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CONTINUED ANALYSES OF SURFICIAL DEPOSITS

ON

TEXAS SUBMERGED LANDS

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SUBMERGED LANDS OF TEXAS

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INTRODUCTION

The state owned submerged lands of Texas are vast. They encompass nearly 6,000 sq. miles (15540 KM^2) and extend from Mexico to Louisiana. The area includes the bays, estuaries, and lagoons as well as the inner continental shelf 10.3 miles (16.6 KM) seaward of the Gulf shoreline (fig. 1). There are many uncertainties as to the future utilization of the state submerged lands, and we are probably incapable of anticipating all the potential uses for these areas. We can, however, expect multiple and diverse uses related to food production, energy production, recreation, resource extraction, industrial processing, transportation, and the like. Initial planning for many of these activities requires a knowledge of the regional geology, the active geological processes, and the potential environmental impacts of human activities.

A comprehensive investigation of the state submerged lands is being conducted in order to develop a baseline inventory of geological and biological data for future environmental monitoring. The program was designed to provide the basic scientific data necessary to assess and predict the problems and potential impacts resulting from energy, mineral, transportation, recreation, and industrial development along the Texas coast and on the adjacent Federal outer continental shelf. Results of this project will provide

Texas with comprehensive natural resources data with which to assess the various development scenarios that can be anticipated by the Texas Coastal Management Program. Support for this comprehensive research project was provided by (1) funding from the Coastal Zone Management Program of the Texas General Land Office to the Bureau of Economic Geology (McGowen and others, 1977a) and (2) substantial financial and logistical contributions made through the joint research program between the U. S. Geological Survey and the Bureau of Economic Geology.

Because the same equipment and analytical procedures are being used, data collected for the state submerged lands are compatible with data generated by the U. S. Geological Survey for the South Texas outer continental shelf as part of a study funded by the Bureau of Land Management (Berryhill, 1977). Thus, sedimentological, geochemical, geophysical, and biological data are available for South Texas coastal waters and adjacent continental shelf extending to the shelf break. Such a massive effort would not have been possible without the full cooperation of both research organizations and the pooling of funds, shiptime, equipment, and personnel.

DATA ACQUISITION

Bottom sediment samples and geophysical profiles (fig. 2) form the core of field data and the basis for integrated studies. Comparable data were acquired for the entire study area, however physical limitations in the bays and estuaries, primarily water depth, precluded using the same equipment in the bays as on the inner shelf. Navigation techniques also varied in these two areas.

Surficial Sediments

Sediment samples were collected with grab samplers at sites spaced approximately one mile apart. Penetration depths ranged from 4 to 18 cm and sediment volume depended largely on sediment type. Ponar clam-shell grab samplers used in the bays and estuaries have a capacity of 0.13 ft^3 (.003 M^3) whereas Smith-McIntyre samplers used on the shelf have a capacity of 0.45 ft^3 (.001 M^3). Sample locations in the bays were determined by triangulation and dead reckoning navigation. By contrast, shelf sediment samples were located primarily by a portable precision radio-navigation system operating with a shipboard master station and two shore-based slave stations. In some shelf areas, shipboard radar was also used to locate nearshore sample stations along the transponder baseline.

Samples of approximately the upper 15 to 18 cm of sediment were described at the time of collection, using a three-component classification of sand, mud, and shell. Visual estimates of the three components were used to describe the sediment type, and sediment color was determined by comparison with a standard color chart. Pertinent information on other characteristics such as worm tube abundance, degree of bioturbation, presence of organic (plant) material, and anomalous features such as brackish water fauna, caliche nodules, and rock fragments were also recorded.

Field descriptions are entirely visual and the 14 sediment types that have been recognized are based on three sediment end-members (shell, sand, and mud) and mixtures thereof (fig. 3). Two reef types (oyster and serpulid reefs) have been included with sediment types for convenience of mapping.

The vertical sequence of sediment types collected in each sample was recorded to provide the most complete information possible. Consequently, the descriptions of surface sediments are complex, reflecting the variability of modern and relict sediment types, and of related physical and biological processes. Similar sediment types from the full range present in the bays and on the inner shelf were grouped to facilitate mapping. A total of nearly 6,700 samples was collected (table 1), but the total number of samples to be analyzed is much greater. In general, each sample was subsampled for sedimentological, geochemical, and biological analyses (fig. 2). Furthermore, a storage or back-up sample was retained to provide material for possible future studies.

Bathymetry

Bay Bathymetry

Soundings were made and recorded at each bay sample locality. The line (rope) that was attached to the grab sampler was marked at one-foot intervals. Bathymetric maps for all bays, except the Matagorda Bay system, were constructed from these sounding data; depths were contoured at two-foot intervals. Bathymetry for the Matagorda Bay system is also shown at two-foot increments, but these depths were taken from published navigation charts. Although depth data were not adjusted to a sea-level datum, and effects of wind set-up were neither added to nor subtracted from data at each station, soundings data are adequate to indicate changes in bathymetry when compared with published navigation charts.

Shelf Bathymetry

Water depths were continuously recorded and times were recorded at each sample station during sediment sampling cruises on the inner shelf. Despite the abundance of recent (1976-1977) fathometer profiles (fig. 4), these data were not used because substantial variations, both temporally and spatially, in wave height and tidal stage were experienced. Correction of these parameters to a sea-level datum suitable for mapping would require several assumptions and sophisticated computer programs which are not readily accessible. Therefore, maps published by the National Ocean Survey (formerly the U. S. Coast and Geodetic Survey) were used for shelf bathymetry. Smooth sheets presenting original soundings and survey lines taken in 1938 and 1939 were used for inner shelf bathymetry between the Rio Grande and Pass Cavallo; navigation charts derived from similar surveys provided bathymetry along the remainder of the central and upper coast.

Shelf Geophysical Surveys

Total length of geophysical surveys on the state submerged lands exceeded 4,100 nautical miles (7600 KM) (table 1). Several acoustical sources were used during the geophysical surveys, but most of the data were acquired with an 800 joule mini-sparker system. A 3.5 KHz energy source and a precision depth recorder (PDR) were also used sparingly on the inner shelf on separate occasions. Primary data for the inner shelf were derived from profiles continuously recorded at a 1 sec sweep after the signal passed through an analog signal processor. Most of the surveys on the inner shelf between Matagorda Peninsula and the Rio Grande (fig. 1) were also recorded at a 0.5 sec sweep.

Penetration was generally less than 0.5 sec two-way travel time, with most time records exhibiting penetration of 0.3 to 0.4 sec. These times represent maximum subsurface depths of between 850 and 1,150 ft. (260 and 350 M). Strata at these depths are Pleistocene in age; Holocene sediments are generally thin and occur at depths commonly less than 100 ft. (30 M). Greatest Holocene sediment thicknesses are related to deposition in entrenched valleys during the latest interglacial rise in sea level.

Geophysical track lines in the Gulf were located by LORAC and LORAN-A navigation systems. Location points were marked on the records at intervals of approximately 1,000 ft. (305 M). Track lines in the Gulf of Mexico form a closely spaced grid comprising (1) 232 dip lines oriented perpendicular to the shoreline and spaced 1.5 miles (2.4 KM) apart and (2) two strike lines oriented parallel to the shoreline and spaced about 4 miles (6.4 KM) apart. This closely spaced grid on the inner shelf is supplemented by eight dip lines extending to mid-shelf reefs and five dip lines extending to the shelf break. The latter two groups of lines display some stratigraphic sequences not seen on the inner shelf, and they also provide regional stratigraphic control.

PLAN FOR CONTINUING STUDIES

Perhaps the greatest contributions of a project such as this are the numerous and diverse applications of the data for management and planning purposes, for environmental monitoring, for assessing environmental impacts, and for determining areas and subjects for future studies. Of immediate interest are the bottom substrate conditions, the animal-sediment relationships, the existence of high concentrations and potential for resuspension of pollutants such as certain trace elements, and the location of active or potentially active faults and diapiric structures. The distribution of sediment types and potential active faults on the inner shelf should lead to a better understanding of Quaternary geological processes and in particular recent shoreline changes. Moreover, geological and biological conditions have a strong bearing on most of the ongoing and anticipated offshore activities such as dredging of navigation channels, resource exploration and exploitation, siting of nuclear power plants, solid and liquid waste disposal, siting of deep water ports, highway construction, and archeological surveys. Other applications include the location and extent of natural resources such as sand and shell material which can be used respectively for beach nourishment and construction purposes.

The foregoing statements of existing and potential uses of these and other data clearly point to the need for studies that integrate sedimentology, geochemistry, biology, and geophysics (fig. 2) in order to answer some of the difficult questions posed by public concern for environmental quality. Several years will be required to analyze properly and present the results of this research because of the tremendous quantity of data generated by the sampling program. In the meantime, studies initiated following data collection are completion and others are expected to begin shortly. A brief description of ongoing and anticipated analytical studies follows.

Textural Analysis

Grain-size data are important not only for sedimentological studies but they also provide valuable information for understanding animal-sediment relationships and the dependency of some trace element concentrations on sediment size. Quantification of sediment textures will focus on the coarse (sand) and fine (mud) fractions which are being analyzed separately. Size distribution of the coarse fraction is estimated with a Rapid Sediment Analyzer (Schlee, 1966), and following oxidation of organic material and removal of soluble salts, the fine fraction is analyzed by Coulter Counter techniques (Shideler, 1976).

Geochemical Analysis

Subsamples selected for geochemical investigations are being analyzed for total organic carbon (TOC) content and trace element concentrations. After air drying and crushing, total organic carbon is determined by a wet combustion technique (Jackson, 1958). Over 3,000 TOC determinations have been made (table 1) and preliminary maps have been prepared from those analyses (table 2). Procedures for determining trace element concentrations were described by Grime and Marranzino (1968). The samples are scanned for 30 trace elements, and those elements occurring in detectable quantities are recorded and mapped. To date, semi-quantitative analyses suitable for mapping regional trends are available for over 1,100 samples and include the following elements: barium, chromium, iron, lanthanum, lead, manganese, strontium, vanadium, and zirconium.

Biological Studies

Many taxa such as protozoa, bryozoans, annelids, arthropods, and echinoderms are represented in biological samples from the bays and inner shelf, however the molluscs are presently being studied in greatest detail because of their relative abundance. Individual molluscs are identified to species level, where possible, and live and dead whole shells are counted in order (1) to prepare species lists, (2) to document species diversity, and (3) to define relative degrees of productivity in different geographic areas.

Results of the biological studies will be combined with sedimentological, geochemical, and bathymetric data in order to better understand the complex relationships of benthic fauna to the physical and chemical environments.

Geophysical Studies

Initial interpretations of geophysical records have been limited primarily to mapping faults, shallow diapirs, structural dip, and disconformable relationships. These same records serve as primary data sources for interpretation of seismic stratigraphy as well as geometry, facies distribution, and chronology of Quaternary deposition. Features that are expected to be portrayed by maps include structural attitude ascertained by shallow seismic reflectors and thickness of Late Quaternary sediments. In certain areas where geophysical records are closely spaced and of high quality, cross-sections will depict the genetic depositional units interpreted from the seismic signatures.

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Throughout the program, research personnel of the U. S. Geological Survey, Corpus Christi, Texas, cooperated fully, matched certain funds, and supplied critical equipment and personnel. Consequently, the submerged lands of Texas program was integrated fully 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.

A field investigation of the magnitude of the Texas submerged lands program requires the support of many people, some performing specific individual tasks and others providing the principal technical support throughout the life of the project. It would be impossible to list all the people that contributed in one way or another to the success of this work; therefore, a list of the major tasks and the primary participants for each of those tasks is provided in order to establish major responsibilities for various phases of the work.

Bay bathymetry, sediment sample collection and descriptions. -- J. H. McGowen, J. L. Chin, T. R. Calnan, J. P. Herber, C. R. Lewis, L. C. Safe, W. A. White, Dale Solomon, Charles Greene, Carl Christiansen, Dwight Williamson, John Kieschnick.

Bay bathymetry mapping. -- J. H. McGowen, J. L. Chin, C. R. Lewis.

Bay sediment mapping and interpretation. -- J. H. McGowen, J. L. Chin, C. R. Lewis.

Shelf sediment sample collection. -- R. A. Morton, J. H. McGowen, J. L. Chin, T. R. Calnan, J. P. Herber, C. R. Lewis, L. C. Safe, M. K.

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Fault and diapir mapping and interpretation. -- R. A. Morton.

Cartography was by R. L. Dillon and D. R. Scranton under the direction of J. W. Macon.

C. M. Woodruff, Jr., deserves mention for convincing state and federal planners that firm knowledge of substrate, processes, and biota on the inner continental shelf (i.e. the offshore state submerged lands) has bearing on environmental issues related to both production and transportation of petroleum found on the outer continental shelf.

BAY SURFACE SEDIMENT

General Description

All Texas bays, estuaries and lagoons, except Sabine Lake, are separated from the Gulf of Mexico by a system of barrier islands and peninsulas. In general, the larger bays and estuaries occupy the central and upper parts of the Texas coastal zone; bay size is determined, to a large degree, by the size of the Pleistocene rivers which scoured the valleys now occupied by bays and estuaries.

Sediment is contributed to bays, estuaries and lagoons by rivers that discharge at the heads of bays, and from the Gulf of Mexico through tidal inlets (mostly under normal sea conditions) and across barrier islands and peninsulas during storms. Sediment type delivered to the coastal zone by Texas streams is chiefly a function of climate. Identifiable sediment delivered to bays, estuaries and lagoons from the Gulf of Mexico is chiefly sand, shell and rock fragments that are eroded from the inner shelf, shoreface and beaches by tropical storms and hurricanes.

Rainfall decreases from east to west across the state, and both temperature and evaporation increase from east to west. These climatic conditions are reflected in (1) vegetation cover (dense in the east and sparse in the west), (2) the type of fluvial systems that traverse the coastal plain (continuously flowing sinuous streams in the east, and flashy straight to sinuous streams to the west), and (3) the type of sediment delivered to the bays, estuaries, and lagoons (streams in the east are characterized by a high suspension load/bed load ratio whereas streams in the west have a high bed load/suspension load ratio).

Texture of bay, estuary, and lagoon sediment is generally (1) coarsest at river mouths, along bay margins where erosion of Pleistocene deposits is prevalent, near tidal inlets, and adjacent to barrier islands and peninsulas, and (2) finest in the deeper bay center areas. The relative proportion of mud (fine-grained sediment) to sand (coarse-grained sediment) is greatest in the bays of the upper Texas coast and least in the bays and lagoons of the lower coast; this is a reflection of decreasing rainfall across the state from east to west.

Non-terrigenous sediment comprises an insignificant volume of the fill when all of the Texas bays, estuaries, and lagoons are considered. Non-terrigenous deposits are found in (1) shell beaches, spits, and berms situated along bay margins, (2) in oyster and serpulid reefs, and (3) oolite and coated-grain shoals. Oyster reefs are prolific in the area defined by the Trinity-Galveston Bay system on the east and Copano Bay on the west. Bays in this area are typified by salinity that ranges from almost fresh to that of the Gulf of Mexico. Salinity varies directly with fresh-water inflow.

Serpulid reefs, now dead, are well developed in Baffin Bay and in parts of Laguna Madre adjacent to the mouth of Baffin Bay. These reefs probably flourished in Baffin Bay prior to closing of the tidal inlet through Padre Island opposite the mouth of Baffin Bay (Andrews, 1964). As a consequence of the closing of the tidal inlet, Baffin Bay is no longer directly linked to the Gulf of Mexico. During tropical storms and hurricanes aftermath rainfall and runoff from adjacent uplands converts Baffin Bay into a temporary fresh-water body (Behrens, 1969). On the other hand, prolonged dry climatic conditions, accompanied by excessive evaporation renders Baffin Bay hypersaline. It has been suggested that the serpulids in Baffin Bay could not tolerate hypersaline conditions.

Some bay-margin deposits are characterized by high shell content. These deposits are representative of reworking by wave and current activity, slow sediment accumulation rates, and/or high rates of biological productivity. Oyster reefs are commonly flanked by shell debris, and oyster shell spits develop downcurrent from some reefs and headlands.

Oolites and coated grains are mostly confined to Baffin Bay where input of terrigenous clastics is low. Shoals, underlain by these carbonate sands, are situated along the north shore of Baffin Bay, which is affected by waves and currents generated by the prevailing south-southeast winds.

Depths of bays range from about 2 to 16 feet (0.6 to 4.9 m). The larger bays are generally the deepest. Laguna Madre is the shallowest of the larger coastal water bodies; it is being filled principally with sand that is transported from the beaches across Padre Island by wind and storm activity. Depths of bays are maintained in the coastal water bodies through wave activity, which resuspends much of the fine sediment, and removal of fine sediment from the bays through tidal inlets. Other mechanisms that aid in depth maintenance are dewatering and compaction of recent bay muds, and subsidence related to tectonics, compaction of older sediments, and man's activities.

Beaumont-Port Arthur Area

Sediment is delivered to Sabine Lake primarily through the Sabine and Neches Rivers. Smaller drainage systems to the west, such as Taylor Bayou, discharge into either the Sabine Neches Canal or the Port Arthur Canal; most of the sediment delivered by these streams bypasses Sabine Lake and is transported to the Gulf of Mexico through Sabine Pass. Some of this sediment may be transported into Sabine Lake during flood tide, and a small amount is derived from the adjacent shoreline, through erosion. *Crassostrea virginica* and *Rangia sp.* also contribute to the bay fill. Man's activities too have affected the natural distribution of sediment; for example, both fresh water and sediment have been diverted through channelization and by spoil disposal.

The sediment distribution map was constructed from field descriptions of 157 surface sediment samples. Ten sediment types were recognized, and their spatial relationships are depicted on the sediment distribution map. Sand and muddy sand are found most commonly at the head of Sabine Lake, reflecting sediment contribution through the Sabine and Neches Rivers; sand also is found locally in the Sabine River, the Neches River, and some dredge channels. Muddy sand is situated along bay margins as a result both of reworking of Pleistocene materials forming the shoreline, and of reworking of spoil, particularly in the Port Arthur vicinity.

Sandy mud is found at the head of Sabine Lake, adjacent to the shoreline, and offshore from spoil disposal areas. At the head of Sabine Lake muddy sand displays a natural distribution pattern; sediment tends to become finer grained with distance from a river mouth. Small areas of sandy mud are restricted to the lake margin along the Louisiana shoreline, and along the banks of Sabine Pass. The largest area of sandy mud lies along the west shore of the lake, and extends east and northeast into the lake center; this sandy mud was deposited by dredging activity, and by the reworking of dredge material by waves and currents.

Mud composes the largest part of the lake bottom; it occurs in both the shallow and deep parts of the lake, and extends from the head of the lake through Sabine Pass.

The remaining sediment types are mud with shell material (shelly mud, sandy shelly mud), sand with shell material (muddy shelly sand), and shell (clean, gravel-size shell debris, and shell in a mud matrix). Shelly mud is situated along the southern shore in 3 to 6 feet (0.9 to 1.8 m) of water and in Sabine Pass in 15 feet (4.5 m) of water, as well as in parts of the Sabine-Neches Canal and the Gulf Intracoastal Waterway. Shell within the lake is primarily *Crassostrea virginica* and *Rangia sp.* Sandy shelly mud (station 27) is a minor sediment type found along the south lake margin in about 4 feet (1.2 m) of water; there are live *Rangia* in this area. Muddy shelly sand (station 57) is situated in 5 feet (1.5 m) of water near the west shore, adjacent to a spoil disposal area. Muddy shell occurs in two small, widely separated areas (see stations 10.5, 12 and 73), one at the south end of the lake in 8 feet (2.4 m) of water, and the other near the north end in 5 feet (1.5 m) of water. Live oysters are present at stations 10.5 and 12. Shell gravel (station 11.5) is associated with muddy shell at the south end of the lake. Shell gravel lies in about 11 feet (3.3 m) of water, contains live *Crassostrea virginica,* and probably represents reef flank material.

Relict Pleistocene mud is present in Sabine Pass at stations 1 and 4 in 17 to 45 feet (5.2 to 13.7 m) of water respectively.

Houston-Galveston Area

The Houston-Galveston area is characterized by the largest bay-estuarine system in the entire Texas Coastal Zone. The system comprises Trinity, Galveston, East, West, Chocolate, Christmas, and Bastrop Bays. Maximum depths of Galveston and Trinity Bays are 10 and 9 feet (3 and 2.7 m) respectively. Bolivar Roads, the tidal inlet for Galveston, Trinity, and East Bays, and part of West Bay, has a maximum depth of 40 feet (12.2 m) where maintained by dredging, and a maximum of 23 feet (7 m) in a natural state. East and West Bays reach maximum depths of 7 and 6 feet (2.1 and 1.8 m) respectively. The other bays are approximately 3 to 4 feet (.8 to 1.2 m) deep at their centers.

Sediment is supplied to this bay-estuarine system by rivers, from the Gulf of Mexico through tidal inlets and across barrier islands during storms, through erosion of Pleistocene deposits forming mainland shorelines, and from production of shell material by molluscs. From east to west, the fluvial systems that contribute sediment to the bay-estuarine system include Trinity River, Cedar Bayou, San Jacinto River, Buffalo Bayou, Clear Creek, Dickinson Bayou, Halls Bayou, Chocolate Bayou, and Bastrop Bayou.

Distribution of sediment within the system is related to such factors as (1) site of fluvial discharge, (2) lithology of the Pleistocene forming the mainland shoreline, (3) bathymetry, (4) location of tidal inlets, and (5) proliferation of molluscs such as *Crassostrea virginica*.

Most of the fluvial systems discharging into the bay-estuarine system are characterized by a large suspension load relative to bed-load material. Consequently, the shoreline and bay bottom adjacent to the mouths of most of these streams are typically muddy. The Trinity River is an exception; a relatively large delta has been constructed at the head of Trinity Bay, with fringing subaqueous delta front sands.

Much of the mainland shoreline consists of Pleistocene deltaic muds and sands. In some areas the mainland shoreline is composed of Pleistocene strandplain sand. Where the mainland shoreline is represented by Pleistocene deltaic deposits, bay margin deposits are sand, muddy sand, sandy mud, or mud--depending, for the most part, upon the local occurrence of Pleistocene sand within the shoreline materials. Pleistocene strandplain deposits (predominantly sand) form the mainland shoreline in the vicinity of Smith Point and Dollar Bay; bay margin deposits in these areas are predominantly sand and muddy sand.

Mud is the dominant sediment type within the deeper parts of the bay-estuarine system. Deeper parts of bays are relatively far away from river mouths, tidal inlets, and shallow bay margin areas. Hence, the deeper parts of bays are perhaps the lowest physical energy environment of the bay-estuarine system; the deeper, lower-physical energy part of the system is conducive to accumulation of the finest fraction of the terrigenous clastic sediment delivered to the bay.

Gulf and bay-estuarine water and sediment are mixed or exchanged either through natural or man-made inlets. In the Houston-Galveston area there is one man-made tidal exchange pass (Rollover Pass), one jettied and dredged natural pass (Bolivar Roads), and one semi-pristine natural pass (San Luis Pass). Normally, part of the bay water and its associated suspension sediment load leave the system through inlets; bay water and fine sediment form a sediment plume that overrides the more saline Gulf water as the plume moves seaward. Longshore currents move sand along the beach and shoreface of Bolivar Peninsula, Galveston Island, and Follets Island. If it is not stopped by jetties or groins, part of this sand moves into the bay-estuarine system with currents produced by flood tides. Some of this sand, the bed load, accumulates within the bays as flood tidal deltas at the termini of tidal channels. Another part of the sand returns to the Gulf of Mexico with the ebb tide. Some of this sand accumulates at the seaward terminus of the tidal channel as a poorly-defined ebb delta, and the remainder is picked up by longshore currents and is carried down the coast.

Locally, the bay bottom has been built upward by *Crassostrea virginica* to within a few feet or inches of the water surface. Oyster reefs and flanking shell-bearing deposits are most numerous in the constricted part of Galveston Bay. Most of the other bays also have oyster reefs; however, they are not as well developed as those in Galveston Bay.

Seven hundred and five sediment samples were collected from the bay-estuarine system in the Houston-Galveston area. From field descriptions of these samples, 15 sediment types (including oyster reefs) were plotted, and their spatial distribution were mapped. There are 4 terrigenous clastic textural types within this bay-estuarine system--sand, muddy sand, sandy mud, and mud. The other sediment types, except oyster reefs, shell gravel, and rock fragment gravel, are representative of these four basic textural types, with shell mixed in.

Quartz sand occurs, for the most part, in the higher physical energy environments, such as (1) near the mouth of the Trinity River, (2) in shallow bay margins, and (3) in tidal inlets and tidal deltas. There are also local concentrations of sand adjacent to the Intracoastal Waterway. This sand was reworked from spoil placed beside the dredged channel.

Muddy sand generally is found in depositional environments having a somewhat less intense physical processes than those which characterize the clean quartz sands. Muddy sand forms bands that approximately parallel the bay shoreline. This type of sand is situated adjacent to, but in deeper water than clean quartz sand. Where physical energy is is reduced by marine grasses or by shoreline orientation muddy sand may occupy the same position relative to shoreline and water depth as clean quartz sand.

Sandy mud generally lies adjacent to sand or muddy sand along bay margins and tidal deltas. Within some protected areas (for example, Moses Lake, Chocolate Bay, and Bastrop Bay) sandy mud abuts against the shoreline. Sandy mud is, in most areas, a transitional facies between muddy sand and mud, and, as such, extends from the more shallow to deeper parts of the system.

Mud, the finest terrigenous clastic fraction, is found in lowest physical energy environments and deeper parts of the system. Many of the small, shallow bodies of water are floored with mud. In the Baytown area, the small bodies of water that parallel the San Jacinto River receive suspension load material mainly from overbank flow of the river. Most of the mud contained in the bay-estuarine system was derived from rivers and creeks that discharge into the system. Lesser amounts of mud are derived through shoreline erosion, from the Gulf of Mexico during tidal exchange through tidal inlets, and from the sea during the passage of tropical storms.

The coarsest sediment in the system is gravel-size shell debris and rock fragments. Shell gravel is an integral part of oyster reefs, where it forms reef flank deposits. Shell gravel also serves as a floor for part of Bolivar Roads. It forms (1) beaches on some spoil mounds, (2) shell veneer over bay muds where spoil has been reworked, and (3) small patches where oyster clumps have been reworked. Gravel-size rock fragments, a rare sediment type, result from redistribution of spoil adjacent to the Gulf Intracoastal Waterway.

Shell with sand and mud form three minor facies: sandy shell, muddy sandy shell, and muddy shell. Sandy shell occurs (1) in Bolivar Roads, and is transitional with shell to the north and with sand to the south, (2) next to the Houston Ship Channel in a spoil area, and (3) along the bay margin near Swan Lake, where it is associated with rather large areas of shell deposits. Muddy sandy shell occurs in Trinity Bay (station 296), Galveston Bay (station 248), and in West Bay (stations 29, 42, and 45), where it is associated with oyster reefs and a relatively large area in the vicinity of North Deer Island and South Deer Island. Muddy shell has very limited distribution in Bastrop Bay, where it lies next to dredge channels, and in Christmas Bay (station 131).

Sand with shell has very limited distribution; it is represented by two facies: shelly sand, and shelly muddy sand. Shelly sand occurs in Bolivar Roads (station 29), in Galveston Bay in association with oyster reefs (stations 136 and 139), and in the Swan Lake area (stations 2 and 11).

Mud with a shell admixture forms three subordinate sedimentary facies: shelly mud, sandy shelly mud, and shelly sandy mud. Shelly mud is most commonly associated with oyster reefs (see, for example, Redfish, Hanna, and Carancahua Reefs). Shelly mud also occurs in Bolivar Roads (station 18), in the Swan Lake area (station 1), and locally within West Bay, Bastrop Bay, and Christmas Bay (stations 96, 15, and 132, respectively). Sandy shelly mud occurs in three areas in Galveston Bay (stations 9, 70, and 106), primarily where man has affected the natural environment through dredging activities. Shelly sandy mud was identified at one station (station 141) in Galveston Bay, in an area that also has been affected by dredging.

Large oyster reefs are present in Trinity, Galveston, East, and West Bays. A few small reefs are situated between Christmas and Drum Bays. Reefs generally develop where currents are strong, and in areas where the bay bottom is relatively free of mobile sand or shell debris. Where the width of bays or estuaries narrows, for example, between San Leon and Smith Point, current strength increases; oyster reefs were at one time continuous in this area.

Bay City-Freeport Area

The Bay City-Freeport area includes East Matagorda, Matagorda, Tres Palacios, and Turtle Bays, all of which are components of the Matagorda Bay system. This system is second in size only to the Trinity-Galveston Bay system. Maximum depth of East Matagorda Bay is about 7 feet (2.1 m). Brown Cedar Cut, the only tidal inlet for East Matagorda Bay, has a maximum depth of about 8 feet (2.4 m); it decreases in depth over short distances seaward, and toward the bay. Near the western limit of the map area, Matagorda Bay reaches a maximum depth of 12 feet (3.6 m). Maximum depths of Turtle and Tres Palacios Bays are 5 and 7 feet (1.5 and 2.1 m) respectively. Some tidal exchange occurs between the Gulf of Mexico and Matagorda Bay through the lower part of the Colorado River (a man-made channel through Matagorda Peninsula), and through Tiger Island Channel.

Sediment accumulating in the Matagorda Bay system is transported to the area by rivers, from the Gulf of Mexico through tidal inlets and across Matagorda Peninsula during tropical storms, through erosion of Pleistocene and Holocene deposits constituting bay shorelines, and in situ production of molluscan shell material. Streams contributing sediment to the bay system are, from east to west, Boggy Bayou, Live Oak Bayou, Peyton Creek, Big Boggy Creek, Colorado River, Tres Palacios Creek, Turtle Creek, and Reed Creek. Much of the sediment delivered by streams to East Matagorda Bay, however, is intercepted by the Gulf Intracoastal Waterway.

Sediment distribution within the bay system is affected by (1) site of fluvial discharge, (2) height and lithology of Pleistocene and Holocene shoreline features, (3) bathymetry, (4) location of tidal inlets and washover channels, and (5) proliferation of *Crassostrea virginica*.

All the streams discharging into the bay system, except the Colorado River, are small, and originate in the coastal plain. Since their sediment loads are relatively small, they have not filled their estuaries (for example, see heads of Tres Palacios and Turtle Bays). The Colorado River, on the other hand, has filled its estuary, and between 1929 and 1935, after a log jam was removed by the U. S. Army Corps of Engineers, the Colorado constructed a delta across Matagorda Bay (Wadsworth, 1941, 1966). Bottom sediment adjacent to the Colorado delta and the mouths of lesser streams is typically muddy.

Much of both the mainland shoreline and bay shore in the Bay City-Freeport area is eroding (McGowen and Brewton, 1975; McGowen and others, 1976a). Mainland shorelines from the vicinity of Lake Austin eastward are composed of Holocene deltaic sands and muds. From Lake Austin westward, they are composed of Pleistocene fluvial-deltaic and marine sands and muds. Most of the bay sediment adjacent to the mainland is mud; sand occurs locally in headland areas. Bay margin deposits associated with Matagorda Peninsula are predominantly sand; this sand, which is transported across the peninsula during storms, is derived chiefly from the Gulf of Mexico.

Mud is the dominant sediment type in the deeper parts of bays and estuaries, which are relatively far from river mouths and other areas of terrigenous clastic sediment input. Deeper parts of bays are typically the bay segments of lowest physical energy and are therefore sumps in which the finest-grained sediment accumulates.

Brown Cedar Cut is the only natural, active tidal inlet in the Bay City-Freeport area. Sand, shell, and rock fragments are transported by currents through this inlet during flood tides and storms. Sediment accumulates as a flood tidal delta within East Matagorda Bay (Piety, 1972).

Several oyster reefs are located west of the Colorado delta (see Dog Island Reef, Shell Island Reef, Mud Island Reef, and Half Moon Reef). Part of Dog Island Reef was covered by the Colorado delta, and much of the remaining reef was removed by shell dredgers. Reefs are oriented approximately perpendicular to elongation of the bay, and they have grown upward to distances from a few feet to a few inches below the water surface.

Distribution of 6 sediment types is shown on the Bay City-Freeport map. These sediment types are based on shell/sand/mud ratios from the laboratory study of 322 samples. Four terrigenous clastic types (sand, muddy sand, sandy mud, and mud), a mixture of shell material (shell gravel), and a mixture of terrigenous clastics and shell (muddy shelly sand) all characterize the bay and estuary bottoms.

Quartz sand occurs along bay margins, and locally at the head of Tres Palacios Bay. Sand is representative of the highest physical energy environments within the bay. A broad, almost continuous band of sand exists along the bay side of Matagorda Peninsula. This sand was deposited by normal tidal processes and storms at Brown Cedar Cut, and by storm washover along the remainder of Matagorda Peninsula. A small lobate sand body has accumulated at Tiger Island Cut; this is an active subdelta of the Colorado River. Similarly, a small sand area has accumulated at the head of Tres Palacios Bay, where Tres Palacios Creek enters the bay. At other points within the bay area, sand occurs both as narrow beaches and as a veneer over truncated Pleistocene deposits in the shallow bay margin.

Muddy sand occurs along bay margins in juxtaposition with both clean quartz sand and the bay shoreline, and it extends to the southwest from spits and other salient features. Muddy sand accumulates in a less intense physical environment than does quartz sand. There is a band of muddy sand extending across Lake Austin; this band is coincident with Pleistocene sand exposed in the low bluffs forming the lake shoreline.

Sandy mud occurs in all the bays, as well as in Lake Austin. Sandy mud is present at both the north and south ends of the Lake; the north end is dominatedby fluvial processes and the south end by tidal processes. Within East Matagorda Bay, sandy mud lies adjacent to the north shore, is found downcurrent from promontories, and occurs as a fringe around part of the Colorado delta. The area of East Matagorda Bay defined by stations 9, 10, 37, 38, and 39 contains representative sediment derived from dredge spoil. Distribution of sandy mud in Matagorda Bay is similar to that in East Matagorda Bay, except for the area partly defined by stations 179, 185, and 190. Here sandy mud extends from Matagorda Peninsula almost across the bay; this pattern is the product of storm processes. The broadest band of sandy mud in the bay system covers much of the bottom of southwestern Tres Palacios Bay; this pattern results from the operation of counterclockwise currents.

The dominant sediment type is mud, which is present in all bay segments at all water depths. Mud accumulates at or near mouths of streams, in protected bay-margin areas, and in the deeper parts of bays.

Gravel-sized shell, including disarticulated valves as well as shell fragments, is associated primarily with oyster reefs and oyster flats, and in shallow bay margin areas where oysters occur in scattered clumps. Shell-gravel forms reef flank deposits, it grades away from the reef into bay mud. Individual oyster clumps in the shallow bay margin areas are commonly attached to a firm substrate which is normally a cohesive Pleistocene mud. Large waves rip up these clumps from the substrate, disarticulate and fragment the shell, and redistribute it as shell pavement and shell beaches.

Muddy shelly sand was identified in only two areas: (1) Lake Austin (station 9), and (2) Tres Palacios Bay (station 9). Water depth in Lake Austin is about 2.0 feet (0.6 m), and shell is mostly *Rangia sp.* and *Crassostrea virginica.* Water depth in Tres Palacios Bay is about 3.0 feet (0.9 m), and shell is predominantly *Crassostrea virginica.*

Oyster reefs are very small in East Matagorda Bay. Reefs were at one time well developed in the area west of the Colorado River delta (see Dog Island, Shell Island, Mad Island, and Half Moon Reefs). In the early 1950's some of these reefs were dredged (Dog Island Reef, for example), and only isolated patches remain. Sampling in some former reef areas failed to produce any shell material.

Port Lavaca Area

The Port Lavaca area is characterized by numerous interconnected bays and estuaries that form a continuous water system bounded on the Gulf side by Matagorda Peninsula, Matagorda Island, and San José Island.

For convenience of discussion, these bays and estuaries are divided into three areas. Area (1) includes Matagorda, Carancahua, Keller, Cox, Lavaca, and Chocolate Bays, and Powderhorn Lake. Area (2) includes all the water bodies from Pass Cavallo on the northeast, through Mesquite Bay to the southwest. Aransas, St. Charles, and Copano Bays make up the third area.

In the Matagorda Bay system (area 1), maximum water depth of 14 feet is in Matagorda Bay. Maximum depths of the subsidiary Carancahua, Keller, and Lavaca Bays are 5, 6, and 7 feet, (1.5, 1.8, and 2.1 m) respectively. Matagorda Ship Channel is 36 feet (11 m) deep, and Pass Cavallo ranges from 9 to 33 feet (2.7 to 10 m) in depth.

The San Antonio Bay system (area 2) is somewhat shallower. Maximum water depth of the system is 8 feet (2.4 m) in Espiritu Santo Bay. Maximum depths in San Antonio Bay are 6 feet; (1.8 m) and 4 feet (1.2 m) in Ayers, Mesquite and Carlos Bays. Cedar Bayou, a small,long, narrow tidal pass connecting Mesquite Bay with the Gulf of Mexico, is only 2 to 3 feet (0.6 to 0.9 m) deep.

Parts of Aransas and Copano Bays, and all of St. Charles Bay (area 3), constitute the Aransas Bay system. Maximum water depth in Aransas and Copano Bays is 9 feet (2.7 m), and in St. Charles Bay it is 5 feet (1.5 m).

Sediment sources for the bays in the Port Lavaca area are, as for other areas, rivers, the Gulf of Mexico, Pleistocene deposits forming uplands adjacent to bays, and shell produced by bay organisms.

Fluvial systems discharge into Carancahua, Keller, Lavaca, Chocolate, San Antonio, St. Charles, and Copano Bays. Streams transporting a sizeable bed load (sand or coarser material), in conjunction with suspension and washload (silt and clay), deposit the coarse material almost immediately upon entering the bay. Lavaca River, Garcitas Creek, and Guadalupe River each transports sufficient sand to construct bayhead deltas. The washload from these and other streams travels beyond the river mouths to accumulate in quieter, deeper water.

Sediment from the Gulf of Mexico accumulates as flood tidal deltas at the termini of tidal channels, and as washover aprons along the bay margins of barrier islands. Both bedload and suspension load arrive at the bays through tidal inlets and storm channels. However, only sand and shell derived from the Gulf can be identified visually.

Most of the sand forming mainland beaches and bay margin deposits was derived through erosion of Pleistocene fluvial-deltaic and strandplain deposits exposed in bluffs that form the shoreline. Widespread sand distribution in certain bay margin areas indicates that adjacent Pleistocene deposits have a high sand percent.

Oyster reefs have contributed significantly to the fill of some bays. San Antonio, Aransas, and Copano Bays exhibit the greatest development of oyster reefs. Shell dredging has been pursued extensively near the head of Lavaca Bay, within the northwestern part of Matagorda Bay, and throughout San Antonio Bay.

The distribution patterns of 8 sediment types, including oyster reefs and flanking shell debris, was determined from field and laboratory descriptions of 786 sediment samples. Bay deposits comprise 3 dominant sediment groups: (1) terrigenous clastics consisting of sand, muddy sand, sandy mud, and mud; (2) terrigenous clastics with shell consisting of shelly sandy mud and shelly mud; and (3) biogenic sediment represented by muddy shell and oyster reefs.

Matagorda Bay System

Six sediment types (sand, muddy sand, sandy mud, mud, shell, and oyster reefs) are present in the Matagorda Bay system. Sand has wide distribution and occurs in the shallow bay margin adjacent to almost all shoreline segments. It is present in Lavaca River and occupies a narrow zone west of the Lavaca delta. Sand in Garcitas Cove was derived from Garcitas Creek. The Gulf of Mexico is the primary source for bay margin sand along Matagorda Peninsula and in the Pass Cavallo area. In other areas bay margin sand was eroded from Pleistocene deposits exposed in the bluffs forming most of the mainland shoreline.

Muddy sand is confined primarily to the shallow bay margin areas, but locally it extends into deeper water. Muddy sand deposits exist as a low sill lying between Lavaca and Matagorda Bays.

Sandy mud extends locally along bay margins paralleling trends of sand and muddy sand. It occupies a significant area at the head of Lavaca Bay, and floors most of Carancahua Bay. A large sandy mud area extends from the Half Moon Reef area (see also Bay City-Freeport map) into the deeper waters of Matagorda Bay. Sandy mud accumulates in quieter water than does either sand or muddy sand, and sandy mud is supplied to the bay system from rivers, shoreline erosion, and the Gulf of Mexico.

Mud has the greatest areal extent of all sediment types, and occurs in all water depths and in all bays, accumulating in the areas of lowest physical energy.

Biogenic sediment constitutes a very small total area of the bay. Gravel-sized shell occurs in inlets between Carancahua and Matagorda Bays, and between Huisache Cove and Cox Bay. Plentiful *Crassostrea virginica* shell is derived from oyster clumps. Reefs are rare in the Matagorda Bay system. Before dredging, reefs were widely distributed in Lavaca Bay; now there are only small, scattered reefs at the head of the Bay.

San Antonio Bay System

Bays comprising this system form an inverted "T," with San Antonio and Hynes Bays as the stem. Nine sediment types are represented in the San Antonio Bay system. These are sand, muddy sand, sandy mud, mud, shelly mud, shelly sandy mud, muddy shell, shell, and oyster reefs.

Clean quartz sand is distributed over a relatively small area of the bay margin. At the east end of Espiritu Santo Bay, sand, derived principally from the Gulf of Mexico, forms part of a large asymmetrical flood tidal delta. Bay margin sand, also derived indirectly from the Gulf of Mexico, occupies a narrow band adjacent to the bay shore of Matagorda and San Jose Islands. At other locations within the system, bay margin sand was derived from the erosion and redistribution of Pleistocene strandplain and fluvial-deltaic sand (McGowen and others, 1976b).

Muddy sand occupies the same general areas as the clean quartz sand, but muddy sand extends beyond the areas of sand distribution to form a complete band around the bay system, except at the head of Hynes Bay and in Mission Lake. Muddy sand is supplied to the system through Lavaca River, Gulf of Mexico, and shoreline erosion. It normally accumulates in more protected areas or in deeper water than does clean sand.

A much larger area of bay bottom is covered by sandy mud than by sand or muddy sand. Like muddy sand, sandy mud forms an almost continuous band around the bay system; it also is locally absent, however, at the head of Hynes Bay and in most of Mission Lake. Panther Reef appears to have served as a barrier to sediment dispersal; a large sandy mud area lies "upcurrent" (northeast) of the reef. Sandy mud forms the floor of most of Ayers and Carlos Bays.

Mud is primarily confined to the deeper parts of bays. However, it extends to the bay shore in protected areas such as Hynes Bay and Mission Lake.

Shelly sandy mud has very limited distribution, and, indeed, was identified at only one locality (station 31). It occupies the same position along the bay margin as clean sand. Distribution of shelly mud is coincident with oyster reefs. Shell derived from reefs is mixed with terrigenous mud to form a transitional deposit from reef to muddy bay bottom.

Muddy shell is present in Espiritu Santo Bay (between the Ferry Channel and flood tidal delta), and in Ayers, Mesquite, and Carlos Bays, where it forms reef flank deposits. Muddy shell in Espíritu Santo Bay is not related to oyster reef; its occurrence may be related to storm activity.

Gravel-sized shell debris was identified at one locality (station 105) adjacent to Panther Reef. Shell, derived from the reef, accumulates as a reef-flank deposit.

Oyster reefs are perhaps better developed in the San Antonio Bay system than in any other bay area of the Texas Gulf Coast. However, their areal distribution is steadily decreasing because of dredging activities.

Aransas Bay System

Only a small part of the Aransas Bay system is present in the Port Lavaca map area. Fine-grained terrigenous clastics are the dominant sediment type.

Clean quartz sand has very limited distribution along bay margins. Within Copano Bay, bay margin sand is derived from erosion of shoreline materials. At stations 10 and 22 (north shore of the bay), sand is eroded from Pleistocene deltaic deposits, and at station 16 (just west of the causeway), sand is being eroded from Pleistocene strandplain deposits. Sand also occurs adjacent to the bay shore of San José Island.

Muddy sand forms a band adjacent to and parallel with the shoreline of Copano Bay. Within Aransas Bay, muddy sand lies more than a mile offshore from the mouth of St. Charles Bay, in water 6 to 8 feet (1.8 to 2.4 m) deep. This appears to be an anomalous occurrence, perhaps related to dredging activities.

Sandy mud occupies a relatively large part of the bay bottom in the northern part of the system. Bottom sediment in St. Charles Bay is almost entirely sandy mud. The possible source of this sediment type is the Blackjack-Lamar Peninsula area, which is underlain by Pleistocene strandplain sand.

Mud is found in the deeper bay segments and in protected areas, such as parts of bays enclosed by oyster reefs.

Terrigenous clastic sediment with biogenic components is represented by shelly mud, which forms reef flank deposits, and by shelly sand. Two areas in Aransas Bay are characterized by a limited extent of shelly sand--the area adjacent to Long Reef (station 70), and the area near the west shore of the bay (station 76). These are areas of high physical energy in 2 to 3 feet (0.6 to 0.9 m) of water.

Gravel-sized shell debris (stations 71, 77, 78, and 91 in Aransas Bay, and station 4 in St. Charles Bay) either is associated with oyster reefs, or was derived from redistribution of individual oyster clumps. Muddy shell forms reef flank deposits, in association with the oyster reefs separating Carlos from Aransas Bay.

Oyster reefs form long, relatively continuous, resistant structures in Aransas and Copano Bays. The larger reefs are barely awash, and at times their upper surfaces are exposed.

Corpus Christi Area

Bays and estuaries of the Corpus Christi map area are interconnected, and they form a continuous, although variable, water body. San José, Mustang, and Padre Islands separate bays and estuaries from the Gulf of Mexico. These water bodies are divided into three bay systems to facilitate the following discussion. Aransas Bay system includes all water bodies north of Aransas Channel (part of Redfish Bay, Aransas Bay, Copano Bay, and Mission Bay). The Corpus Christi Bay system is composed of Redfish Bay south of Aransas Channel, Corpus Christi Bay, and Nueces

Bay. Packery Channel and the John F. Kenedy Causeway form the boundary between the Laguna Madre and Corpus Christi Bay systems.

In the Aransas Bay system maximum water depths of component bays are (1) Mission Bay, 2 feet (0.6 m); (2) Copano Bay, 8 feet (2.4 m); (3) Aransas Bay, 12 feet (3.6 m); and (4) the northern part of Redfish Bay, 5 feet (1.5 m), with tidal channels attaning depths to 9 feet (2.7 m). Lydia Ann Channel has a maximum depth of 23 feet (7 m) near its confluence with Aransas Pass.

The Corpus Christi Bay system is made up, for the most part, of Corpus Christi Bay, with a maximum depth of 13 feet (4 m). Water with a depth of 12-13 feet (4 m) makes up a large part of the bay; a large part of this area is underlain by fine-grained sediment. Maximum depth of Redfish Bay south of Aransas Channel is about 2 feet (0.6 m). Nueces Bay is shallow (depths of 2 to 3 feet (0.6 to 0.9 m) are common), with maximum depth being about 4 feet (1.2 m).

Sediment sources for the bays in the Corpus Christi system are the same as for the bays and estuaries to the northeast--rivers, Gulf of Mexico, Pleistocene deposits forming the mainland shoreline, and biogenic products. Rivers in this map area play a less important role in bay sedimentation than in some other systems because a climatic gradient causes a decrease in rainfall from east to south across the state (Carr, 1967).

Fluvial systems issue into Mission, Copano, Corpus Christi, and Oso Bays. All streams, except the Nueces River, are small and originate within the coastal plain. Because of their small size, these streams normally contribute relatively little sediment to the bay-estuary system; their discharges, however, are excessively high during the passage of tropical storms. Nueces River is building a delta into the bay; a large part of the suspension load material moving beyond the river mouth is trapped in Nueces Bay (Compare maximum depth of 4 feet (1.2 m) in Nueces Bay with maximum depth of 13 feet (4 m) in Corpus Christi Bay.).

Sediment from the Gulf of Mexico is transported into the bays through tidal inlets and storm channels, and across low-lying barrier segments, such as North Pass near the southern tip of San José Island (see Price, 1956; Nordquist, 1972). In the recent past, sediment moved through Aransas Pass and Corpus Christi Pass (shown as Packery Channel on recent charts and on this map) to form extensive flood-tidal deltas. Aransas Pass has been jettied since the late 1800's. Jetties have reduced the volume of sand moving along the Gulf shore and into the bay via the tidal inlet. Corpus Christi Pass became inactive in the early 1900's because of a change in bay circulation brought about by channel dredging in Corpus Christi Bay (Price, 1952). Storm surge floods overwash both the southern parts of San José (North Pass area) and Mustang Islands. Large volumes of sand have been contributed to bay margins by hurricane washovers.

Sand that accumulated in bay margin areas adjacent to the mainland shoreline has its source in Pleistocene fluvial-deltaic and strandplain deposits (Brown and others, 1976). Widespread distribution of sand in some bay margin areas reflects the local occurrence of Pleistocene deposits with high sand content; such shoreline segments face either the prevailing south or north winds.

With the exception of Copano Bay, the bays within the Corpus Christi map area have not been prolific producers of biogenic features such as oyster reefs.

Sediment distribution patterns were determined from field descriptions of 485 grab samples. Bay deposits are composed of three dominant sediment groups: (1) terrigenous clastics consisting of sand, muddy sand, sandy mud, and mud; (2) terrigenous clastics with an admixture of shell (shelly sand, muddy shelly sand, shelly mud, sandy shelly mud); and (3) biogenic sediment represented by shell gravel, sandy shell, sandy muddy shell, muddy shell, and oyster reefs.

Aransas Bay System

Twelve sediment types have been mapped in the Aransas Bay system. Sediment exhibits a pattern of distribution for most of the area with sand at the margin and mud in bay centers. The exception is Redfish Bay, which displays a patch-work distribution pattern resulting from dredging and spoil disposal.

Clean quartz sand occupying bay margins in Copano and Aransas Bays in the Rockport-Fulton area was derived from erosion of Pleistocene deltaic and strandplain deposits (Brown and others, 1976). Reworked spoil is indicated as the source of sand adjacent to dredge channels in southwestern Aransas Bay (stations 14, 15, and 27). Bay margin sand adjacent to San José Island (Allyns Bight area) was reworked from the island by waves and currents, and sand in the North Pass area was deposited by storm surge flooding (Nordquist, 1972).

Muddy sand is largely confined to Mission and Copano Bays. Here, the sand is derived principally from erosion of Pleistocene deposits forming the shoreline. Very limited distribution of this type can be seen in Aransas Bay, next to San José Island (stations 21 and 48). Muddy sand at station 21 represents an area of spoil disposal. One area of muddy sand was mapped in Redfish Bay (station 19); this is related to the large flood-tidal delta, "Harbor Island" (see Hoover, 1968; Munson, 1975).

The area of sandy mud is much smaller in the Aransas Bay system than in the map areas to the northeast, occurring in discrete patches of various sizes rather than continuous band along the bay margin. The floor of Mission Bay consists primarily of sandy mud derived from the Mission River. Most of other areas of sandy mud probably represent the mixing of sand, derived from the Pleistocene exposed along the shoreline, with mud transported to the bays through fluvial systems. Sandy mud also records mixing of sediment types through dredging activities (Aransas Bay, stations 9, 25, 28, and 29).

Mud covers large, continuous parts of bay centers, and also accumulates in small, shallow, protected areas. Small areas of mud deposition include Mission Lake, at the mouth of Aransas River, and at the northern part of Redfish Bay.

Most of the mixed shell and terrigenous clastics occurs in the Redfish Bay area where dredging has been conducted. Three such sediment types are shelly sand (adjacent to the dredged part of Lydia Ann Channel, and at stations 26 and 39 in Aransas Bay), muddy shelly sand (confined to Redfish Bay--stations 25 and 28), and shelly mud (relatively wide, although patchy distribution). Shelly mud is found in Copano Bay (stations 3, 13, 16, 24, 38, 41, 42, and 50); most of these areas are representative of the natural association of terrigenous clastic sediment with shell-producing organisms.

Shell material occurs in deposits of gravel-sized shell fragments that are virtually free of terrigenous clastics, and as shell debris mixed with sand and mud. Gravel-sized shell occurs both in Copano Bay (stations 29 and 30), and in Aransas Bay (station 52) adjacent to Frandalig Island, where there has been considerable dredging. Sandy shell is found near Hog Island (station 24) in about 4 feet (1.2 m) of water adjacent to a tidal channel in Redfish Bay. Sandy muddy shell forms a band that lies to the west of Taylor and Talley Islands (stations 29 and 30), and adjacent to a spoil disposal area (station 21) associated with the Gulf Intracoastal Waterway. Muddy shell is found in Copano Bay, where it primarily forms reef flank deposits; in Aransas Bay (station 20), in association with dredge spoil; and in Redfish Bay (stations 20, 21, 22, and 23), in association with marine grasses.

Oyster reefs are restricted to Copano Bay, where they are oriented perpendicular to its long dimension.

Corpus Christi Bay System

The distribution of 14 sediment types was mapped from field descriptions of sediment grab samples. Most of Corpus Christi Bay exhibits a natural sediment dispersal trend. Redfish and Nueces Bays have been affected by channelization and extensive shell dredging; distribution of bottom sediment in these bays reflects man's activities.

Bay margin sand adjacent to the mainland shoreline was reworked from Pleistocene deltaic and strandplain deposits. Some spoil islands are flanked by sand reworked from dredge spoil (stations 40 and 44). Longshore currents and waves have reworked some of the sands associated with Mustang Island (stations 4, 22, and 24). Sand that underlies the relatively broad area defined by the Gulf Intracoastal Waterway, Fish Pass, and Packery Channel was transported from the Gulf of Mexico (1) through Packery Channel (formerly Corpus Christi Pass) when it was an active tidal inlet; and (2) across the southern part of Mustang Island through washover channels (for example, Newport and Corpus Christi Passes) during tropical storms.

Muddy sand is present at the head of Nueces Bay and along its north and east shores; muddy sand at the bay head was derived from the Nueces River. Muddy sand, eroded from the Pleistocene, also occupies the bay margin along the west and north mainland shores of Corpus Christi Bay. Muddy sand along the margin of Mustang Island and within tidal inlet-tidal delta areas is related, in part, both to the daily tidal regime and to seasonal storm processes.

Sandy mud covers a large part of the Nueces Bay bottom. In other areas sandy mud is found in rather small isolated patches (Oso Bay, station 5; Corpus Christi Bay, stations 6, 7, 9, 25, 59, and 155). In general, sandy mud accumulates in deeper or quieter water than does sand and muddy sand; this does not apply to Nueces Bay because it has been dredged extensively for oyster shell.

The centers of Nueces and Corpus Christi Bays are characterized by mud. Small areas of mud accumulation are found in northeastern Nueces Bay (station 5), southwestern Corpus Christi Bay, eastern Oso Bay, and eastern Redfish Bay (station 18). Mud accumulates in the deeper-water areas, and in the areas of lowest physical energy.

The Corpus Christi Bay system contains 4 sediment types resulting from the mixing of shell with terrigenous clastic deposits. These types are shelly sand, muddy shelly sand, shelly mud, and sandy shelly mud. Most of these sediment types result from the mechanical mixing of shell and terrigenous clastics, a process caused directly or indirectly by man's activities. Shelly sand occurs only in Redfish Bay; it covers most of Redfish Cove and parallels the Intracoastal Waterway. Muddy shelly sand is situated adjacent to dredge channels at the head of Nueces Bay (station 31), and along La Quinta Channel in Corpus Christi Bay (stations 154 and 156). One can demonstrate that shelly mud is associated with dredging in at least 3 areas (Redfish Bay, stations 4 and 12; Corpus Christi Bay, station 65). In other areas, however, this sediment type apparently is associated with high biologic activity. Sandy shelly mud occurs in the east-central part of Nueces Bay (probably a product of shell dredging), in Corpus Christi Bay next to Shamrock Island, and in several areas of Redfish Bay. In Corpus Christi and Redfish Bays this sediment type probably is related to high shell productivity combined with relatively strong tidal currents.

Sediment composed predominantly of shell fragments (sandy shell, sandy muddy shell, and muddy shell) has limited distribution. Sandy shell is present in the shallow waters of Redfish Bay (stations 13 and 14), and in Nueces Bay (stations 1 and 17). Sandy muddy shell is found only in Redfish Bay (station 11), inside the area of numerous spoil islands. Muddy shell, in most instances, appears to be a product of natural physical and biological processes. Muddy shell normally is associated with oyster reefs (Nueces Bay, station 22; Corpus Christi Bay, stations 142 and 151); these are reef flank deposits. In the vicinity of Ransom Island (Redfish Bay, station 10), muddy shell is juxtaposed to shell islands.

Oyster reefs cover a small part of the bay bottom in the Corpus Christi system. During the sampling of Nueces Bay only one reef was encountered (see station 22); most of the reefs in this bay have been removed by shell dredging operations. Known reefs in Corpus Christi Bay are situated in the western part of the bay (Alta Vista Reef), in the northwestern part of the bay at Indian Point (Indian Reef), and near the north shore (Donnel and Long Reefs).

Laguna Madre System

Laguna Madre differs from the bays and estuaries to its north and east in having very limited water exchange with the Gulf of Mexico by (1) having no perennial streams discharging into it, (2) being extremely shallow, and (3) lying in an arid climatic belt. These factors acting in concert have produced a long, north-south trending water body with higher than normal salinity. The system is relatively unaffected by daily fluctuations of astronomical tide. The water level in Laguna Madre fluctuates with wind direction, intensity, and duration. Because of its hydrologic regime and the rate and kind of sediment delivered, Laguna Madre contains considerably less mud than bays and estuaries to the north and east.

Ten sediment types have been recognized in the northern part of Laguna Madre. These are sand, muddy sand, sandy mud, mud, shelly sand, muddy shelly sand, sandy shelly mud, shelly mud, shell gravel, and sandy shell.

Sand forms a narrow band next to mainland and barrier island shorelines; near the southern map limit sand is displaced toward the center of the lagoon. Muddy sand generally occurs adjacent to sand and approximately parallels the lagoon shorelines. In some spoil areas muddy sand, reworked from that spoil, is the dominant sediment type. Sandy mud, in the absence of reworked spoil, covers most of the central lagoon. Mud is rare in Laguna Madre; it accumulates in protected areas formed by dredge channels and spoil mounds (stations 7, 11, 26, and 33). It appears that most of the other sediment types are associated with man's activities within the lagoon. Exceptions are shelly sand (stations 51 and 52), and sandy shell (station 59). Shell gravel (station 14), shelly mud (stations 41, 46, and 56), sandy shelly mud (stations 45, 50, and 57), and shelly sand (station 49) all appear to be associated with dredging or drilling activities.

Kingsville Area

Bays and lagoons in the Kingsville map area lie in an arid to semi-arid climatic zone, and they receive a limited amount of fresh water from streams draining the adjacent uplands. Hurricanes contribute large volumes of fresh water to the system; during this time fresh water virtually replaces saline water in the bays and lagoons (Behrens, 1969). Since evaporation exceeds precipitation, the salinity of water bodies is generally greater than that of seawater (Brown and others, 1977).

Under normal sea conditions there is no direct communication between bays and lagoons in the map area, and the Gulf of Mexico.

To the north water flows into Laguna Madre from Corpus Christi Bay, which is connected to the Gulf of Mexico both through Aransas Pass and through a man-made water-exchange pass (Watson and Behrens, 1976). There is water exchange between Laguna Madre and the Gulf of Mexico to the south (see Brownsville map area). Laguna Madre, south of Baffin Bay, has been compartmentalized by two large salient features known as Middle Ground (see Zupan, 1970; Brown and others, 1977), and Land-Cut Area (see Fisk, 1959; Brown and others, 1977). This division was caused by large washover and wind deposits.

Astronomical tides are virtually nil in the Kingsville map area except in the spring and fall, when the water level may be raised a foot to 1.5 feet (Breuer, 1957). Strong winds are common to the area; these winds produce "wind tides" which bring about noticeable changes in water level in the Baffin Bay and Laguna Madre systems. Calculations based on wind velocity and fetch indicate that wind tides in the one- to four-foot range are common in the Laguna Madre area (Rusnak, 1960). Winds from the south and southeast (1) raise water level in the northern part of Redfish Bay which floods a large part of the Land-Cut Area, (2) drive the water out of The Hole across Middle Ground into the southern part of north Laguna Madre, and (3) cause the water to flow from Laguna Madre into Baffin Bay thereby increasing water depth. "Northers" produce wind tides that are (1) low in Baffin and Redfish Bays, and (2) are high in the Middle Ground-The Hole area and adjacent Land-Cut Area.

Within the Baffin Bay system strong currents generated by wind tides are evident at the mouths of Baffin and Alazan Bays.

High average wind velocities cause strong wave action in the Baffin Bay and Laguna Madre systems throughout most of the year. Continuous wave action coupled with a low volume of terrigenous sediment input into the Baffin Bay system contributed to development of oolites and coated grains adjacent to the north shore of Baffin Bay and across the mouth of Alazan Bay.

Water within the Baffin Bay-Laguna Madre system is hypersaline during most of the year. In the Kingsville map area evapotranspiration exceeds rainfall by about 20 inches (50 cm). Dredging of the Gulf Intracoastal Waterway in 1948 (Breuer, 1957) enhanced the communication between the Gulf of Mexico and the Laguna Madre system. Creation of the Intracoastal Waterway has virtually eliminated the existence of long-term hypersaline conditions; salinity may still attain values of 80 parts per thousand. During summer months salinity of the water of the Baffin Bay system is greatest near bay heads and least near Laguna Madre. During the rainy season salinity is least near bay heads and increases toward Laguna Madre.

These factors--low rainfall, excessive evaporation, limited water exchange with the Gulf of Mexico, wind tides, and compartmentalization of bays and lagoons--have exerted a tremendous influence both upon the types of sediment delivered to and produced within these water bodies, and upon the distribution of these sediments.

Bays and lagoons of the Kingsville map area have been arbitrarily divided into two systems: (1) the Baffin Bay system, which is oriented approximately perpendicular to the Gulf shoreline; and (2) the Laguna Madre system, a long, shallow water body elongated north-south and bounded on the east by Padre Island. The Baffin Bay system consists of four bay segments: (1) Baffin Bay, maximum depth of 9 feet (2.7 m); (2) Alazan Bay, maximum depth of 6 feet (1.8 m); (3) Cayo del Grullo, maximum depth of 5 feet (1.5 m); and (4) Laguna Salada, maximum depth of 7 feet (2.1 m). In the map area, Laguna Madre falls into three natural divisions: (1) north of Middle Ground, where depths reach 6 feet (1.8 m); (2) The Hole, which is on the order of 2 feet (0.6 m) deep; and (3) Redfish Bay, south of the Land-Cut Area, where depth is up to 6 feet (1.8 m).

Sediment is delivered to the Baffin Bay system by Tunas, San Fernando, and Olmos Creeks, all of which are small, ephemeral streams (Dalrymple, 1964; Brown and others, 1977). Sediment also is contributed to the system through erosion of Pleistocene strandplain, deltaic-marine and loess deposits that form the shoreline. Wind is also a factor in bay sedimentation; sand and silt are delivered to the bay from the southeast under prevailing wind conditions, and from the north during "northers." Considerable carbonate sediment, ranging from serpulid reefs (Andrews, 1964; Dalrymple, 1964) through oolites (Dalrymple, 1964; Behrens, 1964; Frishman, 1969), is generated within the bay system. Baffin Bay is unique among the Texas bays in that carbonates form a significant volume of sediment.

The Laguna Madre system receives sediment from (1) the Gulf of Mexico, from (2) Baffin Bay, (3) the mainland via runnoff from hurricane aftermath rainfall and thunderstorms, and (4) Padre Island chiefly from south to southwest winds. Serpulid reefs (east of the Gulf Intracoastal Waterway) and beach-rock (west of the Waterway) are common in the area south of the mouth of Baffin Bay; neither are actively accreting at the present. These carbonate rock types formed in situ as a result of biological or a combination of biological and chemical processes.

Baffin Bay System

Distribution of 13 sediment types was mapped from field descriptions of 159 samples. Baffin Bay, in addition to 3 sediment end members common to other bays (terrigenous clastics, terrigenous clastics with shell admixture, and biogenic sediment), also has carbonate deposits (for example, coated grains and oolites).

Terrigenous clastics are sand, muddy sand, sandy mud, and mud. Sand is distributed in a very narrow band next to the shoreline. It is derived primarily from erosion of shoreline materials; some sand is transported to the bay margin by wind. Muddy sand also occurs along the bay margin. It forms discontinuous bands broader than clean quartz sand; some muddy sand occurs at the heads of bays (for example, Laguna de los Olmos). Sandy mud is patchily distributed (mouth of Baffin Bay, southeast shore of Alazan Bay, and Cayo del Grullo). It occurs in somewhat deeper water, or in areas less affected by waves and currents, than do either sand or muddy sand. Mud occupies the central, deeper parts of all bays, and it would form a continuous blanket throughout the system if sediment sills were not present at the mouths of Alazan Bay and Cayo del Grullo.

Shell-bearing terrigenous clastics are confined primarily to bay margin areas. These clastics consist of shelly sand, muddy shelly sand, sandy shelly mud, and shelly mud. Shelly sand occupies approximately the same position relative to shoreline as clean quartz sand, and along the south shore of Laguna Salada it grades laterally (along shore) into clean quartz sand. Along the north shore of Baffin Bay shelly sand grades eastward and westward into coated grains. Muddy shelly sand is present (1) near Point of Rocks, (2) in the Penascal Ricon region, (3) at the head and near the south shore of Alazan Bay, and (4) in Cayo de Grullo (stations 70, 77, and 78). This sediment type accumulates in areas of relatively low physical energy (for example in areas protected from the prevailing southeast wind). Sandy shelly mud occupies areas of low physical energy comparable to those occupied by muddy shelly sand. Sandy shelly mud occurs in Cayo del Grullo (stations 68 and 72), and in Alazan Bay (station 6). Shelly mud is confined to the western part of the system in the following areas: (1) along the axis of Cayo del Grullo (stations 71 and 75); (2) at the mouth of Cayo del Grullo (station 58.5); (3) in Laguna Salada (station 61); and (4) near Kleberg Point (station 57). These sites are representative of deeper, quieter water bay segments, or else they lie in shallow water near shore, in a wind-shadow area.

Biogenic sediment, either pure calcium carbonate or varying terrigenous admixture, is represented by gravel-sized shell, sandy shell, sandy muddy shell, and serpulid reefs. Only 2 areas of clean gravel-sized shell debris were identified in the Baffin Bay system--at Riviera Beach (station 82), and opposite Kleberg Point at station 54. Sand and shell ridges are prominent shoreline features in the vicinity of station 54, suggesting either tropical storms or northers as the agents of shell gravel deposition. Sandy shell has limited distribution, and was identified in only one area (station 5 near Point of Rocks). Here, sandy shell is associated with five sediment facies (mud, sandy mud, shelly sand, serpulid reefs, and sandy muddy shell). Sandy muddy shell occurs in at least three areas: (1) near the mouth of Baffin Bay, in a broad, grass-flat area generally less than 3 feet (0.9 m) deep; (2) near the southeast shore of Alazan Bay, in association with marine grasses in 1 to 2 feet (0.3 tp 0.6 m) of water (station 20); and (3) near the head of Cayo del Grullo in association with *Halodule wrightii* in about 1.5 feet (0.45 m) of water (station 74). Serpulid reefs are abundantly distributed in Baffin Bay, but they are rare in other bays. These reefs occur primarily in bay margin areas, and they reach from about 2 to 8 feet (0.6 to 2.4 m) above the present bay bottom. Reefs are rock-like structures formed by calcareous tubes of serpulid worms. These reefs, which are no longer active, probably thrived when the salinity of Baffin Bay was considerably less than it is at present (Dalrymple, 1964; Andrews, 1964).

Coated grains and oolites (mapped together on this preliminary map) comprise the two carbonate sediment facies. These facies have developed in bay margin areas along the north shore of Baffin Bay (station 19, 20, and 26), across the mouth of Alazan Bay (stations 21, 25, 42, and 42.5), and in the Kleberg Point area (Frishman, 1969). Coated grains occur in shallow water, having accumulated in alternating bars and troughs aligned parallel to the shoreline. Coated grains are associated with sparse to dense growth of marine grasses and green algae. Oolites and coated grains form a bar across the mouth of Alazan Bay. Oolites have been reported in the Kleberg Point area by Dalrymple (1964), Behrens (1964), and Frishman (1969); Bureau samples from that area did not contain oolites. Oolites form beaches in the Starvation Point and Kleberg Point areas. Oolites at the mouth of Alazan Bay, and elsewhere, are in a high physical energy environment where grains are in more or less continuous motion; marine grasses and green algae are rare in these areas.

Laguna Madre System

The distribution of 11 Holocene sediment types was mapped from field descriptions of 162 samples. Sediment types mapped in Laguna Madre are: (1) terrigenous clastics, (2) terrigenous clastics with shell admixture, (3) biogenic deposits, and (4) relict deposits. Pleistocene beach rock (relict sediment) was mapped along the west shore of Laguna Madre between Point Penascal (mouth of Baffin Bay) and Rocky Slough.

Terrigenous clastics are sand, muddy sand, sandy mud, and mud. Sand occurs for the most part along the shallow bay margin adjacent to Padre Island where water depths are mostly less than two feet. A band of sand trends northwest-southeast across Laguna Madre near the northern map boundary where water depths are less than 1 foot (0.3 m) to greater than four feet. Sand is also present along the mainland shoreline at the southern map boundary in similar water depths. Muddy sand commonly is situated adjacent to an lagoonward from clean sand. Muddy sand is also found adjacent to some mainland shorelines (sample stations 85 and 151). Spoil mounds are sites of sediment redistribution, and muddy sand is the most common sediment type in these areas (for example sample stations 88, 98, 118, and 122). Most of "The Hole" is floored with muddy sand; this is an area that receives wind blown sand from Padre Island and suspension load materials from adjacent bays when the area is flooded by wind tides that are generated by north winds. Sandy mud is common to all segments of Laguna Madre in the Kingsville map area. This sediment type occupies almost all segments of Laguna Madre and occurs in water depths from less than 1 foot (0.3 m) to more than 8 feet (2.4 m). Mud is a rare sediment type in Laguna Madre. It was recorded at only sample stations 107 and 137 in water depths greater than eight feet and less than one foot respectively.

Shell-bearing terrigenous clastics, comprising (1) shelly sand, (2) muddy shelly sand, (3) sandy shelly mud, and (4) shelly mud, are present in all parts of Laguna Madre, and have accumulated most commonly along bay-margins. In some areas these deposits reside in the deeper, bay-centers where water depths range from 4 (1.2 m) to greater than 6 feet (1.8 m). Shelly sand is locally distributed in the vicinity of Big Cove (see sample stations 66, 73, and 74) in the northern part of the map area, and adjacent to a dredge channel (station 149) in Redfish Bay. Muddy shelly sand covers a significant part of the bay bottom in Redfish Bay where it occurs in water depths ranging from less than 1 foot (0.3 m) to more than 6 feet (1.8 m). Other areas where muddy shelly sand has accumulated are (1) in the vicinity of Rocky Slough, (2) north of Point of Rocks, and (3) in the vicinity of Big Cove. Only two bay bottom segments are characterized by sandy shelly mud. These are (1) between Point Penascal and Rocky Slough (less than 1 foot (0.3 m) to more than 4 feet (1.2 m) of water), and (2) station 160 in Redfish Bay where water depth is 6 feet (1.8 m). Sandy shelly mud comprises a relatively insignificant area of the total bay bottom. Shelly mud has the same distribution as sandy shelly mud; it occurs in the Rocky Slough area (station 114) and in the deeper water of Redfish Bay (stations 153A and 156).

Biogenic sediment is represented by sandy muddy shell, muddy shell, and serpulid reefs. These sediment types cover a very small part of the total area of the Laguna Madre System. Muddy shell lies to the west of the Intracoastal Waterway between Rocky Slough and Point Penascal where water depths range from less than 1 foot (0.3 m) to more than 6 feet (1.8 m). Sandy muddy shell occurs in two small areas: (1) along the mainland shore south of Point Penascal; and (2) along the west shore of Redfish Bay adjacent to Ricon de San José. Serpulid reefs are present to the south and southwest of the mouth of Baffin Bay where they reside in about 2 (0.6 m) to greater than 6 feet (1.8 m) of water. Like the reefs in Baffin Bay those in Laguna Madre are also dead.

Beach rock is of probable Pleistocene age and consists of well-cemented shell fragments. Most of the shell material has been thoroughly recrystallized and individual shells are unrecognizable. These deposits have been recognized along the mainland shoreline south of the mouth of Baffin Bay between Point Penascal and Rocky Slough. Beach rock is exposed along shore, and occurs in water ranging from less than 2 (0.6 m) to more than four feet (1.2 m).

Brownsville-Harlingen Area

Laguna Madre, in the Brownsville-Harlingen area, is characterized by broad wind-tidal flats stretching from the north map boundary southward to the vicinity of La Punta Larga. These flats are alternately either part of the bay bottom or emergent, depending upon wind direction, velocity, and duration. In general, water depths of Laguna Madre are shallowest where wind-tidal flats are broadest. North of the Port Mansfield Ship Channel maximum depth of Redfish Bay is about 8 feet (2.4 m); this area is adjacent to the Gulf Intracoastal Waterway and is elongate north-south. The lagoon between Hawk Island on the north and Arroyo Colorado Cutoff on the south is generally less than 2 feet (0.6 m) deep. From Arroyo Colorado Cutoff southward water depth increases, and in the vicinity of Port Isabel maximum depth is about 8 feet (2.4 m); average depth is 3 feet (0.9 m). South Bay, which lies to the west of Brazos Island and is connected to Laguna Madre, is 1 (0.3 m) to 2 feet (0.6 m) deep.

Climate of the Brownsville-Harlingen area is arid; evaporation exceeds precipitation (Carr, 1967; Brown and others, in press). Prevailing southeast winds transport sand from beach and dune areas of south Padre Island to the northwest. Sand either accumulates on the wind-tidal flat, or moves into Laguna Madre. In recent years fluvial systems in the Brownsville-Harlingen area have been altered through construction of dams, irrigation canals, and channel diversion. There are two fluvial systems in the Brownsville-Harlingen area: (1) Arroyo Colorado, which now discharges into Laguna Madre near Horse Island; and (2) Rio Grande, which discharges into the Gulf of Mexico. At present neither stream, under normal rainfall conditions, contributes much sediment to Laguna Madre. Water and sediment, however, both are contributed to Laguna Madre from the Gulf of Mexico during tropical storms. Heavy rainfall accompanying some hurricanes floods much of the adjacent mainland where resulting runoff transports sediment to Laguna Madre.

The distribution of 10 sediment types was mapped in the area, utilizing field descriptions of 674 grab samples. These 10 sediment types comprise 3 groups: (1) terrigenous sediment consisting of sand, muddy sand, sandy mud, and mud; (2) terrigenous sediment with a mixture of shell; and (3) shell (biogenic sediment) with varying amounts of terrigenous clastics. Laguna Madre contains neither serpulid nor oyster reefs.

The sediment map of the Brownsville-Harlingen area differs somewhat from maps of other bays. Within the central area of the lagoon, the sampling system was changed from 1-mile (1.6 km) centers to ½-mile (0.8 km) centers. The result of this change is a patch-work distribution pattern.

Terrigenous clastics, the dominant sediment types, are distributed throughout the lagoon. Clean quartz sand is present in part of the Port Mansfield Ship Channel, in Brazos Santiago Pass, in some spoil disposal areas, along parts of the mainland shoreline, and along the bay margin of Padre Island, particularly in wind-tidal flat areas. Sand that accumulated along the margin of south Padre Island was emplaced chiefly by hurricane overwash and by prevailing southeast winds that transport sand northwest across the island. Quartz sand is found at water depths ranging from 2 to 4 feet (0.6 to 1.2 m); it occurs most commonly adjacent to south Padre Island in water less than 2 feet (0.6 m) deep. Muddy sand occurs adjacent to spoil mounds, sporadically in the shallow bay margin area next to the mainland shoreline, lagoonward of the broad sand belt adjacent to the wind-tidal flat, and in a narrow band at the edge of the wind-tidal flat. Muddy sand accumulated in water whose depths range from less than 1 foot (0.3 m) to greater than 8 feet (2.4 m). The largest area of muddy sand lies within Redfish Bay and Laguna Madre to the north and south of the Port Mansfield Ship Channel. Muddy sand distribution does not appear to be depth controlled; its distribution is related to hurricane washovers, dredging activities, and reworking of relict sediment. Sandy mud is restricted for the most part to the lagoon bottom south of the Port Mansfield Ship Channel. Sandy mud was recorded at only one station (station 194) in Redfish Bay. Depth of water in which sandy mud occurs ranges from less than 2 feet (0.6 m) along the mainland margin to greater than 8 feet (2.4 m) at the south end of the lagoon near Brazos Santiago Pass. Sandy mud increases from north to south in the direction of deeper water, and in the area where sediment is discharged into the lagoon from small streams and drainage ditches. Sandy mud is also present in South Bay (see station 3) where water depth is less than two feet. Mud covers the smallest area of any of the terrigenous sediment types. Mud occurs as discontinuous patches along bay margins, at mouths of sloughs and adjacent to dredged channels within Laguna Madre, and covers most of the bottom of South Bay. Water depths in which mud occurs ranges from less than 1 foot (0.3 m) to more than 4 feet (1.2 m).

Terrigenous clastic sediment with shell admixtures comprises shelly sand, muddy shelly sand, sandy shelly mud, and shelly mud. These sediment types have apparent random distributions; some are clearly related to dredging activities, whereas others probably record storm events. Shelly sand occurs adjacent to (1) ship channels (stations 203 and 351), and (2) clean quartz sand (stations 192, 224, 230, 306, 314, 315, and 330). Water depths in which shelly sand is found ranges from less than 2 (0.6 m) to greater than 8 feet (2.4 m). Muddy shelly sand is found throughout the Laguna Madre system. It is situated in bay margin areas, next to ship channels, and in central lagoonal areas. Distribution of muddy shelly sand does not appear to be depth controlled; water depths where this sediment type is found range from less than 1 foot (0.3 m) to greater than 8 feet (2.4 m). Sandy shelly mud covers a larger area of the lagoon bottom than muddy shelly sand; these two sediment types occur together in some areas but are mutually exclusive in others. Sandy shelly mud has patchy distribution, and covers larger areas of the lagoon bottom in the region south of the Arroyo Colorado Cutoff than it does in the area to the north. Sandy shelly mud infrequently occurs in bay margin areas; it is most commonly found in the deeper lagoon segments. Range of water depths in which sandy shelly mud is situated is from less than 2 (0.6 m) to more than 4 feet (1.2 m). Shelly mud was encountered in only one area (sample station 127) where it is surrounded by muddy shell, muddy sand, sandy mud and sandy shelly mud. This sediment type occurs in water that is slightly more than 2 feet (0.6 m) deep.

Pure shell deposits were not encountered during the collection of bay samples in the Brownsville-Harlingen map area. Sandy muddy shell and muddy shell are the two biogenic sediment types that have been identified in Laguna Madre; each type was identified at only one sample station. Sandy muddy shell occurs at station 176 (in Redfish Bay) in approximately 6 feet (1.8 m) of water. Muddy shell is present at station 128 (in Laguna Madre) in slightly greater than two feet of water. Both sandy muddy shell and muddy shell are situated near the Gulf Intracoastal Waterway and may be related to dredging activities.

SHELF SURFACE SEDIMENTS

Regional Discussion

Texture and Composition

Most sediments on the inner shelf of Texas have grain sizes less than 0.5 mm. Sands are fine to very fine, but silts and clays (mud) predominate in most areas. Sediments coarser than 0.5 mm are generally whole shells and shell fragments; however, caliche nodules and rock fragments are also present. Carbonate content of shelf sediments depends mainly upon shell content, which in rare instances is greater than 75 percent. Other minor carbonate constituents include calcareous nodules.

Composition of sediment load transported by major rivers emptying into the Gulf of Mexico determines composition of terrigenous clastic sediments on the inner continental shelf. This relationship has been demonstrated by Bullard (1942), Goldstein (1942), and Van Andel and Poole (1960), among others. Light minerals are quartz with some feldspar; minor amounts of glauconite and pyrite are also present. Durable heavy minerals characterize sediment sources and specific suites of heavy minerals are diagnostic of the Rio Grande, Brazos, Colorado and other Texas rivers. A more complete discussion of shelf sediment composition was presented by Curray (1960).

Clay minerals of the northwest Gulf of Mexico are characterized by montmorillonite, illite, and kaolinite, in decreasing order of abundance. Grim and Johns (1955) reported measurable quantities of chlorite, which they attributed to rapid diagenetic processes in the marine environment. However, subsequent studies by Morton (1966, 1972), Manheim and others (1972) and Sorenson (1975) among others, have shown conclusively that chlorite is neither being transported by Texas rivers, nor being formed diagenetically or authigenetically in Texas bays or along the inner continental shelf. Chlorite from sediment sources including the Mississippi River drainage basin has been reported, however, for the Northeastern Gulf of Mexico.

Surface Sediment Types (General)

Samples of approximately the upper 15-18 cm of shelf sediment were described at the time of collection, using a three-component classification of sand, mud, and shell. Visual estimates of the three components were used to describe sediment type, and sediment color was determined by comparison with a standard color chart. Pertinent information on other characteristics such as worm tube abundance, indications of bioturbation, presence of organic (plant) material, and anomalous features such as bay molluscs, caliche nodules, and rock fragments were also recorded.

Vertical sequences of sediment types collected in each sample were recorded to provide the most complete information possible. Consequently, descriptions of surface sediments are complex, reflecting the variability of modern and relict sediment types, and of related physical and biological processes. Because of the complex distribution of surface sediments, general sediment types (dominantly sand, abundant shell, relict sediment) are described in order to show regional trends of lithofacies and the occurrence of relict beach and deltaic deposits.

Dominantly Sand

Dominantly sand samples include the following sediment types and vertical sequences: sand, muddy sand, sand over muddy sand, muddy sand over sand, shelly sand, and muddy shelly sand. Other samples, with a greater estimated volume of sand than mud, were also included, but these samples were generally identified either by description (thin veneer of mud over sand), or by actual thicknesses of individual sediment layers.

Abundant Shell

Samples with abundant shell include the following types: shell gravel, sandy shell, muddy shell, shelly sandy mud, sandy shelly mud, muddy shelly sand, and shelly muddy sand. Samples described with shell as a modifier are the most common sediment types in the abundant shell category.

The regional distribution of abundant shell in bottom sediment samples reflects modern and relict physical and biological processes; this classification, however, does not discriminate between all modern and relict sediments. The identification of gravel size terrigenous clastics and brackish-water species, however, provides a basis for distinguishing modern, palimpsest, and relict sediments.

Relict Sediment

During sampling operations it was apparent that some samples were modern, while others were clearly relict. By definition, relict sediments are not in equilibrium with extant physical processes, but are sediments deposited under pre-existing conditions (Emery, 1968) that are different from modern environments. The reworking and mixing of relict and modern sediments, however, creates a transitional group of sediments (palimpsest) that cannot be distinguished from some relict sediments. For example, the erosion of relict shelly mud and its incorporation with modern shelf sandy mud yields a sandy shelly mud that can be transported by modern processes. In the strictest sense this mixture would be palimpsest because it is in equilibrium with modern shelf processes, but it would be difficult to distinguish such a mixture from a relict sandy shelly mud.

For the purposes of this study the term relict sediment describes only those samples containing material that was considered "in place" and not reworked. Consequently, the relict sediments most easily identified are generally firm oxidized muds and sandy muds with root casts. Exceptions are clean, well-sorted, gravel-size deposits comprised of shell, caliche nodules, and rock fragments. These clean gravels are interpreted as relict beach deposits because of their similarity to modern beaches east of High Island, at Sargent Beach, and west of the Colorado River on Matagorda Peninsula.

Perhaps the most important reason for mapping relict sediments is that the stiff muds have engineering properties that are vastly different from modern muds. In general, occurrences of these stiff relict muds can be predicted and this predictive capability should be useful in evaluating inner shelf activities affected by engineering properties. For the same reasons, encrusted or thinly veneered outcrops of calcite cemented sand, mud, and shell are of equal or greater importance; however, a paucity of areal control precludes mapping specific locations of indurated sediments. At the present, they can best be predicted by the occurrence of highly irregular bathymetry charted on the 1938-39 smooth sheets. The pinnacles, knolls, and ridges represent erosional remnants of relict sediments that have been preferentially cemented. Some linear trends of rocks are clearly related to potentially active faults whereas others are not. The most thoroughly studied indurated outcrops on the inner shelf are Freeport Rocks (Curray, 1960; Winchester, 1971) and the 7½ fathom reef (Thayer and others, 1974) north of Mansfield Channel. Despite the lack of confirming data, similar rocks probably crop out over much of the inner shelf southward from the vicinity of Mansfield Channel as suggested by irregular bathymetry and occurrence of rock fragments among backbeach sediments on South Padre Island.

Pinnacles, knolls, and ridges on the continental shelf have received considerable attention and have been attributed to a multiplicity of origins. New sedimentological and geophysical data made available in the past few years demonstrate that many banks and ridges are lithologically, structurally, and morphologically dissimilar. An important conclusion arising from these data is that no single theory satisfactorily explains the apparent multiple origins of the bathymetric irregularities. In the absence of geophysical data Shepard (1937) mistakenly interpreted most bathymetric highs on the continental shelf as surficial expressions of salt domes. This misconception was perpetuated by Lankford and Curray (1957) who may have mistakenly interpreted Quaternary sediments as mid-Tertiary in age because of reworked microfauna in otherwise unfossiliferous deposits. Rusnak (1960) suggested that ridges on the south Texas inner shelf were surficial expressions of barrier islands and distributary channels. In the same volume, Curray (1960) held to the belief that shelf banks with more than two fathoms relief were related to salt domes but he also recognized that many banks with less relief were of different origins. Curray proposed that these lower relief features were indurated Quaternary shoreline deposits. While this interpretation appears to be valid for some banks, such as Freeport rocks, we now know that many banks on the inner shelf are lithic erosional remnants, not necessarily of marine origin, and many are controlled by faults.

Distribution of Sediment Types

Dominantly Sand

Offshore extent of dominantly sand sediments varies greatly along the Texas coast. Except for a thin band of beach and upper shoreface sand, the upper coast from Sabine Pass to Bolivar Roads is essentially void of sand; shelf mud is the most extensive sediment type. One small area of muddy shelly sand (probably relict) is located at the outer limit of the inner shelf near Sea Rim State Park.

Sand sediments are patchy from Bolivar Road to approximately 8 miles (13 km) west of the Colorado River. Greatest concentrations are along Galveston Island and Follets Island, from the Brazos River to Cedar Lakes, and for 11 miles (17.6 km) east of the Colorado River on Matagorda Peninsula. Along this regional segment of the coast, dominantly sand sediments extend less than 2 miles (3.2 km) offshore. Extensive mud deposits are located in the vicinity of Freeport Harbor, off the mouth of the Brazos River, along Sargent Beach, and in the vicinity of the Colorado River.

In the same region, an arcuate trend of sand associated with relict sediment extends from Matagorda Peninsula to 11 miles (17.6 km) off Freeport. Sand is relatively continuous along the remainder of the Texas Coast. It extends progressively farther offshore from Matagorda Ship Channel to the area of maximum extent at the Willacy-Cameron County line on South Padre Island; the offshore extent decreases markedly, however, toward the mouth of the Rio Grande. About 5 miles (8 km) north of Mansfield Channel, a sheet of sandy sediments extends 8 to 9 miles (12.8 to 14.4 km) offshore. South of Mansfield Channel sandy sediments extend as far as 11 miles (17.6 km) offshore, but in this area sandy sediments are generally discontinuous.

Offshore changes in sediment type are least complicated from Malaquite Beach to just south of 27^{o}N latitude, where shelf sediments grade from sand to muddy sand and from sandy mud to mud in bands subparallel to the shoreline. This area also has the most extensive blanket of mud without substantial quantities of sand or shell, which may be attributed to a lack of discharge from fluvial systems and tidal inlets. It also suggests either that seaward transport of sand by storms is minimal at present in this area, or that mud deposition is substantially greater. When viewed separately, the continuous band of sand adjacent to the shoreline exhibits seaward projections oriented northward from the Rio Grande to Cedar Bayou on Matagorda Island. In contrast, offshore protrusions of dominantly sand sediments show a bimodal distribution, suggesting important differences in the direction of net sediment transport between the wind-driven longshore currents adjacent to the shoreline, and the currents operating farther seaward on the inner shelf.

Abundant Shell

Sediments containing abundant whole shells and shell fragments are patchy over most of the inner shelf. Typically, shelf samples from the Colorado River to Yarbrough Pass lack abundant shell material. The greatest concentration of shell occurs from south-central Padre Island to South Padre Island, an area extending roughly 20 miles (32 km) on either side of Mansfield Channel. In this area shell concentrations are continuous, but are generally restricted to the outer 6 miles (9.6 km) except at the northern limits, where the trend comes to within 3 miles (4.8 km) of the shoreline. North of the Colorado River, abundant shell is closely related to relict sediments.

Although a few samples from inlet areas have abundant shell, most samples adjacent to inlets and river mouths contain only minor amounts of shell material. Furthermore, there is little correlation between the shelf areas of abundant shell, and shell beaches such as those on Sargent Beach, Matagorda Peninsula east of Greens Bayou, and Big Shell and Little Shell beaches on central Padre Island.

Relict Sediment

There is good correlation between the occurrence of offshore relict sediment and the onshore distribution of fluvial-deltaic depocenters. From Rollover Pass to Sabine Pass the relict sediments represent exposures of the Pleistocene Beaumont Formation. In the vicinity of the Holocene Brazos-Colorado delta, the relict sediments follow the same arcuate trend as the dominantly sand and abundant shell samples. Similarly, relict sediments associated with the ancestral Rio Grande delta were encountered south of Mansfield Channel. In the interdeltaic areas, relict sediments are rare and limited to a few samples, except for two small areas of relatively continuous relict sediment off Galveston Island. This distribution pattern suggests that modern sediments are probably thickest between Pass Cavallo and just south of Yarborough Pass.

Sediment Color

Color of sediment varies according to depth, sediment type, and whether the material is of recent origin or is relict. The upper 2 cm of most samples exhibited an oxidized layer of yellowish brown (10YR4/2) water-saturated mud. A similar thin surface layer was described by Nelson and Bray (1970). The underlying muds and dominantly muddy sediments are olive gray (5Y4/1), dark greenish gray (5GY4/1, 5G4/1), and greenish black (5GY2/1). The relict muds, however, display a variety of colors due to alteration of their original colors by burrowing organisms, iron fixation by plant roots, and oxidation during subaerial exposure. Widely varying tones of gray (5Y5/2, 5B5/1, 5G6/1, 5G8/1) and brown (5Y5/6, 5YR6/4, 5YR4/4, 10YR4/2, 10YR5/4) are common colors for relict muds, but grayish red (10R4/2), blue green (5BG5/2), and olive (10Y6/2) also occur. The clean sands are also yellowish brown (10YR4/2), but increased amounts of mud, organic material, or heavy minerals in conjunction with reducing conditions cause the sand to be dark gray (N3, N4) or greenish black (5GY2/1, 5G2/1).

Relationship of Sediment Types to Physiography and Bathymetry

Fathometer profiles recorded simultaneously with sampling, as well as published navigation charts and smooth sheets, indicate that much of the inner shelf is a smooth, low-sloping surface with increased gradient across the upper shoreface. The shelf widens considerably from south to north, and the shoreface gradient is more distinct along the central and south Texas coast.

Topographic features control sediment type in several areas. A linear ridge off the western half of Galveston Island in about 45 feet (13.7 m) of water is the site of high concentrations of coarser sediment, including sand and shell. Similar but less extensive ridges in the vicinity of Freeport Bank (Curray, 1960; Winchester, 1971) are also the sites of coarser-grained sediments. Perhaps the most distinct control of sediment type by a topographically high area occurs off South Padre Island where clean, well-sorted sand outlines a narrow ridge in 60 feet (18.3 m) of water trending oblique to the shoreline. Muddy sands are prominent gulfward of the ridge, while sandy mud with shell is most abundant on the lee or landward side.

Where the distribution of sediment type is not affected by fluvial discharge relict sediments or bottom topography, there is a general relationship between grain size and water depth. This is best illustrated between Aransas Pass and 27^{o}N latitude. In this zone of net sediment transport, increases in water depth are generally accompanied by decreases in grain size.

Comparison with Previous Studies

Although other regional studies have been conducted of the surface sediment distribution on the inner continental shelf, none of these previous studies exhibit systematic and close spacing of samples on the state submerged lands portion of the shelf. For example, reconnaissance sampling reported by Stetson (1953) included very few samples on the inner shelf because of the limited number of traverses from the Texas Coast (seven), the spacing of samples along each traverse (3.2 km), and the starting point for each traverse (in most instances, between 11.2 and 22.4 km offshore).

A similar study was conducted in the 1950's (see Curray, 1960), but again few samples were taken on the state lands portion of the shelf. Less than 100 samples were collected from the inner shelf, and more than half of these samples were obtained offshore from Matagorda and San José Islands. Despite the limited number of samples, several important trends delineated by that study were: (1) the general offshore gradation from sand to mud along the central and south-central portion of the coast; (2) the increased shell content and the predominance of sand between the Rio Grande and Mansfield Channel; and (3) the dominance of mud along the upper coast.

Other studies of shelf sediment have greater sample density but are limited to particular areas such as Sabine-High Island (Nelson and Bray, 1970), and Galveston Island (Bernard, and others, 1962). In general, the present data show close agreement with the general trends established by the previous work.

Specific Area Descriptions

Beaumont-Port Arthur Area

Shelf sediments in the Beaumont-Port Arthur area are dominated by both modern and relict mud. The modern mud blanket is only a few inches thick over much of this area and modern mud thickness generally increases offshore. As a consequence of the thin veneer of modern mud, cohesive relict mud crops out along the shoreline and on the sea floor between High Island and Clam Lake. Relict muds extend 9 miles (14.4 km) offshore in up to 40 feet (12.2 km) of water and commonly contain, or are overlain by, caliche which indicates subaerial exposure and soil formation. In a vertical sequence, the transition zone between modern and relict sediments contains sand and granule-size mud clasts that were derived from the underlying stiff mud. Vibracores show that erosional surfaces, mud cracks, and shell layers representing transgressive lag deposits sometimes overlie the relict mud.

A roughly linear trend of coarse sediment, probably also relict, occurs from 8 to 11 miles (12.8 to 17.6 km) offshore and for approximately 22 miles (35.2 km) westward from Sabine Pass. Along its western extremity, this trend coincides with a subtle topographic ridge. Most of the sediment landward of the coarser sediment trend is relatively homogeneous mud containing rare worm tubes and shell debris. Offshore from High Island surficial sediments are more diverse and patches of shelly mud and sandy mud are surrounded by the homogeneous mud previously described. Higher shell content appears to be related to the underlying relict muds, sands, and muddy sands that contain an abundant brackish-water fauna of *Rangia cuneata* and *Crassostrea virginica*.

Clean quartz sand deposits are thin and limited to a narrow strip parallel to the beach and upper shoreface. East of Sea Rim State Park, however, the beach is characterized by marsh and mud flat deposits. Although shallow water depths prevented sampling in this area, nearshore sediments west of Sabine Pass are most likely mud; this interpretation is supported by the observations of Turner (1903).

Whole valves, comminuted shells, and occasionally indurated and rounded rock fragments comprise the gravel-size fraction. These biogenic and inorganic gravels, however, are usually mixed with the terrigenous clastics.

Sediment types in spoil disposal areas and adjacent areas are not noticeably different. Thus, it appears that surficial sediments are not drastically affected by material dredged to deepen and maintain the navigation channel to Sabine Pass.

Two minor sediment sources supply the Beaumont-Port Arthur shelf area. Modern marsh and beach ridge deposits (Gould and McFarlan, 1959) as well as the earliest historical records for Sabine Pass (Morton, 1977b) indicate that mud is delivered to the area from southwestern Louisiana by westward-flowing littoral currents and from Sabine Lake by seaward-flowing currents generated by riverine discharge, astronomical tides, and wind. The deposition of mud and subsequent shoreline progradation and development of a broad mud flat also may have been enhanced by Sabine Bank, which acts as a submerged breakwater that dampens wave energy. Sediment production within the shelf area is attributed to biogenic contributions and reworking of relict sediments; however, these are minor components of the sediment budget.

Nelson and Bray (1970) used numerous closely spaced dredge samples and several short cores to delineate the surficial shelf sediments in the Sabine-High Island area. The patterns of modern and relict (Beaumont) sediments mapped by Nelson and Bray, and map patterns of the same area prepared for the present study are similar. Moreover, schematic cross-sections by Fisher and others (1973) showing relict mud on the shoreface west of Sabine Pass agree with the field conditions presented on the surface sediment map.

Houston-Galveston Area

The Houston-Galveston area exhibits diverse sediment types, but mud and sandy mud are predominant shelf sediments. Clean sand is limited to the beach and upper shoreface along Bolivar Peninsula whereas along Galveston Island and Follets Island sand generally extends more than a mile offshore where water depths are about 25 feet (7.6 m); the greatest extent of sand is associated with the ebb tidal deltas at Bolivar Roads and San Luis Pass. The muds are generally homogeneous and contain few shells and worm tubes; the worm tubes and burrows are usually filled with sand or muddy sand. In contrast, areas of sandy mud and patches of muddy sand are not homogeneous and they generally contain alternating layers of mud with other sediment types. Highest concentrations of shell material are also patchy and are generally associated with coarser sediment trends farther offshore. In a few places off Follets Island the normal grey shelf muds overlie red muds suggesting an earlier period of high rates of sedimentation from the Brazos River.

Stiff relict muds, probably Pleistocene, were encountered in only two areas, just offshore of Rollover Pass and near the entrance to Bolivar Roads. Cores taken from the inner shelf, however, indicate that the modern sediments are generally thin and overlie Pleistocene deltaic muds in this area. The trend of sandy sediment 7 to 8 miles (11.2 to 12.8 km) offshore from the western part of Galveston Island in about 48 feet (14.6 m) of water probably represents relict beach deposits. This trend also coincides with a topographic high which appears to be related to faulting in the shallow subsurface.

Gravel-size sediments are typically whole shells and comminuted shell debris with a few rock fragments and caliche nodules (samples 3007, 2964, 2897). Disposal areas for material dredged from the entrance channel to Galveston Harbor exhibit a variety of sediment types that are slightly more diverse and somewhat coarser nearest the channel.

Sediment supply to the Galveston-Houston area is minimal and generally limited to (1) sand and mud derived from updrift shoreline and shoreface erosion and (2) suspended sediment, principally mud, introduced from offshore and from the bays through two tidal inlets, Bolivar Roads and San Luis Pass. Sand supply and rates of sedimentation were probably higher when the Holocene Brazos-Colorado delta extended farther onto the shelf (Morton, 1977a) and riverine discharge was greater owing to higher rainfall during the past.

Mapping of shelf sediments off Galveston Island was previously conducted by Bernard, and others (1962). That mapping was based on two sampling transects perpendicular to the shoreline and a sediment classification with three types; sand, mud, and shell. The few samples and restricted classification permitted only gross distinctions in surface sediment variations. Despite these limitations, the map presented by Bernard and others shows a trend of beach and shoreface sand and offshore linear trend of sand and shell that are comparable to trends delineated by the present study.

Bay City-Freeport Area

Inner shelf sediments within the Bay City-Freeport area are composed predominantly of mud and sandy mud. The mud is generally homogeneous with little shell material and few worm tubes. Continuous areas and patches of muddy sand and sandy mud commonly comprise alternating layers of mud, sand, sandy mud or muddy sand. Some mud samples in the vicinity of the Brazos River exhibit a distinct color change where normal grey shelf muds overlie red muds attributed to the old Brazos delta that prograded shelfward following jetty construction at Freeport Harbor (Morton, 1977b). The Brazos River muds also contain a high proportion of silt. Sand is generally restricted to the beach and adjacent upper shoreface where water depths are less than 15 feet (4.5 m). Protrusions of sand beyond these limits occur near the Brazos and San Bernard Rivers and off east Matagorda Peninsula midway between Brown Cedar Cut and the Colorado River.

Whole and comminuted shells including the brackish water species *Rangia cuneata* and *Crassostrea virginica* make up the greatest proportion of gravel-size sediment. Other gravel-size constituents, which are relatively minor, include rock fragments and caliche nodules. Clean gravel deposits are rare and the gravel-size sediments are typically mixed with the terrigenous clastics.

Patches of sand, shell, rock fragments, and other coarse sediment are associated with an arcuate trend extending roughly from the Gulf shoreline east of the Colorado River to the most seaward limits of sampling offshore from Freeport. These coarser sediments are probably relict beach deposits that are partially buried by a thin blanket of modern mud. Along their western margin, these sediments overlie stiff relict muds that probably represent delta plain deposition associated with an ancestral Brazos-Colorado delta.

Sediment samples from spoil disposal areas adjacent to Freeport Harbor Channel are slightly sandier than surrounding sediments. The increased sand content is probably an artifact related to maintenance dredging of the navigation channel.

The inner shelf of the Bay City-Freeport area has more potential sediment sources than any other shelf area along the Texas Coast. The Brazos, San Bernard, and Colorado Rivers debouch directly into the Gulf of Mexico but bedload introduced by these three rivers is relatively minor compared to the suspended load. Moreover, much of the bedload transported by the Colorado River is deposited and trapped in the Colorado delta or within the low gradient channel dredged across Matagorda Peninsula in 1936 (Morton and others, 1976). Sediment discharge of the San Bernard River is relatively low owing to a small interior drainage basin that is contained wholly within the coastal plain. Of the three rivers, the Brazos River has the greatest sediment discharge reaching the Gulf, but the minor sand fraction from the Brazos and the other rivers is removed and transported alongshore by the wave energy and longshore currents in the area.

The surface sediment map suggests that maximum nearshore sedimentation associated with the Brazos River is represented by the blanket of mud that occurs within 7 or 8 miles (11.2 to 12.8 km) of the shoreline. The offshore extent of the mud blanket decreases to about 4 miles (6.4 km) off Brown Cedar Cut. Active deposition of mud also occurs off the mouth of the Colorado River. Except for the areas previously described, sedimentation rates over most of the area are very low, and palimpsest and relict sediments are predominant.

Inner shelf sediments in the vicinity of the Brazos River were also studied by Nienaber (1963) who used, among other things, Folk's (1954) sand, silt, and clay classification and grain-size parameters (moment statistics, sorting) which do not include shell content, to interpret the physical processes and geologic history of the sediments. Nienaber also emphasized control of the sediment distribution in certain areas by submerged topographic ridges and knolls associated with the relict deltaic plain. These topographic features, referred to as Freeport Rocks, were described in detail by Winchester (1971). The topographic highs are composed of calcite cemented sand, shell, and caliche nodules that Winchester interpreted as Holocene beach or offshore bar deposits composed primarily of sediment reworked from the underlying Pleistocene Beaumont Formation.

Port Lavaca Area

Distribution of shelf sediment types in the Port Lavaca area is related, in part, to bathymetry. Water depths for most seaward samples range from 66 to 80 feet (20 to 24 m). Nearshore sands grade offshore into muddy sands and sandy muds which, in turn, grade into muds. Offshore extent of sand and muddy sand increases southwestward from 2 miles (3.2 km) off Matagorda Peninsula to over 5 miles (8 km) off San José Island. These offshore distances correspond to water depths of 36 and 48 feet (11 and 14.6 m) respectively. Sand, especially in deeper water, may be overlain by soupy saturated mud deposited from suspension during quiescent periods, but storm waves and near-bottom currents are capable of entraining not only this veneer of mud but also some of the underlying sand.

Sediments containing gravel-size shell debris are not extensive. The two areas with abundant shell are off Matagorda Peninsula and the northern end of Matagorda Island. Cohesive relict muds were not encountered and although much of the coarser sediment (sandy muds) may be attributed to reworking of underlying relict material only one possible muddy beach deposit, now nearly buried, is suggested by the data. Samples taken at points 1833 and 1864 may be remnants of such a deposit.

A major reentrant of mud is located near Pass Cavallo where inner shelf gradient steepens in comparison to the surrounding bathymetry. Bioturbated muds contain little shell material, but worm tubes and sand-filled burrows are common. Sandy muds and muddy sands that extend to the seaward edge of the map are thought to be composite deposits of interbedded mud and sand attributed to modern shelf processes as well as stratification resulting from incorporation of underlying coarser relict sediment.

The homogeneity of samples taken near spoil disposal areas suggest that the distribution of shelf sediment types adjacent to Matagorda Ship Channel is not noticeably affected by dredging operations.

Fine grained sediments are delivered to the area from several external sources. Suspended sediment from Matagorda Bay is introduced primarily through Pass Cavallo and Matagorda Ship Channel. Other less important contributors of suspended sediment are longshore and cross-shelf currents. Spplies of bedload material to the inner shelf in the Port Lavaca area are negligible. Sand released by shoreline erosion and transported along the shoreface as littoral drift is the only identifiable source of bedload material, however, it is not a major contributor to shelf sedimentation in this area.

Corpus Christi Area

Shelf sediments in the Corpus Christi area are composed of sands and muds with muds being slightly more abundant than sands. Sediment types are controlled largely by bathymetry and position in relation to the shoreline. Grain size typically decreases offshore and passes gradationally from sand through muddy sand and sandy mud to mud. Sand and muddy sand typically are found 3 to 6 miles (4.8 to 9.6 km) offshore in 45 to 60 feet (13 to 18 m) of water. Muddy sands are most extensive offshore from Packery Channel and the southern end of Corpus Christi Bay. Muds generally occur along the most seaward portion of the inner shelf where water depths range from 70 to 80 feet (21 to 24 m); water depths increase progressively from north to south. The sandy muds are heterogeneous, and vertical sequences of alternating layers of sand and mud are common. In contrast to the sandy muds, the muds are usually homogeneous, completely bioturbated and contain little shell debris.

Most of the sediment sizes are fine sand or finer and the only gravel-size sediments are shell debris which represent less than 1 percent of the total sediment by volume. Most whole shells and shell fragments are of modern but small shelf species such as *Mulinia lateralis*. Shell material is less abundant than in adjacent areas and no relict stiff muds were encountered, suggesting greater thicknesses of modern sediment and higher rates of sedimentation than in adjacent areas. This observation is significant because the area is void of major sources for initial introduction of terrigenous clastics. Barrier islands (San José, Mustang, and north Padre Islands) separate the inner shelf from the mainland and only Aransas Pass, formerly a natural tidal inlet, and the recently (1972) constructed water exchange pass permit sediment exchange between the inner shelf and the uplands and bays. Sediment exchanged between the bays and shelf is almost exclusively in suspension, and sediment volumes are necessarily limited because of the low number of transportation pathways that presently exist and have existed in the geological past. The close proximity of shelf muds and sandy muds to Aransas Pass suggests that deposition of these fine-grained sediments has been actively influenced by currents issuing from the tidal inlet, especially strong currents produced by winter storms and tropical cyclones. Most coarse and fine shelf sediments, however, are transported to the inner shelf from laterally adjacent areas by cross-shelf and longshore currents. The Corpus Christi area encompasses the northern limits of the littoral drift convergence zone, consequently this area is receiving more transported shelf sediment than areas to the northeast.

Sediment types are more diverse within and immediately adjacent to the navigation channel through Aransas Pass but sediments exposed in nearby spoil disposal areas are similar in composition to surrounding shelf sediments.

On the basis of samples with spacing similar to that described herein, Shideler and Berryhill (1977) also mapped and reported greater proportions of mud to sand and general seaward decreases in grain size in sediments offshore from Mustang and north Padre Island.

Kingville Area

Muddy sediments are slightly more abundant than sandy sediments in the northern two-thirds of the Kingsville area. In general, grain size and bathymetry are closely related as illustrated by bands of sands, muddy sands, sandy muds, and muds oriented subparallel to the shoreline that reflect the systematic decrease in grain size offshore. From north to south in the sampling area most seaward water depths increase progressively from about 80 to 95 feet (24 to 29 m). Sands and muddy sands extend 3 to 6 miles (4.8 to 9.6 km) offshore in water depths ranging from 55 to 65 feet (17 to 20 m). Bands of muddy sands and sandy muds that separate the clean quartz sands from the homogenous muds are comparatively narrow and together average slightly more than three miles in width. There is a noticeable reentrant of mud located near Yarborough Pass where the homogeneous muds come within 4 miles (6.4 km) of the shoreline.

In contrast to the northern two-thirds of the Kingsville area, the southern third exhibits considerably coarser material. For example, shell gravel and shelly sand extend 8 to 10 miles (13 to 16 km) offshore beneath water as much as to 85 feet (26 m) deep. Gravel-size sediments are predominantly shell including whole valves and large fragments of *Rangia cuneata*, *Crassostrea virginica*, and *Mercenaria mercenaria* but rock fragments and caliche nodules are also common. Concentrations of abundant shell are located in a linear trend 4-6 miles (6.4-9.6 km) offshore and south of Yarborough Pass but the largest area with the greatest concentrations of shell is found in an arcuate trend. Seaward limits of this trend probably represent relict beach deposits that subsequently were transgressed as the Rio Grande delta subsided. Stiff relict muds that probably are outcrops of Pleistocene deltaic deposits were encountered only at two stations offshore from Malaquite Beach. Shelf sediment characteristics and inferred thicknesses suggest that rates of sedimentation are slightly higher in this area than adjacent areas to the south. Areas of abundant shell mark the sites of negligible sedimentation.

The relationship of Big Shell and Little Shell beaches to areas of abundant offshore shell is interesting because the shell beaches and shelly areas offshore are not necessarily adjacent. The arcuate trend of abundant shell developed along the outer margin of the Brownsville-Harlingen area becomes continuous with the southern limits of Big Shell beach. The linear trend of abundant shell debris extending south from Yarborough Pass is isolated from the shoreline by 4 miles (6.4 km) of sediment with very low concentrations of shell. Shell concentrations are also very low in shelf sediments adjacent to Little Shell beach.

Homogeneous sands and muds, in particular in the central and northern parts of the area and the reentrant of mud near Yarborough Pass are attributed to the extant shelf regime and convergence of littoral drift and shelf currents. This segment of the Texas Coast is farthest removed from tidal inlets and river mouths and much of the sediment being deposited is derived from the suspended load transported by along-shelf and cross-shelf currents. Most of the coarse fraction is delivered to the area from adjacent shoreface and shelf areas by littoral currents. Another mechanism for the introduction of sand onto this segment of the Texas inner shelf was proposed by Hayes (1967) who mapped and described a coarse graded bed and sand layer associated with hurricane Carla.

These sediments were derived from the marine environment, transported onto Padre Island by washover and eolian processes, over a relatively long period of time and then recycled back into the marine environment. by erosion during the storm. The graded bed covered over 300 sq miles (777 sq km) and extended offshore more than 15 miles (24 km). Hayes suggested that density currents initiated by increased hydraulic head from storm surge were the transporting agents responsible for the graded bed. Storm layers a few cm thick such as the one described by Hayes are easily incorporated into the preexisting sediment by burrowing organisms and their preservation is largely dependent on subsequent rates of sedimentation.

Brownsville-Harlingen Area

Shelf sediment types are highly diverse in the Brownsville-Harlingen area and trends are poorly defined. Sands and muddy sands are more abundant than sandy muds and muds. A relatively clean, continuous sheet of fine grained sand extends one to seven miles offshore from the shoreline. The sand areas generally grade into muddy sands.

In this area, active sedimentation generally occurs within approximately 5 miles (8 km) of the shoreline where water depths range from about 60 to 70 feet (18 to 21 m). Near the mouth of the Rio Grande mud is being deposited over an area with a radius extending roughly 5 miles (8 km) offshore and downdrift (northward). However, sand and muddy sand are the most common sediment types presently being transported in the nearshore zone. They extend offshore from one to nine miles with greatest distances located off Mansfield Channel. The abundance of sand and muddy sand suggests relatively high energy and an abundant supply of bed-load material. This was probably true during the recent geological past when the Rio Grande was an important source of sediment for this part of the inner shelf. Under present conditions, however, the Rio Grande is principally a source of fine-grained suspended sediment as are other sources of sediment including Laguna Madre and the outer continental shelf.

Except for the nearshore trend of quartz sand most shelf sediments are heterogeneous with the upper few inches being slightly coarser than the underlying muds. High concentrations of shell material also contribute substantially to the inhomogeneity. Large areas containing shell debris are generally found along the outer perimeter of the area and seaward of the sands and muds where water depths range from 90 to 95 feet (27 to 30 m). Sandy and muddy shell, shelly muds, and shelly sands characterize the most seaward sediments. Shell debris constitutes up to 33 percent of the total sediment in a few samples; but most samples contain less than 10 percent shell debris by volume. Gravel size sediments include caliche nodules, rock fragments, and shell debris, with the latter being the most abundant. Anomalous mollusc species in conjunction with inorganic gravel components point toward a relict origin for the coarser shelly sediment. Although they presently occur beneath relatively deep water this coarser material probably represents relict beach and shoreface deposits associated with previous shorelines that were contemporaneous with the latest transgressive phase of the Rio Grande delta. This part of the delta underlies the present shelf surface sediments. Outcrops and near-surface subcrops of stiff muds are scattered throughout the area south of Mansfield Channel and these stiff muds probably are relict delta plain deposits of the ancestral Rio Grande delta. They contain oyster shell and other brackish water fauna such as *Rangia* and some caliche nodules.

In some areas sediment type is controlled by topography. For example, a linear trend of clean quartz sand oblique to the shoreline is situated over a topographic ridge that is controlled by recent faulting on the inner shelf.

In contrast to some other areas, the presence of homogeneous sands suggest that maintenance dredging operations are not important in determining the sediment type in disposal areas adjacent to Brazos-Santiago Pass and Mansfield Channel.

In a broadly descriptive study Lohse (1952) used heavy minerals, grain-size data excluding shell material, and wind vectors to interpret the general directions of sediment transport in the vicinity of the Rio Grande delta. The northern third of Lohse's study area falls within the southernmost 20 miles (32 km) of the Texas inner shelf. In that area Lohse recognized an increase in sand northward from Brazos-Santiago Pass and offshore decreases in grain size that were modified by local irregular topography.

FAULTS AND SALT DIAPIRS

Tectonic Elements

Regional tectonic features along the Texas Coastal Plain include the Rio Grande and East Texas Embayments, which are separated by the San Marcos Arch (Murray, 1961). Within this broad structural framework are smaller sags and structural highs. The Rio Grande Embayment and San Marcos Arch apparently exerted the greatest control on Late Quaternary sedimentation, as indicated by thickening of sediments offshore and along depositional strike toward the Rio Grande. By contrast, sediment thickening is less noticeable northeast of the San Marcos Arch and along the upper Texas coast changes in stratigraphic thickness are imperceptible. The San Marcos Arch also marks the limits of salt domes and other diapiric structures, which prevail over much of the northwestern Gulf of Mexico (Garrison and Berryhill, 1970). A much broader perspective of the history and development of the Gulf of Mexico was presented by Garrison and Martin (1973).

Faults

Both potentially active and relatively inactive shallow subsurface faults were interpreted from geophysical records based on bedding offsets and discontinuities in seismic records (fig. 5). Potentially active faults were defined by their position near the sea floor. Faults were mapped as potentially active if they exhibited even minor offset within 50 feet (15 m) of the sea floor. This arbitrary upper limit was necessary because fault displacement decreases rapidly upward in the sediment column, and because displacements of a few feet or less are below the resolution of the seismic recording devices. Thus, it is possible that active faults with displacements of a few feet intersect the sea floor, but could not be detected with available data. On the other hand, while these faults are not necessarily active, they may have been active in the recent geological past, and they are considered potentially active because of their close proximity to the sediment-water interface.

The faults are normal, en echelon growth faults subparallel to the coast. Most faults are down-to-the-basin, but up-to-the-basin faults are also common. These faults belong to the Willamar system (Murray, 1961), a relatively young fault system extending onshore in the vicinity of the Rio Grande. Many of the faults are nearly vertical, and apparent dips are generally greater than 70^{o}.

Fault density, continuity, orientation, and displacement are diverse along the coast. For example, faulting is concentrated: (1) off South Padre Island between the Rio Grande River and the Mansfield Channel; (2) off Mustang and North Padre Islands between Malaquite Beach and Port Aransas; (3) between the Colorado River and Bolivar Peninsula; and (4) near Sabine Pass. Because of this diversity, faulting will be discussed by geographic area.

Rio Grande Delta

Shallow subsurface faulting along the southern part of the coast is closely related to the geographic limits of the Holocene Rio Grande delta. Faults in this area are extensive, some being laterally continuous for up to 17 miles (27 km). Displacements range from 10 to 110 feet (3 to 33 m), but most displacements are between 10 and 30 feet (3 and 9 m). The coincidence of potentially active faults with bottom topography suggests that the oblique linear ridges off Padre Island are fault-related (see Brownsville-Harlingen map). Perhaps these ridges resulted from preferential cementation along the fault plane by subsurface fluids. Differential erosion of the sediment, controlled by the degree of cementation, caused the more resistant sediments to stand in topographic relief above the sea floor. Similar ridges of cemented sediment on the inner shelf that apparently are not fault-related were studied by Thayer and others (1974).

Central Coast

Faults offshore Mustang and North Padre Islands are oblique to the shoreline, and the most extensive faults are arcuate in plan and generally down-to-the-basin. The most extensive faults in this area are 7 to 10 miles (11 to 16 km) long, but less extensive faults are also common. Displacements range from 10 to 50 feet (3 to 15 m), and larger displacements are associated with more extensive faults.

Brazos-Colorado Delta

Faults between the Colorado River and Galveston Island are related to ancestral deltas formed by the combined Brazos and Colorado Rivers. The majority of faults are roughly parallel to the shoreline, although some are nearly perpendicular. Faults range up to 10 miles (16 km) in length, but most are between 2 and 5 miles (3.2 and 8 km) long. Apparent displacements for these faults at depth are commonly between 10 and 30 feet (3 and 9 m).

Apparently the bathymetric high charted offshore from the western end of Galveston Island, which controls nearby surface sediment types, is fault-related (see Galveston-Houston sheet). In fact, comparing the position of potentially active faults with the surface sediment distribution suggests that subtle sea-floor irregularities, and larger-scale sea-floor relief caused by active faults, are both responsible for some of the variability in sediment types.

Upper Coast

Faulting east of Galveston Island is sparse, and it is concentrated in two areas, near the southern end of Bolivar Peninsula and west of Sabine Pass. Faults are similar in both areas. The most extensive faults are 5 miles (8 km) long, but most are 2 to 3 miles (3 to 5 km) long. The faults, which are generally parallel to the coast, have displacements up to 50 feet (15 m), but displacements of 10 to 30 feet are more common.

Origin of Faulting

Over the past few decades, several theories explaining the origin of regional Gulf Coast faulting have been advanced. Most of the theories centered around the sedimentation style within the basin, and the facts that (1) thick clastic wedges of fluvial-deltaic and shallow marine sediment are developed with basin subsidence, and (2) the clastic wedges overlie a mobile salt bed. The earlier theories, recognizing that many of the faults merge with bedding planes at depth, proposed that on gravity sliding was the main mechanism of faulting. Gravity sliding clearly is responsible for some of the faulting, for example at the shelf break, but other mechanisms may also be important. Although basement involvement has been documented in some instances (Shelton, 1968), most of the theories do not require basement tectonics, and the faulting generally is restricted to the sediment column. In fact, some faults are known to die out at depth.

More specific mechanisms for the origin of faulting that have been proposed include differential sediment compaction (Carver, 1968), salt tectonics (Quarles, 1953), and deformation related to the geopressured shale section common throughout the northern Gulf of Mexico (Bruce, 1973). All of these theories have merit, and it is doubtful that a single mechanism is responsible for all faulting. It appears rather that these mechanisms are interdependent and cannot be completely isolated.

Salt Diapirs

Piercement structures (Braunstein and O'Brien, 1938) that penetrate the sediment column near the sea-floor on the inner shelf (fig. 6) are restricted to an area between Sabine Pass and San Luis Pass. Deep-seated massifs in these and other areas are also marked by structural highs with roughly circular closure, but mapping was limited to those diapirs whose mobile sediment core appeared on the geophysical records. The three structures that exhibited these characteristics are salt spines, but similar features also could be caused by shale diapirs. Diameters of the three diapirs are generally 2 miles (3.2 km) or less and depth to the mobile sediment ranges from less than 100 feet (30 m), to more than 2,000 feet (600 m).

The salt dome off San Luis Pass (fig. 6) was studied and described by Nettleton (1957) who used results from shallow drilling and geophysical surveys to map the depth to salt, salt thickness, and shape of the dome. Information from drilling for hydrocarbons by the petroleum industry documented salt cores for the other two diapirs mapped on the inner shelf of Texas. These diapirs, located in Galveston Block 144-L and High Island Block were listed as salt domes by Cockerham and others (1956).

Faults associated with salt diapirs typically comprise a peripheral system of horsts and grabens with radial fault patterns in map view. The relative ages of salt movement are not clearly evident but folding and intrusion of Late Pleistocene sediments suggest a maximum age for the most recent movement. The mechanisms for activation of salt movement were probably contemporaneous with periods of rapid sediment influx and delta progradation. These conditions existed during the Late Pleistocene.

Sea-floor expression of diapiric structures is imperceptible on fathometer records; however, surface sediment maps show subtle changes in sediment type near these structures, which suggests some change in sea-floor slope. Changes in bathymetry related to faults are certainly more evident than changes related to diapiric structures.

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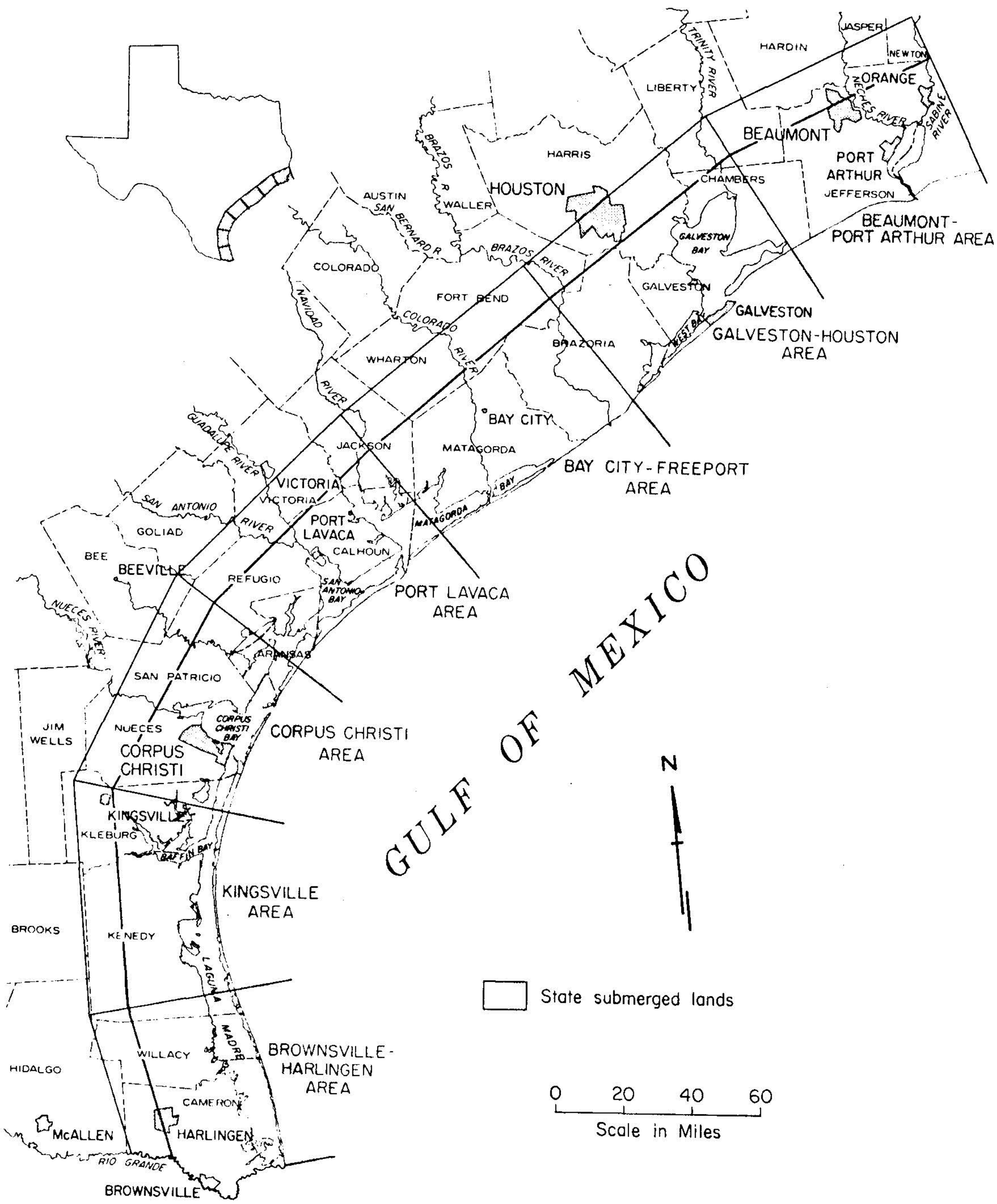
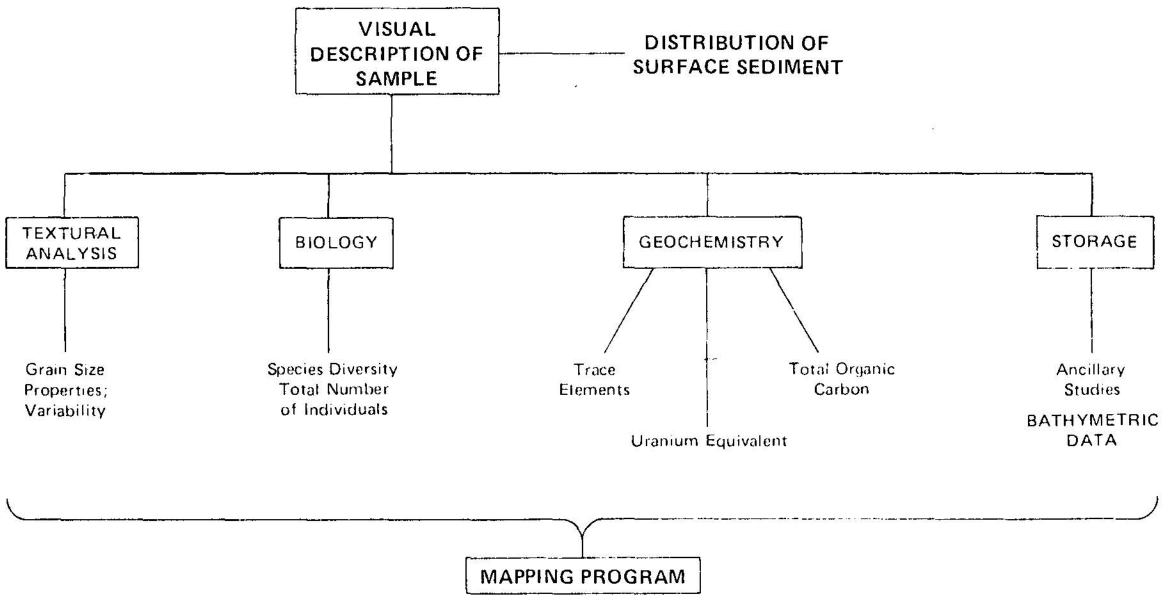

GULF OF MEXICO
BEAUMONT-PORT ARTHUR AREA
GALVESTON-HOUSTON AREA
BAY CITY-FREEPORT AREA
PORT LAVACA AREA
CORPUS CHRISTI AREA
KINGSVILLE AREA
BROWNSVILLE-HARLINGEN AREA
HOUSTON
BEAUMONT
PORT ARTHUR
ORANGE
GALVESTON
BAY CITY
VICTORIA
PORT LAVACA
BEEVILLE
CORPUS CHRISTI
KINGSVILLE
McALLEN
HARLINGEN
BROWNSVILLE
N
State submerged lands
0 20 40 60
Scale in Miles

Figure 1

SAMPLE AND SAMPLE ANALYSIS PROGRAM



GEOPHYSICAL PROGRAM

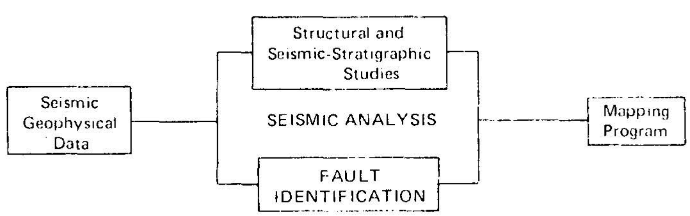


Figure 2

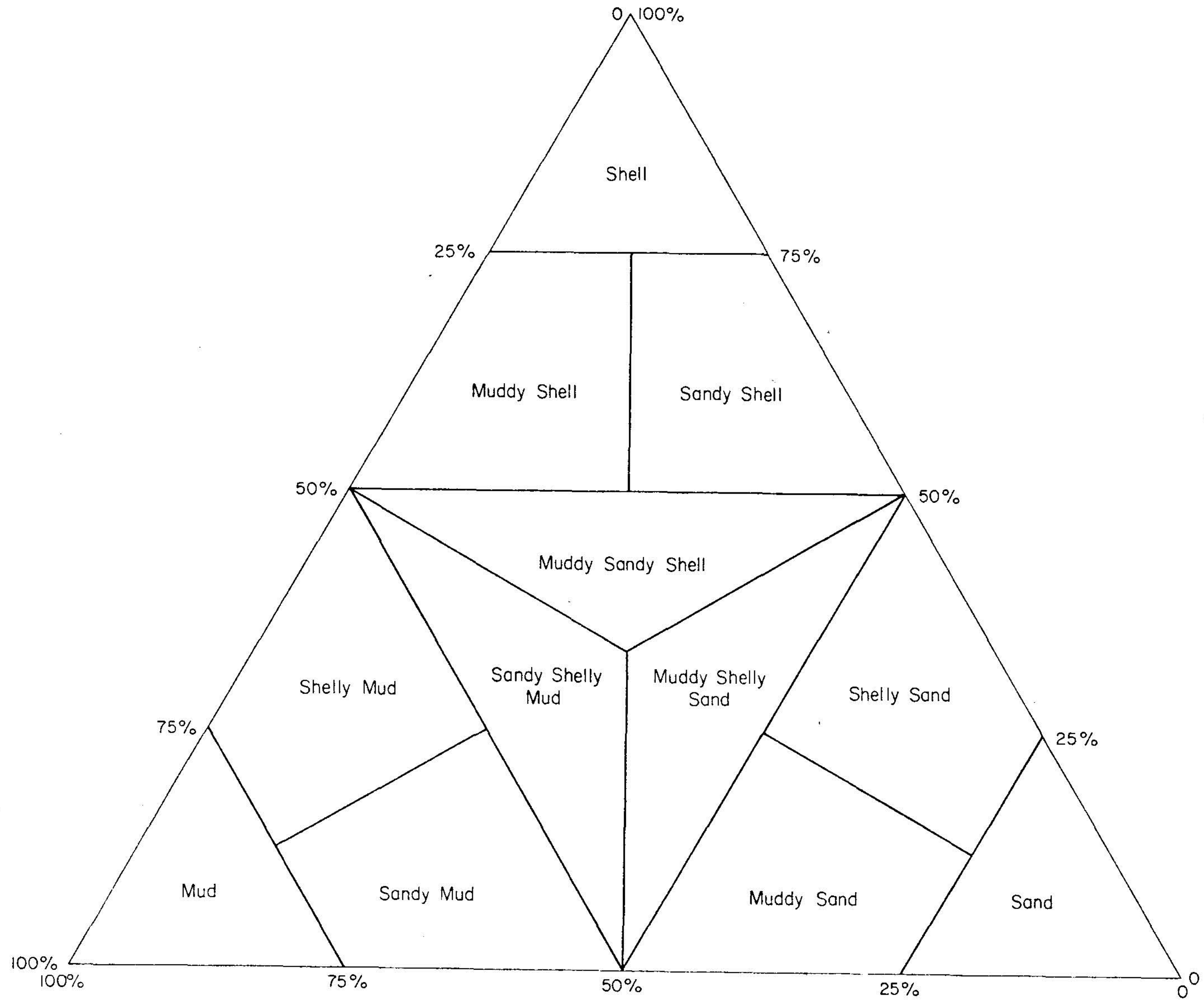


Figure 3. Classification of sediment types based on visual analyses, Texas submerged lands.

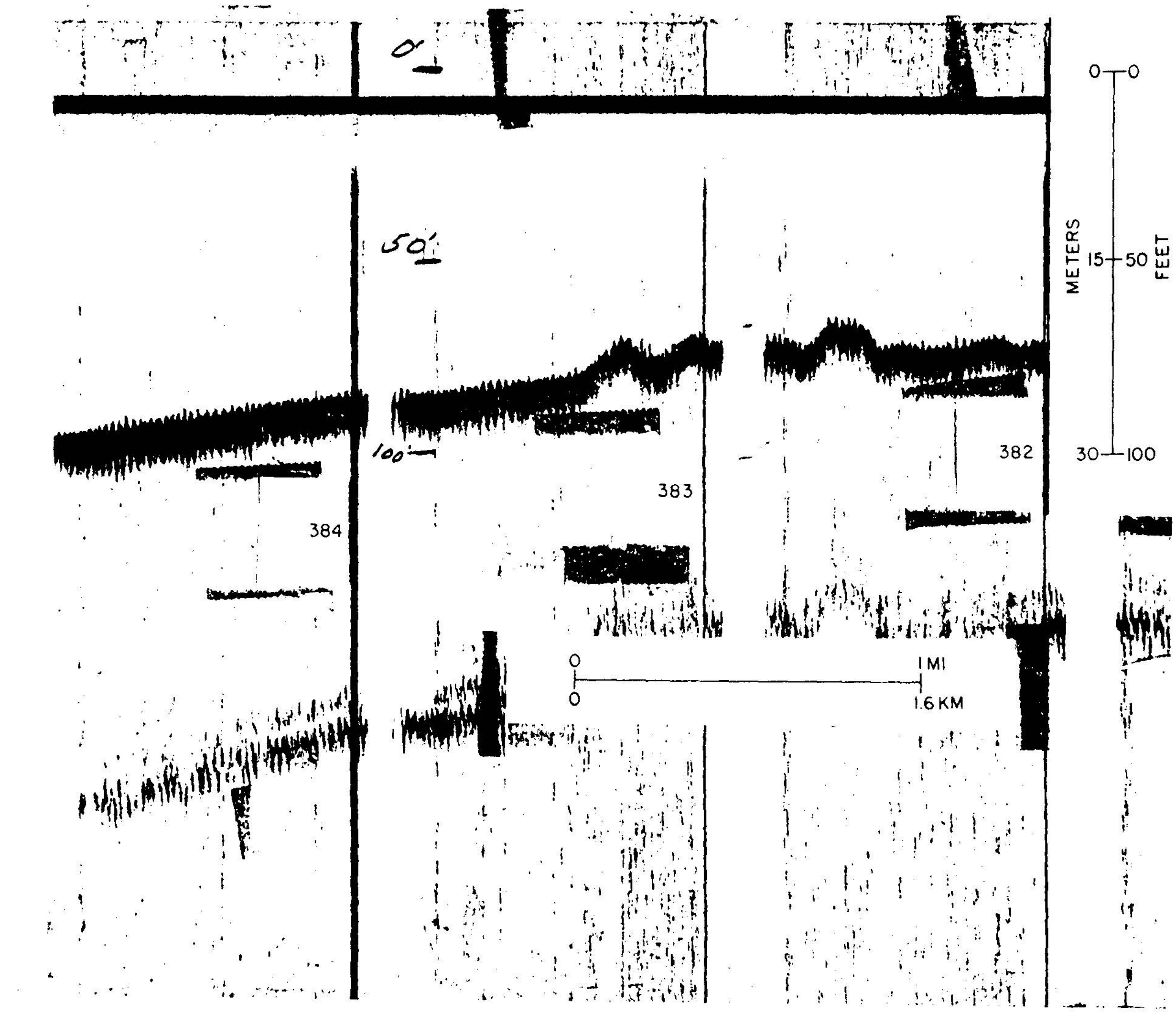


Figure 4

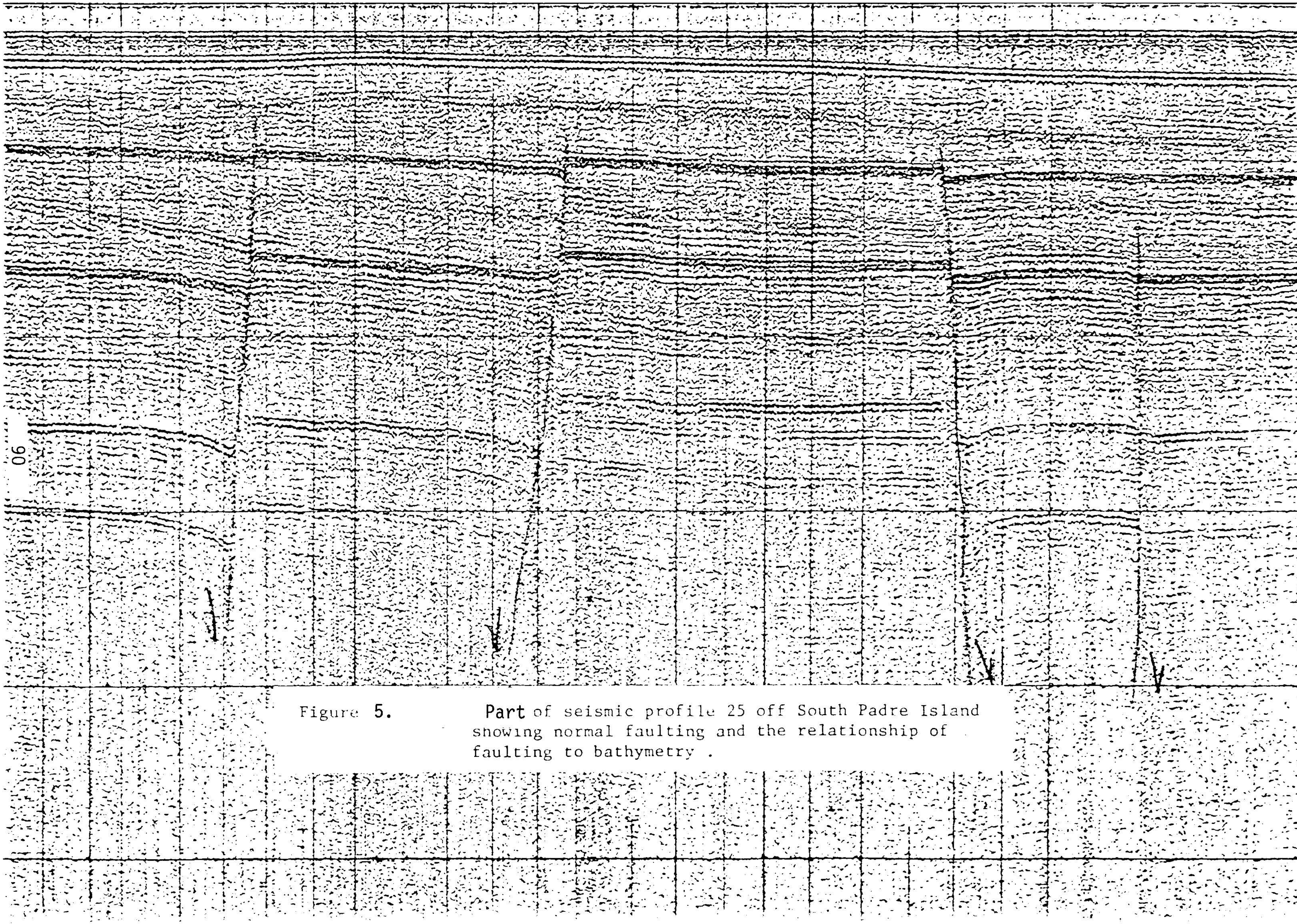


Figure 5. **Part** of seismic profile 25 off South Padre Island showing normal faulting and the relationship of faulting to bathymetry .

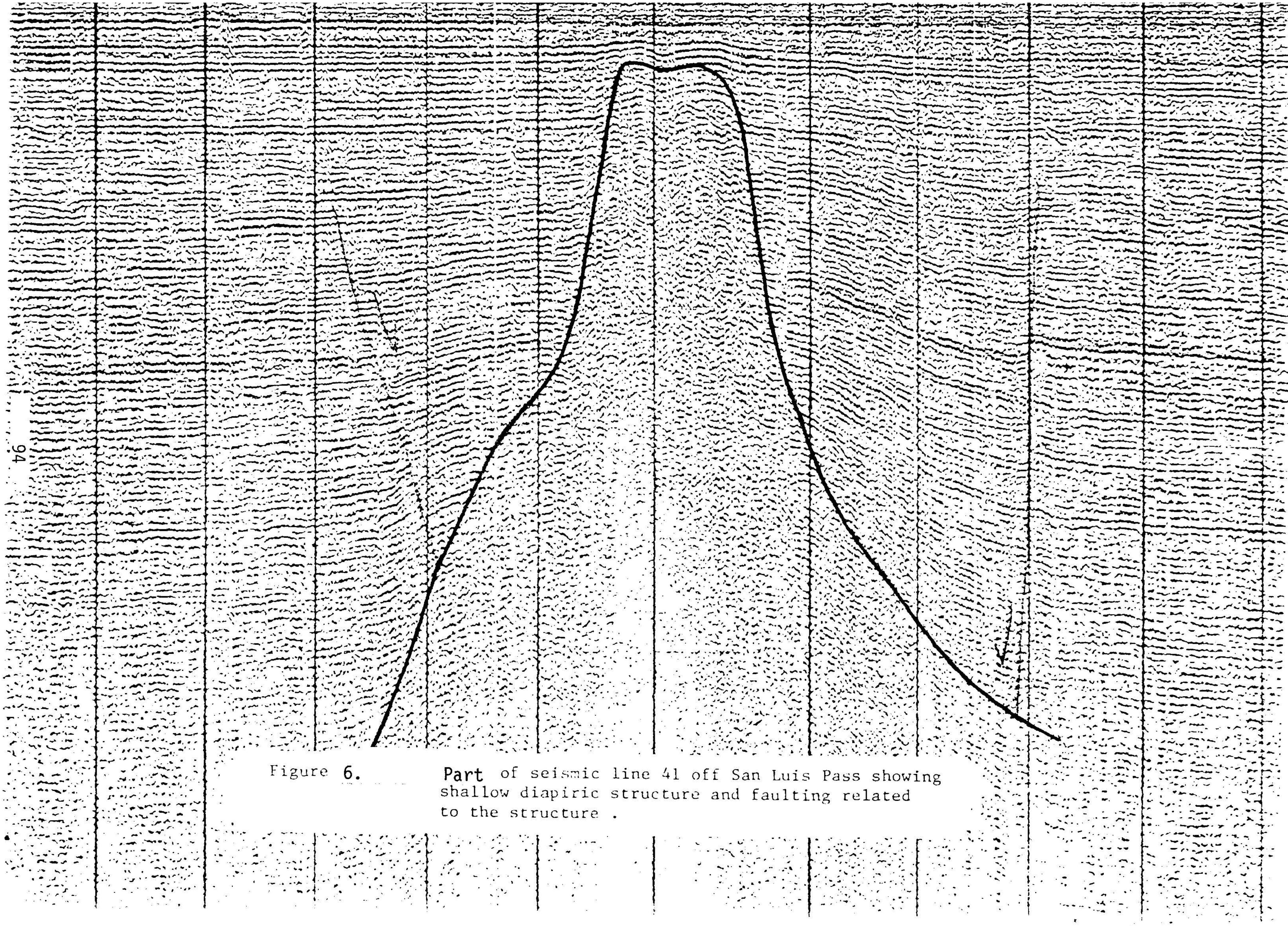


Figure 6. **Part** of seismic line 41 off San Luis Pass showing shallow diapiric structure and faulting related to the structure .

Table 1

Tasks	Bays	Shelf	Total
Total Samples Collected	3197	3500	6697
Geophysics: Nautical miles of high resolution seismic	600	3500	4100
Analyses:			
Sediment textures	Initiated: Complete in FY 78-79		
Geochemistry			
Total Organic Carbon	788	2300	3088
Trace Metals	357	750	1107
Biology	280	300	580
Seismic Interpretation	Initiate in FY 78	Fault Mapping completed; Stratigraphic analysis initiated	

Table 2

	Beaumont-Port Arthur		Galveston-Houston		Bay City-Freeport		Port Lavaca		Corpus Christi		Kingsville		Brownsville-Harlingen	
	Bays	Shelf	Bays	Shelf	Bays	Shelf	Bays	Shelf	Bays	Shelf	Bays	Shelf	Bays	Shelf
Surface Sediment	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Total Organic Carbon			X		X		X*	X	X*	X	X	X	X	X
Biologic Assemblages	X		X				X		X		X		X	
Faults & Diapiric Strs.		X		X		X		X		X		X		X
Barium								X		X		X		X
Chromium								X		X		X		X
Iron								X		X		X		X
Lanthanum								X		X		X		X
Lead								X		X		X		X
Manganese								X		X		X		X
Strontium								X		X		X		X
Vanadium								X		X		X		X
Zirconium								X		X		X		X

*partially completed