, 1850)	D		D	D			
Turrid sp.						D	
Family Pyramidellidae Gray, 1840							
Pyramidella crenulata (Holmes, 1859)	D					1	1
Odostomia dianthophila Wells and Wells, 1961						D	
Odostomia gibbosa Bush, 1909	D	D	D	D		1	1
Odostomia impressa (Say, 1821)	10		1	1			12
Odostomia seminuda (C. B. Adams, 1837)	D			2		D	2
Sayella cf. *livida* Rehder, 1935	D			D			
Eulimastoma cf. *canaliculata* (C. B. Adams, 1850)						D	
Eulimastoma engonia (Bush, 1885)	D		D	6		D	6
Eulimastoma harbisonae Bartsch, 1955	D		D	1		D	1
Eulimastoma weberi (Morrison, 1965)	3	D	D	1	D	4	8
Turbonilla (Chemnitzia) sp. A	D			D		1	1
Turbonilla (Chemnitzia) sp. B						D	
Turbonilla (Chemnitzia) sp. F	D			D			
Turbonilla elegans (Orbigny, 1842)						D	

	G	T	E	w	CL	S	Total
Turbonilla speira	1			1		9	11
Turbonilla cf. *interrupta* (Totten, 1835)	9		D	19		6	34
Turbonilla (Pyrgiscus) sp. B	1			2		24	27
Turbonilla (Pyrgiscus) sp. C						D	
Turbonilla (Pyrgiscus) sp. F				1		2	3
Turbonilla cedrosa Dan, 1884				1			1
Peristichia toreta Dan, 1889						D	
Cyclostemella humilis Bush, 1897	D			D		D	
Family Acteonidae Orbigny, 1842							
Acteon punctostriatus (C. B. Adams, 1840)	D			20		2	22
Family Acteocinidae Pilsbry, 1921							
Acteocina canaliculata (Say, 1822)	13	D	D	135		D	148
Family Cylichnidae A. Adams, 1850							
Cylichnella bidentata (Orbigny, 1841)	D			D		D	
Family Retusidae Thiele, 1926							
Volvulella persimilis (Mörch, 1875)						1	1
Volvulella texasiana Harry, 1967						18	18
Family Cuvieridae Gray, 1840							
Creseis acicula (Rang, 1828)						D	
Cavolina longirostris (Blainville, 1821)						D	

	G	T	E		CL	S	Total
Class Bivalvia Linné, 1758							
Family Nuculidae Gray, 1824							
Nucula proxima Say, 1822						D	
Family Nuculanidae Meek, 1864							
Nuculana acuta (Conrad, 1831)	D			5		8	13
Nuculana concentrica (Say, 1824)	D			1		96	97
Family Arcidae Lamarck, 809							
Anadara brasiliana (Lamarck, 1819)						1	1
Anadara transversa (Say, 1822)	D		D	D		5	5
Lunarca ovalis (Bruguière, 1789)	D			D		2	2
Family Noetiidae Stewart, 1930							
Noetia ponderosa (Say, 1822)	D					D	
Family Mytilidae Rafinesque, 18 5							
Brachidontes exustus (Linné, 1758)	4	D	86	D		D	90
Ischadium recurvum (Rafinesque, 820)	10			D	Q		10
Gregariella coralliophaga (Gmelin, 79)						D	
Amygdalum papyrium (Conrad, 1846)	4			3			7
Family Pectinidae Rafinesque, 1815							
Argopecten gibbus (Linné, 1758)						D	
Argopecten irradians amplicostatus Dall. 898	D			a		D	
Family Plicatulidae Watson, 1930							
Plicatula gibbosa Lamarck, 1801						D	
Family Anomiidae Rafinesque, 1815							
Anomia simplex Orbigny, 1842	n		D	D		D	

	G	T	E	W	CL	S	Total
Family Limidae Rafinesque, 1815							
Lima cf. *locklini* McGinty, 1955						D	
Family Ostreidae Rafinesque, 1815							
Ostrea equestris Say, 1834	D	D	D	D	D	D	
Crassostrea virginica (Gmelin, 1791)	2	D	D	D	D	D	2
Family Lucinidae Fleming, 1828							
Linga amiantus (Dall, 1901)	D			1		17	18
Parvilucina multilineata (Tuomey and Holmes, 1857)	D					1	1
Family Ungulinidae H. and A. Adams, 1857							
Diplodonta semiaspera (Philippi, 1836)	D			D		D	
Diplodonta cf. *soror* C. B. Adams, 1852				D		1	1
Family Chamidae Lamarck, 1809							
Chama congregata Conrad, 1833						D	
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		D			48	D	48
Family Montacutidae Clark, 1855							
Mysella planulata (Stimpson, 1857)		21		2	173	1	197
Family Sportellidae Dall, 1899							
Ensitellops sp.		D			D	D	
Family Crassatellidae Férussac, 1822							
Crassinella lunulata (Conrad, 1834)		1	D	D	D	3	14

	G	T	E	w	CL	s	Total
Family Cardiidae Oken, 1818							
Trachycardium muricatum (Linné, 1758)	D			D		D	
Laevicardium mortoni (Conrad, 1830)	D			4		D	4
Dinocardium robustum (Lightfoot, 1786)						D	
Family Mactridae Lamarck, 1809							
Mactra fragilis Gmelin, 1791	D					D	
Mulinia lateralis (Say, 1822)	72	8	12	482	1	8	583
Rangia cuneata (Sowerby, 1831)	D	D	D	D	D	D	
Rangia flexuosa (Conrad, 1839)	8	7	5	D		D	20
Spisula solidissima similis (Say, 1822)			D				
Raeta plicatella (Lamarck, 1818)						D	
Family Solenidae Lamarck, 1809							
Solen viridis Say, 1821						2	2
Ensis minor Dan, 1900				33		D	33
Family Tellinidae Blainville, 1814							
Tellina aequistriata Say, 1824						D	
Tellina alternata Say, 1822						D	
Tellina iris Say, 1822	6					1	7
Tellina texana Dall, 1900	20	4	1	19		D	44
Tellina versicolor DeKay, 1843	D					118	118
Tellina sp.						7	7
Tellidora cristata (Récluz, 1842)						D	
Strigilla mirabilis (Philippi, 1841)						D	
Macoma brevifrons (Say, 1834)						D	

	G	T	E	W	CL	S	Total
Macoma mitchelli Dal , 1895	16	13	12	9			50
Macoma tageliformis Dall, 1900						D	
Macoma tenta (Say, 1834)	D			D		2	2
Family Donacidae Fleming, 1828							
Donax texasianus Philippi, 1847	D					D	
Donax variabilis Say, 1822	D			D		D	
Family Semelidae Stoliczka, 870							
Semele *bellastriata* (Conrad, 1837)	D					D	
Semele *nuculoides* (Conrad, 1841)						D	
Semele *proficua* (Pulteney, 1799)	D			D		D	
Semele *purpurascens* (Gmelin, 1790)	D					D	
Semele sp.						D	
Cumingia *tellinoides* (Conrad, 183)	D			2			2
Abra *aequalis* (Say, 1822)	2		D	4		38	44
Family Solecurtidae Orbigny, 1846							
Tagelus divisus (Spengler, 1794)	D			4		D	4
Tagelus *plebeius* (Lightfoot, 1786)	1	D	D	D			1
Family Dreissenidae Gray, 1840							
Mytilopsis *leucophaeata* (Conrad, 83)	D	D	D	D	D	D	
Family Veneridae Rafinesque, 1815							
Mercenaria *campechiensis* (Gmelin, 791)	D			1		D	1
Chione cancellata (Linné, 1767)	1			1		D	2
Chione clenchi Pulley, 1952						D	
Chione *grus* (Holmes, 1858)						D	

	G	T	E	w	CL	s	Total
Chione interpurpurea (Conrad, 1849)						D	
Anomalocardia auberiana (Orbigny, 1842)				D		D	
Gouldia cerina (C. B. Adams, 1845)						D	
Agriopoma texasiana (Dall, 1892)						D	
Dosinia discus (Reeve, 1850)	D			1		5	6
Cyclinella tenuis (Récluz, 1852)				D		1	1
Gemma cf. purpurea (Lea, 1842)						D	
Family Petricolidae Deshayes, 1831							
Petricola pholadiformis (Lamarck, 1818)	26		D	D		10	36
Rupellaria typica (Jones, 1844)	D						
Family Myidae Lamarck, 1809							
Paramya subovata (Conrad, 1845)				1		D	1
Family Corbulidae Lamarck, 1818							
Corbula caribaea Orbigny, 1842	D			1		D	1
Corbula contracta Say, 1822	D			D		12	12
Corbula dietziana C. B. Adams, 1852	D			D		D	
Varicorbula operculata (Philippi, 1848)						D	
Family Pholadidae Lamarck, 1809							
Crytopleura costata (Linné, 1758)	D					D	
Diplothyra smithii Tryon, 1862	2		D	7			9
Family Lyonsiidae Fischer, 1887							
Lyonsia hyalina floridana Conrad, 1849	5			252		D	257
Family Pandoridae Rafinesque, 1815							
Pandora trilineata Say, 1822	1			8		1	10

	u	T	E	W	CL	S	Total
Family Periplomatidae Dall, 1895							
<u>Periploma</u> <u>margaritaceum</u> (Lamarck, 1801)	D		c1	46		5	51
<u>Periploma</u> <u>orbiculare</u> Guppy, 1878				20			20
Class Scaphopoda Bronn, 1862							
Family Dentaliidae Gray, 1834							
<u>Dentalium</u> <u>texasianum</u> Philippi, 1848	D			0		D	

G = Galveston Bay
T = Trinity Bay
E = East Bay
W = West Bay
CL = Clear Lake, Houston Ship Channel and San Jacinto River
S = Inner Shelf
D = Dead Only

Distribution of Polychaete Species in the Galveston-Houston Area

	G	T	E	w	CL	s	Total
Phylum Annelida							
Class Polychaeta							
Family Spionidae Grube, 1850	1						1
Apoprionospio pygmaea (Hartman, 1961)	3					23	26
Dispio uncinata (Hartman, 1951)						2	2
Malacoceros vanderhorsti (Augener, 1927)						4	4
Minuspio sp.						1	1
Paraprionospio pinnata (Ehlers, 1901)	24		35	121		272	452
Carazziella hobsonae Blake, 1979			2				2
Polydora _ (Schmarda, 1861)				13			13
Polydora ligni Webster, 1879	86	2	51	8			147
Polydora websteri Hartman, 1943	2						2
Polydora sp.	3		1	2			6
Boccardia hamata (Webster, 1879)	1						1
Scolelepis texana Foster, 1971	3			8			11
Scolelepis cf. *texana*				3		1	4
Scolelepis sp.	2					2	4
Spiophanes bombyx (Claparède, 1870)	4			5		3	12
Streblospio benedicti Webster, 1879	138	3	42	49	2		234
Family Nereidae Johnston, 1845				1		1	2
Nereis micromma Harper, 1979	3					77	80

	G	T	E	w	CL	s	Total
Nereis succinea Frey and Leuckart, 1847	67	1	34	18		4	124
Nereis sp.	1	4	5	1		27	38
Ceratonereis irritabilis (Webster, 1879)						2	2
Nereis sp. "A"						3	3
Family Capitellidae Grube, 1862	2	2		4		2	10
Capitella capitata (Fabricius, 1780)	17	10	4	23		10	64
Mediomastus californiensis Hartman, 1944	225	86	78	155	3	55	602
Notomastus americanus Day, 1973						2	2
Notomastus hemipodus Hartman, 1947						17	17
Notomastus latericeus Sars, 1851						1	1
Notomastus lobatus Hartman, 1947						2	2
Notomastus sp.						2	2
Heteromastus filiformis (Claparède, 1864)				10			12
Family Lumbrineridae Malmgren, 1867						1	1
Lumbrineris verrilli Perkins, 1979				3		45	48
Lumbrineris ernesti Perkins, 1979						19	19
Lumbrineris tenuis Verrill, 1873				10		81	93
Ninoe nigripes Verrill, 1873						58	58
Lumbrineris sp.						14	14
Lumbrineris sp. "B"						10	10
Family Paraonidae Cerruti, 1909							
Aricidea fragilis Webster, 1879				183		5	188
Aricidea taylori Pettibone, 1965				7		1	10
Aricidea sp.				9		5	14

	G	T	E	w	CL	s	Total
Family Maldanidae Malmgren, 1867	1			12		3	16
Asychis carolinae Day, 1973	2					41	43
Asychis sp.						2	2
Axiothella mucosa (Andrews, 1891)						4	4
Axiothella sp.						6	6
Branchioasychis americana Hartman, 1945				6		19	25
Clymenella torquata (Leidy, 1855)	5			99		31	135
Euclymene lombricoides (Quatrefages, 1865)	21			2		5	28
Euclymene sp. "A"	3						3
Family Oweniidae Rioja, 1917							
Owenia fusiformis Delle Chiaje, 1844	6			13		13	32
Family Goniadidae Kinberg, 1866	3					4	7
Glycinde solitaria (Webster, 1879)	50	2	35	99		4	190
Goniada teres (Treadwell, 1931)						1	1
Family Cossuridae Day, 1963							
Cossura delta Reish, 1958	8		2	15		48	73
Family Amphinomidae Savigny, 1818							
Pseudeurythoe ambigua (Monro, 1933)	2		20	1		30	53
Family Onuphidae Kinberg, 1865							
Diopatra cuprea (Bose, 1802)	4		3	6		116	129
Diopatra cf. cuprea						8	8
Diopatra sp.	1						1
Onuphis eremita oculata Hartman, 1951	1					55	56
Onuphis sp.						4	4

	G	T	E	W	CL	S	Total
Fa[illegible]idae Saint-Joseph, 1899	26	19	88	6	1		140
Parandalia fauveli (Berkeley and Berkeley, 1941)	1		4			8	13
Sigambra cf. bassi (Hartman, 1947)	2	,	7	2		65	76
Sigambra tentaculata (Treadwell, 1941)						1	1
Sigambra cf. tentaculata		1	1			15	17
Sigambra wassi Pettibone, 1966						2	2
Sigambra sp.						2	3
Family Glyceride Grube, 1850						5	8
Glycera americana Leidy, 1855						6	6
Glycera sp.						1	1
Ophioglycera sp.							
Family Pectinariidae Quatrefages, 1865	1		3			8	12
Pectinaria gouldii Verrill, 1873						1	1
Pectinaria cf meredithi Long, 1973						3	3
pectinaria sp.							
Family Orbiniidae Hartman, 1942	16		2	123		26	167
Haploscoloplos fragilis (Verrill, 1873)	3		2	31		78	114
Haploscoloplos foliosus Hartman, 1951				1		3	4
Haploscoloplos sp.				12		7	19
Scoloplos rubra (Webster, 1879)				3			3 “
Scoloplos sp.							
Family Nephtyidae Grube, 1850						18	18
Aglaophamus verrilli (McIntosh, 1885)							1
Nephtys picta Ehlers, 1868							

	G	T	E	w	CL	s	Total
Nephtys incisa Malmgren, 1865						4	4
Nephtys sp.						9	9
Family Sigalionidae Malmgren, 1867						1	1
Sthenelais boa (Johnston, 1833)						5	5
Sthenelais sp.						9	9
Sthenolepis sp.						2	2
Family Polynoidae Malmgren, 1867						4	4
Harmothoe trimaculata (Treadwell, 1924)				2		1	3
Harmothoe imbricata (Linné, 1767)						1	1
Harmothoe sp. “A”						1	1
Harmothoe sp.						3	3
Lepidasthenia maculata Potts, 1910				1		5	6
Lepidasthenia sp.						2	2
Lepidonotus sublevis Verrill, 1873						1	1
Family Cirratulidae Carus, 1863							
Tharyx marioni (Saint-Joseph, 1894)	28			35		4	67
Tharyx sp.	8			1		6	15
Family Magelonidae Cunningham and Ramage, 1888							
Magelona sp. “A”						12	12
Magelona riojai Jones, 1963				2		1	3
Magelona pettiboneae Jones, 1963						1	1
Magelona cf. *phyllisae* Jones, 1963	2					267	269
Magelona sp.						1	1

	G	T	E	W	CL	S	Total
Family Phyllodocidae Williams, 1851	5			3		1	9
Eteone heteropoda Hartman, 195			1				1
Eteone sp.				2			2
Eulalia sanguinea Oersted, 1843				5			5
Genetyllis castanea (Marenzeller, 1879)				5			5
Phyllodoce sp.				4		2	6
Family Arabellidae Hartman, 1944							
Drilonereis magna Webster and Benedict, 1887				1			1
Family Hesionidae Sars, 1862	2			7	1	1	11
Gyptis brevipalpa (Hartman-Schröder, 1959)	4		3	14		10	31
Family Eulepethidae Chamberlin, 1919						1	1
Grubeulepis mexicana (Berkeley and Berkeley, 1939)						9	9
Grubeulepis cf. mexicana						3	3
Famil Sabellidae Malmgren, 1867				2		1	3
Chone duneri Malmgren, 1867				19		144	163
Potamilla reniformis (Leuckart, 1849)				5			4
Megalomma bioculatum (Ehlers, 1887)				7			7
Laonome sp.	1			6			7
Family Syllidae Grube, 1850							
Syllis cf. cornuta Rathke, 1843	1			3			4
Brania sp.				1			1
Family Chaetopteridae Malmgren, 1867	1						1
Spiochaetopterus c. oculatus Webster, 1879	1			21			22

	G	T	E	W	CL	S	Total
Family Trichobranchidae Malmgren, 1866							
Terebellides stroemii Sars, 1835						3	3
Family Eunicidae Savigny, 1818							
Marphysa sp. "A"	9						9
Family Chrysopetalidae Ehlers, 1864							
Paleanotus heteroseta Hartman, 1945						5	5
Family Ampharetidae Malmgren, 1867							
Isolda pulchella Müller, 1858						14	14
Melinna maculata Webster, 1879	1			13			14
Hobsonia florida (Hartman, 1951)				1			3
Ampharete sp.						4	4
Family Terebellidae Malmgren, 1867						3	3
Loimia medusa (Savigny, 1818)						106	106
Pista cristata (Müller, 1776)							1
Pista sp.				1		3	4
Family Serpulidae Johnston, 1865							
Hydroides dianthus (Verrill, 1873)				1			1
Family Opheliidae Malmgren, 1867							
Armandia maculata (Webster, 1884)						78	78
Armandia agilis (Andrews, 1891)						7	7
Armandia sp.						1	i
Family Poecilochaetidae Hannerz, 1956							
Poecilochaetus sp.						1	1

G = Galveston Bay
T = Trinity Bay
E . East Bay

Distribution of Crustacean Species
in the Galveston-Houston Area

	G	T	E	w	CL	s	Total
Phylum Arthropoda							
Class Crustacea							
Subclass Ostracoda*				4		6	
Subclass Copepoda*	1			3		27	
Order Mysidacea							
Bowmaniella cf. *dissimilis* Coifmann, 1937				3		1	4
Mysidopsis almyra Bowman, 1964	5	2	1				8
Mysidopsis bigelowi Tattersall, 1926			3	10			13
Order Cumacea							
Cyclaspis varians Calman, 1912	10			9			19
Eudorella monodon Calman, 1912				3			3
Oxyurostylis salinoi Da Silva Bruin, 1966	4		3	37	2	176	222
Order Apseudidae							
Apseudes sp.				1			1
Order Tanaidacea							
Leptochelia rapax I-larger, 1879	14	2		10			26
Order Isopoda							
Ancinus depressus (Say, 1818)				3			3
Cassidinidea lunifrons (Richardson, 1905)	6			2			8
Edotea montosa (Stimpson, 1853)	2		1	6	1		10
Erichsonella attenuata (Harger, 1873)				2			2
Xenanthura brevitelson Barnard, 1925	7		7	6			20

	G	T	E	W	CL	S	Total
Suborder Epicaridea						2	2
Order Amphipoda							
Family Ampeliscidae							
Ampelisca abdita Mills, 1964	5	1	13	600		29	648
Ampelisca agassizi (Judd, 1896)						200	200
Ampelisca verrilli Mills, 1967	2			44			46
Ampelisca sp.			1	3			4
Family Ampithoidae							
Cymadusa compta (Smith, 1873)				46			46
Family Amphilochidae							
Amphilochus sp.							4
Family Aoridae							
Grandidierella bonnieroides Stephensen, 1948				30			32
Family Argissidae							
Argissa hamatipes (Norman, 1869)							1
Family Corophiidae	1						1
Cerapus tubularis Say, 1817	28			85			113
Corophium acherusicum Costa, 1857				19			19
Corophium louisianum Shoemaker, 1934	11	8	4	20			43
Corophium sp.				2			2
Family Haustoriidae							
Acanthohaustorius sp.				55			55
Lepidactylus sp.	2		8				10
Parahaustorius cf. *holmesi* Robertson and Shelton, 1978					3	3	

	G	E	CL	S	Total
Family Isaidae					
Photis sp.	1				1
Family Liljeborgiidae					
Listriella bahia McKinney, 1979	6		18	2	36
Listriella barnardi Wigley, 963			6		6
Family Melitidae					
Elasmopus levis (Smith, 1873)			1		1
Melita nitida Smith, 1873	23		7		30
Family Oedicerotidae					
Monoculodes cf. nyei Shoemaker, 1935	2	3	26		32
Synchelidium americanum Bousfield, 1973	1		7		8
Family Phoxocephalidae					
Trichophoxus floridanus (Shoemaker, 1933)				25	25
Family					
Pontogeneia cf. bartschi Shoemaker, 1948			1		1
Suborder Caprellidea	1		3		4
Order					
Squilla empussa Say, 1818				2	2
ORDER DECAPODA					
Family Sergestidae					
Acetes americanus Ortmann, 893	0	[illegible]	3	0	27
Lucifer faxoni Borradaile, 1915				2	2
Family Pasiphaeidae					
Leptochela cf. bermudensis Gurney, 1939				2	2
Leptochela serratorbita Bate, 1888				1	1

	G	‘r	E	W	CL	s	Total
						4	4
Family Alpheidae						5	5
Alpheus floridanus Kingsley, 1878						16	16
Alpheus Sp.						3	3
Automate cf. evermanni Rathbun, 1901						1	1
Automate sp.							
Alpheopsis sp.						2	2
Family Thalassinidae						7	7
Callianassa acanthochirus (Stimpson, 1866)						3	3
Callianassa cf. biformis Biffar, 1971						13	17
Callianassa latispina Dawson, 1967			2				
Callianassa sp.						25	25
Family Upogebiidae							
Upogebia affinis (Say, 1818)				1		5	6
Family Diogenidae							
Paguristes sp.						38	38
Family Paguridae							1
Pagurus sp.							
Clibanarius vittatus (Bose, 1802)						3	3
Family Porcellanidae							
Euceramus praelongus Stimpson, 1860						8	8
Family Albuneidae							
Albunea paretii Guérin, 1853						1	1
Family Hippidae							
Emerita talpoida (Say, 1817)							

	G	T	E	W	CL	S	Total
Family Calappidae							
Osachila sp.						2	2
Family Portunidae							
Callinectes sapidus Rathbun, 1896				3		2	5
Callinectes sp.				3			4
Family Xanthidae							
Menippe mercenaria (Say, 1818)	3					4	7
Panopeus herbstii Milne-Edwards, 1834	6					6	12
Pilumnus sp.	1		1	1		83	86
Rhithropanopeus harrisii (Gould, 1941)	10	1		7		8	26
Neopanope texana texana (Stimpson, 1859)						1	1
Family Gonoplacidae							
Chasmocarcinus mississippiensis Rathbun, 1931						2	3
Family Pinnotheridae							
Pinnixa cf. chaetopterana Stimpson, 1860						3	3
Pinnixa cf. cristata Rathbun, 1900						11	11
Pinnixa cf. retinens Rathbun, 1900						1	1
Pinnixa sayana Stimpson, 1860	5					145	150
Pinnixa sp.						29	29
Pinnotheres ostreum Say, 1817				2			2
Pinnotheres sp.						2	2
Family Leucosidae							
Persephona crinata Rathbun, 1931						6	6

	G	T	E	W	CL	S	Total
Family Majidae							
Pelia mutica (Gibbes, 1850)						1	1
Family Sicyoniidae							
Sicyonia cf. *dorsalis* Kingsley, 1878						1	1

*Not included in total individual count

G = Galveston Bay
T = Trinity Bay
E = East Bay
W = West Bay
CL = Clear Lake, Houston Ship Channel and San Jacinto River
S = Inner Shelf

Distribution of Other Phyla in the Galveston-Houston Area

	G	T	E	w	CL	s	Total
Phylum Cnidaria							
Class Anthozoa							
Order Actiniaria	5			8		3	16
Phylum Platyhelminthes							
Order Polycladida	1						1
Phylum Nemertinea							
Nemerteans (unidentified)	27	5	5			60	102
Phylum Phoronida							
Phoronis architect Andrews, 1890	6					1	8
Phylum Annelida							
Class Oligochaeta	3	1	1				5
Phylum Sipunculida							
Phascolion strombi (Montagu, 1804)						6	7
Sipunculid sp. "A"						1	1
Aspidosiphonidae						2	2
Phylum Arthropoda							
Chironomid larvae		20					20
Phylum Echinoderrnata							
Class Ophiuroidea							
Hemipholis elongata (Say, 1825)						13	13
Micropholis atra (Stimpson, 1852)						1	3

	G	T	E	W	CL	S	Total
Ophiophragmus sp.						1	1
Brittlestars (unidentified)						41	42
Class Holothuroidea							
Sea cucumbers (unidentified)						2	2
Phylum Pogonophora							
Pogonophorans (unidentified)						1	1
Phylum Hemichordata							
Class Enteropneusta						120	124
Phylum Chordata							
Subphylum Cephalochordata							
Branchiostoma sp.	6					4	10
Subphylum Vertebrate							
Class Osteichthyes							
Family Sygnathidae							
Hippocampus sp.				1			1
Family Ophichthidae							
Eel (unidentified)						2	2
Fish (unidentified)				1			1

G = Galveston Bay
T = Trinity Bay
E . East Bay
w = West Bay
CL = Clear Lake, Houston Ship Channel and San Jacinto River
S = Inner Shelf