ASSESSMENT OF SAND RESOURCES IN THE TRINITY SHOAL AREA, LOUISIANA CONTINENTAL SHELF

Submitted to the
U.S. Minerals Management Service
Through the
Bureau of Economic Geology,
The University of Texas at Austin

Cooperative Agreement No. 14-12-0001-30387

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

This research was funded by the U.S. Department of the Interior, Minerals Management Service through the Bureau of Economic Geology at The University of Texas at Austin, Cooperative Agreement Number 14-12-0001-30387. Additional funding for collection of the high-resolution seismic profiles and vibracores was provided by the U.S. Geological Survey and the Lousiana Department of Natural Resources. We thank K. Westphal, T. McLaughlin, and the Louisiana Geological Survey Cartographic Section for drafting the figures. D. Davis and M. Byrnes reviewed the report. P. Connor performed the grain texture analyses, and S. Bollich and S. Sullivan typed the manuscript.

ABSTRACT

The sand resources of Trinity Shoal, one of four major sand shoals found on the Louisiana continental shelf, were assessed for their suitability as construction aggregate in coastal erosion control projects. Approximately 800 line-km of high-resolution seismic profiles and 30 vibracores were acquired and analyzed. From this data, an isopach map, geologic cross-sections, and grain texture analyses were made. Shoal morphology was divided into four zones, and six distinct depositional environments were identified for both the transgressive and regressive components of the sand body.

Based on the results of this study, it is concluded Trinity Shoal possesses high-quality sand suitable for coastal erosion control projects. Shoal morphology and sand thickness patterns illustrated in the isopach map and geologic cross-sections can be used to target sand dredging sites. Extending seismic and vibracore coverage to the west (of the present grid) will help better define Trinity Shoal's sand volume and areal extent.

INTRODUCTION

Louisiana's coastal zone is faced with the most critical land loss problem in the United States. Headland beaches and barrier islands are eroding at rates of 2 m/yr to 5 m/yr and 10 m/yr to 15 m/yr, respectively. The Isles Dernieres barrier island arc is forecasted to disappear by the year 2017 (McBride et al. 1989), accelerating wetland loss in the Terrebonne estuary. Barrier island restoration and beach replenishment techniques are recognized as feasible solutions to cost-effective coastal erosion control in the United States, even though they require large amounts of construction aggregate for beach, dune, and back-barrier construction.

The objective of year 5 in the Minerals Management Service (MMS)-Continental Margins Program is to continue the sand resource inventory and assessment on Louisiana's continental shelf. Trinity Shoal, located approximately 40 km south of Marsh Island and the coastal communities of Freshwater Bayou, Intracoastal City, New Iberia, and Morgan City was selected for assessment. The site's volume of aggregate, the availability of seismic and vibracore coverage, and its proximity to Louisiana's eroding coastline made it an ideal choice (Figure 1). About 800 line-km of high-resolution seismic data was analyzed in Year 1 of the MMS-Continental Margins Program. This data was interpreted and integrated with 30 vibracores collected during 1986 by the Louisiana Geological Survey. An additional set of seismic profiles collected during 1985 by the Louisiana Geological Survey (LGS) and the U.S. Geological Survey (Figure 2) was also incorporated into the study. This report discusses the coastal erosion problem and strategies in Louisiana, the Holocene geologic framework of the Trinity Shoal area, and suitability of Trinity Shoal sand resources as construction aggregate for coastal erosion control.

METHODOLOGY

Exploration for suitable offshore aggregate resources in the Trinity Shoal region was conducted in two phases. First, potential sand deposits were identified. Their distribution was then mapped through the acquisition and interpretation of high-resolution seismic data. The seismic profiling technique uses sound sources and receivers (transducers) that are towed by a research vessel along pre-plotted tracklines. Among other variables, the type and amplitude of reflections (of sound signals) from the subbottom are functions of seafloor and subsurface lithology. Other factors influencing seismic reflections include the type of seismic source used, sea state, water depth, geometry of the tow, vessel speed, type of receiver, signal filtration, scale

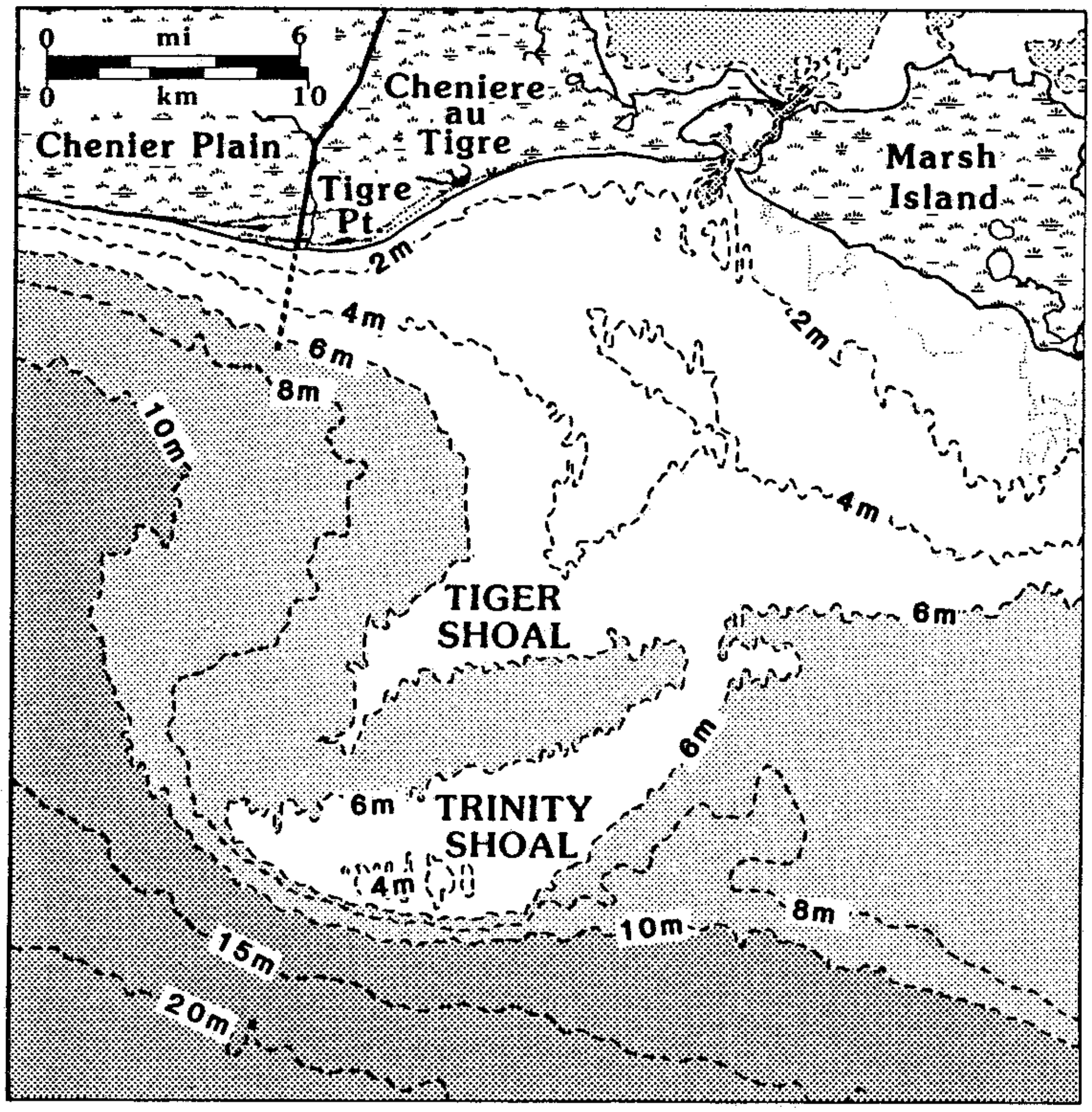


Figure 1. Study area showing the bathymetry of Trinity Shoal, Louisiana inner continental shelf.

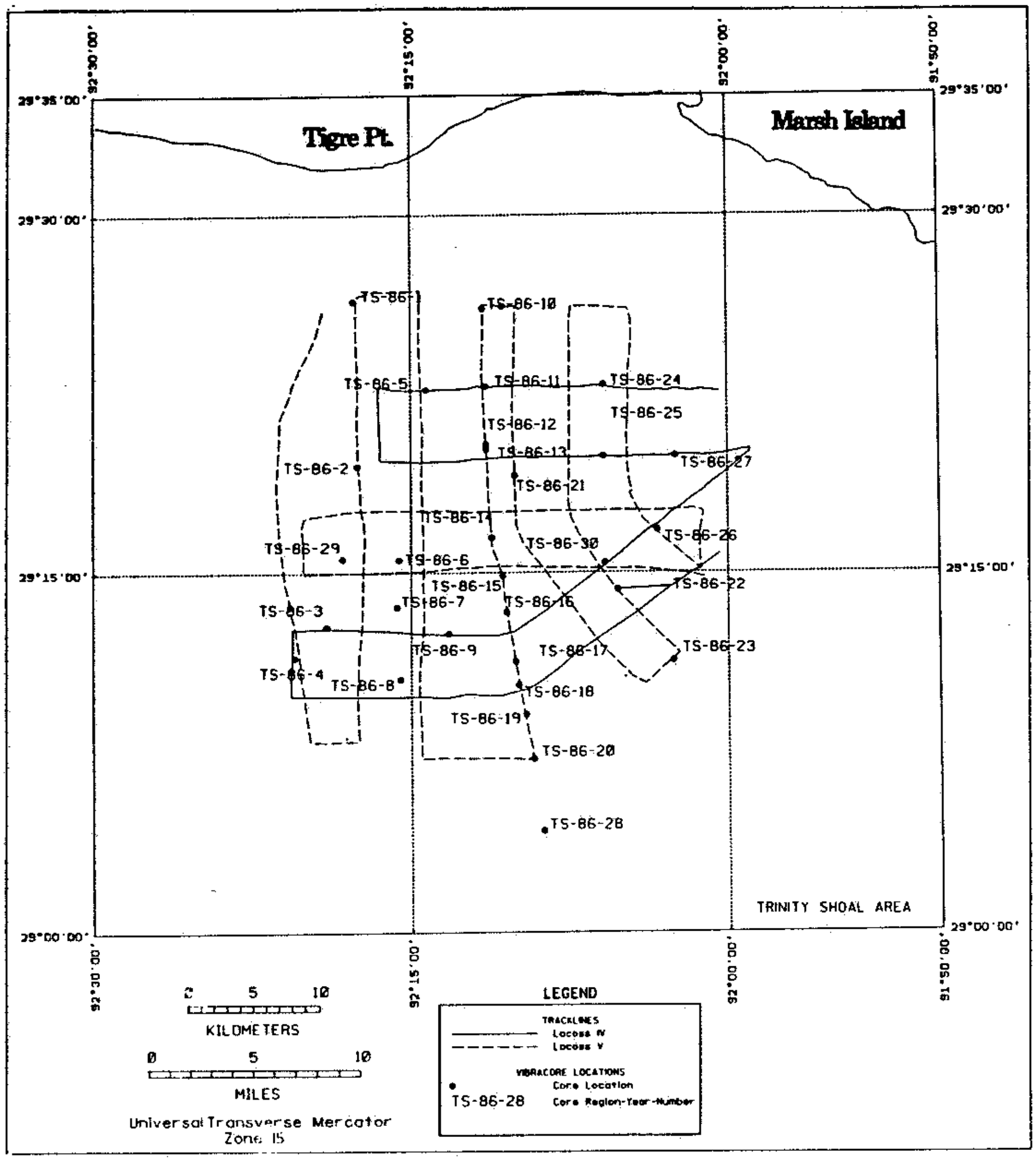


Figure 2. Seismic tracklines and vibracore locations, Trinity Shoal.

of display, and the recorder's chart speed (Suter and Penland 1987).

Throughout the sand resource inventory, a Datasonics 3.5-kHz subbottom profiler was employed as the high-frequency tool; an ORE Geopulse--a uniboom-type system--was used to provide greater penetration. Vertical resolution of these two seismic systems is about 0.5 m and 1.5 m, respectively. Penetration averaged about 15 m for the 3.5-kHz device and 100 m for the Geopulse device in the Trinity Shoal area. The returning signals were split-traced on an EPC 3200 recorder at sweep rates of 1/8 sec for each channel, resulting in an effective display of 1/4 sec for the entire record. Filter settings for the ORE Geopulse were variable, depending upon the area surveyed. All data were recorded on a Hewlett Packard 4300 reel-to-reel magnetic tape machine for subsequent playback. Navigation data were recorded on magnetic tape on a Texas Instruments Silent 700 and processed into trackline maps by the U.S. Geological Survey in Corpus Christi, Texas and at Woods Hole, Massachusetts. Seismic interpretations were plotted onto the trackline charts on mylar overlays at a scale of 1:80,000.

The second phase of sand exploration involved acquisition of cores. Vibracoring is the preferred method of coring in unconsolidated sediment, which uses a vibrating core barrel to achieve penetration in the sediment. The vibracoring technique usually preserves sedimentary structures contained within the core barrel better than other coring methods. Vibracore locations were chosen from interpretations of seismic data and through analysis of current and historical shoreline geomorphology.

The textural suitability of the offshore sand as borrow material was determined by grain size analysis of sediment samples obtained from the vibracores. After completing vibracore descriptions and textural analysis, core data were integrated with the seismic profiles to calibrate the interpreted seismic packages. This procedure allowed a regional interpretation of the seismic facies in terms of the geologic setting and the depositional process. Isopach maps and geologic cross-sections were then produced to illustrate thickness patterns and trends of sand resources throughout the study area.

COASTAL LAND LOSS

Coastal erosion and wetland loss are serious geomorphological problems of national importance--with long-term economic and social consequences. Louisiana is currently experiencing the highest rates of coastal erosion and wetland loss in the United States. Shoreline retreat rates commonly exceed 6 m/yr, and coastal land loss rates exceed 100 km^2/yr (Morgan and Larimore 1957; Adams et al. 1978; Gosselink et al.

1979; Craig et al. 1980; Wicker 1980; Gagliano et al. 1981; Penland and Boyd 1981, 1982; Sasser et al. 1986; Walker et al. 1987; McBride et al. 1989; Britsch and Kemp 1990).

Louisiana's system of barrier islands have helped to create and maintain an extensive estuarine environment. The islands protect salt marshes and bays from offshore wave conditions and saltwater intrusion from the Gulf of Mexico. Barrier island erosion occurs in conjunction with shoreface erosion, tidal inlet development, and subsidence. These elements work to decrease the islands overall areal extent (Peyronnin 1962; Adams et al. 1978; Penland and Boyd 1981, 1982; Morgan and Morgan 1983; McBride et al. 1989). Disappearance of the barrier islands allows more wave energy to impact large estuarine bay systems, potentially accelerating deterioration of wetlands. Behind the protective barrier islands, vast wetland habitats are rapidly disintegrating by pond development, bay expansion, coastal erosion, and human impacts (Morgan 1967; Gagliano and van Beek 1970). Wetland destruction and deterioration will severely impact the fur, fish, and waterfowl industries, valued at an estimated $1 billion/yr, as well as the environmental quality and public safety of south Louisiana (Gagliano and van Beek 1970; Gosselink 1984; Mitsch and Gosselink 1986; Turner and Cahoon 1987; Chabreck 1988; Davis 1990).

The chronic problem of wetland loss in Louisiana is well documented, but poorly understood. Previous studies have shown the land loss problem has persisted and accelerated since the early 1900's. Considerable speculation and scientific debate surrounds the issue of coastal land loss, including the processes driving coastal change, the framework in which coastal change occurs, and the strategy of coastal protection and restoration. The term *coastal land loss* refers to the process or set of processes that convert land to water. *Coastal change* is a more complex concept; it describes the process, or set of processes, that drive the conversion of one geomorphic habitat into another geomorphic habitat. Coastal land loss and change processes typically follow the conversion of vegetated wetlands to estuarine conditions. This is followed by barrier island destruction and conversion to open-water conditions.

In the U.S. Geological Survey's *National Atlas of the United States of America*, Louisiana appears as the nation's hot spot on the coastal erosion and accretion plate (Figure 3). Coastal erosion rates in Louisiana average -4.2 m/yr, with a standard deviation of $\pm$3.3 m/yr, and range between -3.4 m/yr to -15.3 m/yr (Table 1). The average rate of shoreline change in the U.S. Gulf of Mexico is -1.8 m/yr, the highest in the U.S. In comparison, the average rate of shoreline change on the U.S. Atlantic coast is -0.8 m/yr, and

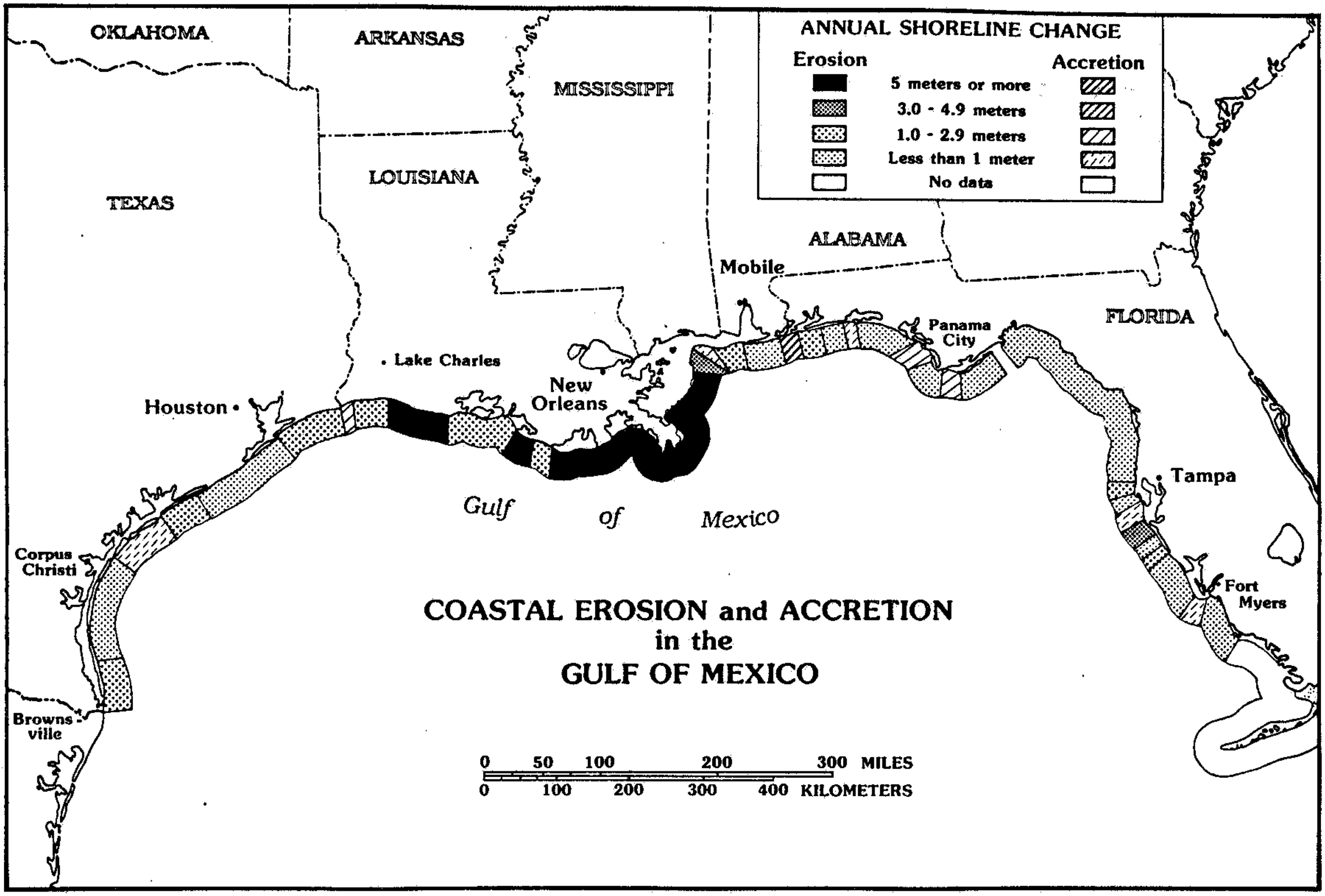


Figure 3. Distribution of coastal erosion and accretion in the Gulf of Mexico (from Dolan et al. 1985).

Region	Mean, m/yr	Standard Deviation	Total Range	N
Atlantic Coast	-0.8	3.2	25.5/24.6	510
Maine	-0.4	0.6	1.9/-0.5	16
New Hampshire	-0.5	---	-0.5/-0.5	4
Massachusetts	-0.9	1.9	4.5/-4.5	48
Rhode Island	-0.5	0.1	-0.3/-0.7	17
New York	0.1	3.2	18.8/-2.2	42
New Jersey	-1.0	5.4	25.5/-15.0	39
Delaware	0.1	2.4	5.0/-2.3	7
Maryland	-1.5	3.0	1.3/-8.8	9
Virginia	-4.2	5.5	0.9/-24.6	34
North Carolina	-0.6	2.1	9.4/-6.0	101
South Carolina	-2.0	3.8	5.9/-17.7	57
Georgia	0.7	2.8	5.0/-4.0	31
Florida	-0.1	1.2	5.0/-2.9	105
Gulf of Mexico	-1.8	2.7	8.8/-15.3	358
Florida	-0.4	1.6	8.8/-4.5	118
Alabama	-1.1	0.6	0.8/-3.1	16
Mississippi	-0.6	2.0	0.6/-6.4	12
Louisiana	-4.2	3.3	3.4/-15.3	106
Texas	-1.2	1.4	0.8/-5.0	106
Pacific Coast	-0.0	1.5	10.0/-5.0	305
California	-0.1	1.3	10.0/-4.2	164
Oregon	-0.1	1.3	5.0/-5.0	86
Washington	-0.5	2.2	5.0/-3.9	46
Alaska	-2.4	2.0	2.9/-6.0	69

Table 1. Rates of shoreline change for U.S. coastal states and regions (from Dolan et al. 1985).

on the U.S. Pacific coast, shoreline position is stable.

Louisiana's coastal erosion is concentrated along the barrier shorelines seaward of the Mississippi River delta plain. The average rate of shoreline change of -4.2 m/yr represents only the long-term conditions exceeding 50 years, which is averaged together by per unit length of shoreline for 630 km of coast. However, because coastal erosion is a variable 365 day-a-year process, the erosion rate is not representative of changes associated with individual storm events that drive the long-term average. Bursts of erosion are associated with passage of major cold fronts, tropical storms, and hurricanes (Harper 1977; Penland and Ritchie 1979; Boyd and Penland 1981; Ritchie and Penland 1988). Major storm events produce energetic overwash conditions that erode the beach and reduce the barrier landscape into low-relief landforms (Penland et al. 1988). Field measurements document 20 m to 30 m of shoreline erosion during a single storm event lasting 3 to 4 days. This is equivalent to several years of erosion at the average rate. The total area of Louisiana's barrier shorelines are also decreasing due to the storm and overwash processes. For example, in 1880 the total barrier island area in Louisiana was measured at 98.6 km^2. By 1980, barrier island area had decreased to 57.8 km^2 , decreasing 41% at a rate of 0.41 km^2/yr (Penland and Boyd 1982).

The barrier shoreline with the highest rate of coastal erosion in Louisiana are the Isles Dernieres in Terrebonne Parish (McBride et al. 1989). Between 1890 and 1988, portions of the Isles Dernieres shoreline experienced 1805 m of erosion at an average rate of 18.4 m/yr. The greatest amount of change occurred in the central barrier arc at Whiskey Island. On this island, the beach retreated 2573 m between 1853 and 1988 at an average rate of 19.1 m/yr. In 1890, the Isles Dernieres' total area was measured at 3360 ha (33.6 km^2); by 1988 the island area had decreased to 771 ha (7.71 km^2). This is a decrease of 2589 ha (25.89 km^2), or 77% over a period of 98 years at a rate of 26.4 ha/yr (0.264 km^2/yr). East Island is the first island of the Isles Dernieres barrier island arc forecasted to be destroyed by coastal erosion by 1998; Trinity Island is the last in the barrier island chain that is forecasted to be destroyed by 2007. The loss of these islands will dramatically impact the stability and quality of Terrebonne Bay and the coastal wetlands in lower Terrebonne basin.

Numerous researchers have documented rates of coastal land loss in the Mississippi River deltaic and chenier plains of south Louisiana. Gagliano et al. (1981) conducted an inventory of land loss in the Mississippi River deltaic plain. This study projected high land loss rates that increased geometrically with time (Figure 4), accelerating from 17.40 km^2/yr in 1913 to 102.10 km^2/yr in 1980. Based on the above accelerated rates of coastal land loss (beginning in 1978), Lafourche Parish is forecasted to be destroyed within 205 years, St. Bernard Parish within 152 years, Terrebonne Parish within 102 years, and Plaquemines Parish within 52 years. Britsch and Kemp (1990) also calculated land loss rates in the Mississippi River deltaic plain for the 1930's to 1956-58, 1956-58 to 1974, and 1974 to 1983 time periods. On a regional scale they found that land loss rates have decreased from an average yearly rate of 72.60 km^2/yr for the 1956-58 to 1974 period to 59.5 km^2/yr for the 1974 to 1983 period. However, the regional land loss rates calculated by Britsch and Kemp (1990) compare closely with those calculated by Gagliano et al. (1981) for those time periods that were similar. Britsch and Kemp (1990) concluded that another data point is necessary to determine whether this trend toward decreasing land loss rates in the deltaic plain is continuing. Britsch and Kemp (personal communication 1990) have also examined land loss rates in the chenier plains of south Louisiana over the same time period. They calculated present rates of land loss in the chenier plain of about 36.3 km^2/yr. Based on these rates, they determined that 67% of the present land loss occurs in the deltaic plain, and 33% occurs in the chenier plain. Gosselink et al. (1979) attributed 80% of the land loss in south Louisiana to occur in the deltaic plain, and 20% of the land loss in the chenier plain.

COASTAL EROSION CONTROL

Strategy

As our population becomes increasingly concentrated in and dependent upon coastal areas, erosion and wetland loss will continue to pose a growing challenge to Louisiana and other gulf states. The U.S. Environmental Protection Agency (EPA) and the National Research Council (NRC) forecast of increasing sea level rise will dramatically accelerate rates of coastal land loss in the future (Barth and Titus 1984; National Research Council 1987; Titus 1987). Because of its geologic setting, the severe coastal land loss problems in Louisiana provide a realistic comparison with worse-case scenarios for future coastal conditions. More importantly, it documents the importance of understanding the processes driving coastal land loss and shoreline retreat.

A key objective of the U.S. Geological Survey and the Louisiana Geological Survey cooperative research programs is to convey the importance of understanding the causative geologic processes and patterns of coastal land loss, and the impacts these processes have on people and resources. Solutions to most coastal

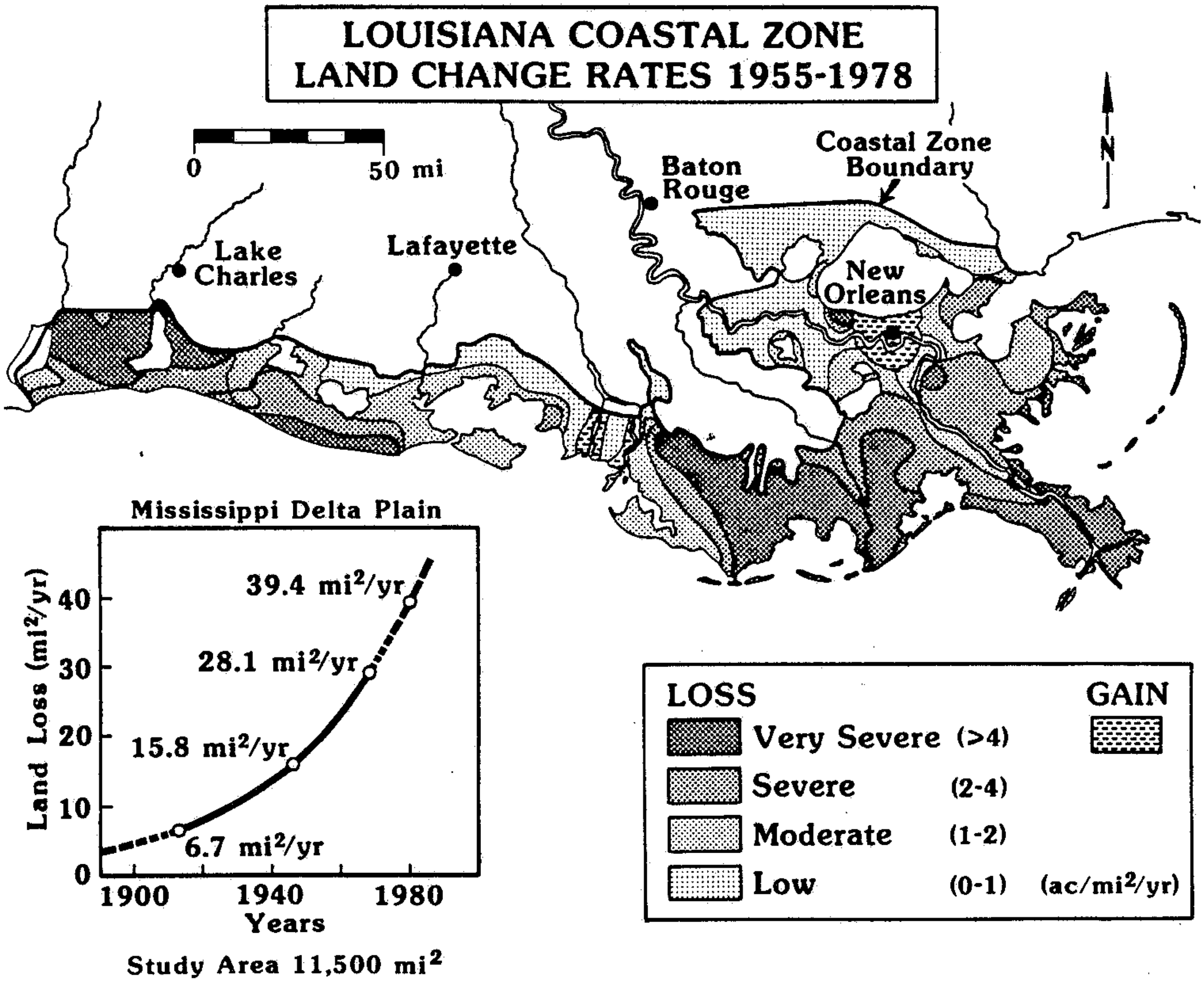


Figure 4. Distribution and rates of coastal land loss in Louisiana (from Gagliano et al. 1981 and van Beek and Meyer-Arendt 1982).

land loss issues overly emphasize stopping the results of the processes, but do not give adequate consideration to the process itself. This approach results in many engineering solutions that rely on costly brute force techniques rather than less expensive approaches, such as beach replenishment, that are in concert with natural processes defined by scientific study. A lack in understanding of natural geologic processes also leads to over-simplified concepts, producing false hope that simple engineering solutions will work over long time periods.

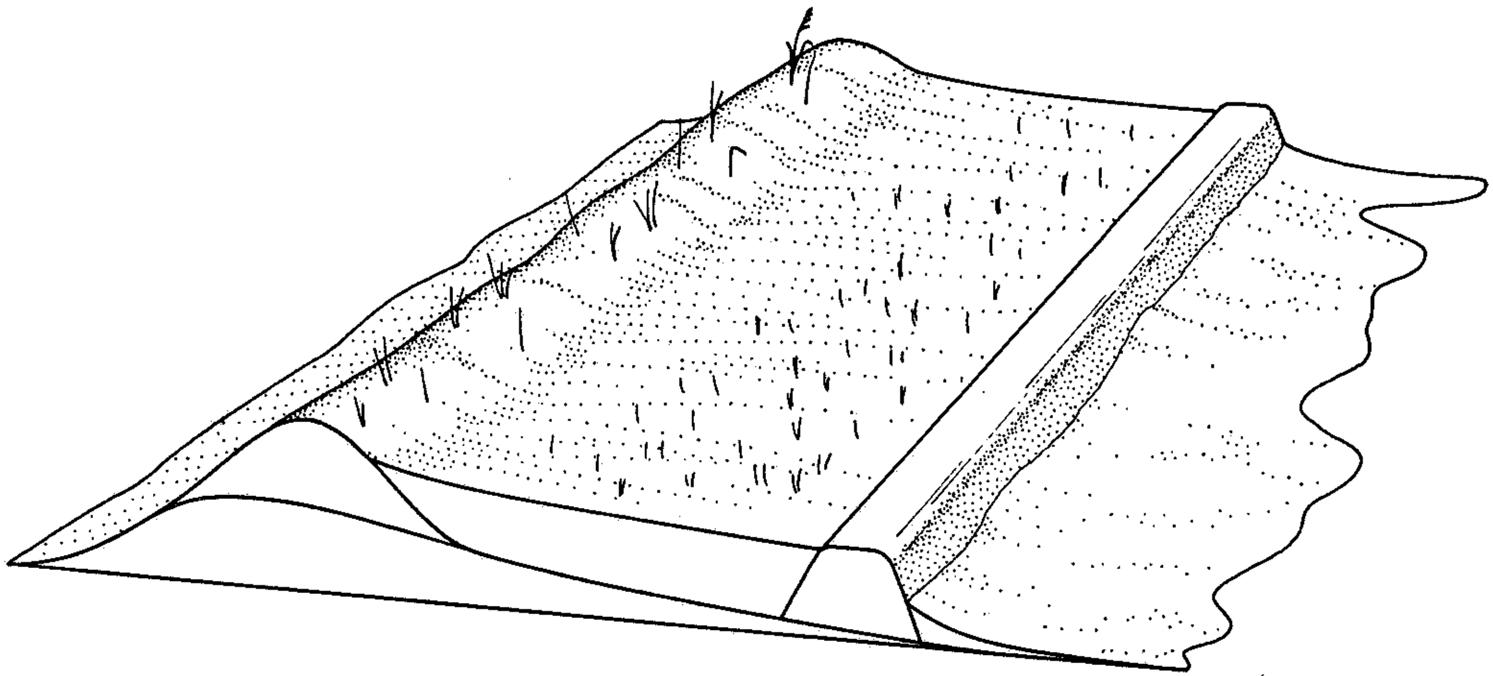
Coastal land loss is primarily a function of sediment deficit, relative sea level rise, and devegetation. Human impacts are secondary, but often serve to drastically increase rates of coastal deterioration. To effectively manage the coastal land loss problem, a consistent strategy must be developed that applies appropriate tactics. Two management options have been applied in Louisiana. One requires construction of coastal structures, such as seawalls, to combat natural processes and thereby stabilize the remaining habitats. The other option replaces material lost from the barrier island system with sand from nearby deposits that is stabilized by planting dune and backbarrier marsh vegetation (Figure 5). The second option, using sediment and vegetation, has proven to be the most cost-effective technique capable of preserving and restoring Louisiana's barrier shoreline habitats. As a consequence, the strategy of any comprehensive management plan to preserve Lousiana's barrier shorelines must pursue sediment and vegetation projects, as well as mitigation projects designed to help reverse human impacts that occur in the coastal zone. The tactics of this strategy include beach and shoreface nourishment, barrier restoration, vegetation, and coastal structure modification. For this approach to be successful, a regularly scheduled maintenance program must be developed for each barrier-built estuary in south Louisiana.

Barrier Restoration

Barrier island restoration is a new technique developed in Louisiana that is designed to restore transgressive barrier island habitats and prevent the island from breaching during storms. In 1984, the Terrebonne Parish government undertook a barrier island restoration pilot project on the eastern Isles Dernieres (Jones and Edmonson 1987). This project involved placement of fill material directly on the beach crest and back-barrier platform. Fill requirements were less per linear meter of shoreline than those for a beach replenishment project; restoration cost per linear meter was $863. This project restored the dunes and vegetated back-barrier terraces and salt marshes. It also prevented the island from breaching during the

PHASE I COMPLETED

SHORELINE AND BARRIER ISLAND RESTORED



- SHORELINE EROSION REDUCED
- DUNES RESTORED
- ISLAND WIDTH AND HEIGHT INCREASED
- BACK BARRIER RETAINING STRUCTURE COMPLETED
- BREACHES SEALED
- MANMADE CANALS FILLED

Figure 5. Schematic illustrating proposed process of shoreline and barrier island restoration and vegetation.

three 1985 hurricanes (Danny, Elena, and Juan) that impacted Louisiana's coastal area.

Beach Replenishment

Beach replenishment projects generally require large volumes of high-quality (fine- to medium-grained) sand. However, because of the scale of such endeavors, construction costs per linear meter of beach are more economical than similar smaller-scale projects. For example, the average construction cost per linear meter for the U.S. Army Corps of Engineers 1985 Grand Isles project was $765 for 11,308 linear meters of beach. This was less than the cost of the Terrebonne Parish barrier island restoration project, which required 10 times less material. In terms of cost per m^3, the average cost was $3.85/$m^3$ of fill. Nationwide, the typical cost of beach replenishment is $1.83/$m^3$ to $15.80/$m^3$ of fill (National Research Council 1987).

Shoreface replenishment is a new technique that has been tested in Australia, Denmark, and Hilton Head Island, South Carolina (Bruun 1988). With this technique, a beach-shoreface profile is constructed that is in equilibrium with its process environment. As a consequence, construction and maintenance costs are lower, and the rapid rates of beach erosion which usually immediately follows construction of dunes in most beach nourishment projects does not occur. The cost advantage of the shoreface nourishment technique lies in the ease of shoreface construction as compared to dune construction, and lower requirements for heavy earth-moving equipment. A Queensland, Australia study reveals the average beach nourishment costs are $4.58/$m^3$ for beach fill, and $1.96/$m^3$ for shoreface material (Bruun 1988a).

Vegetation

Building dunes and back-barrier habitats, and vegetating natural island surfaces or dredged spoil material is the most inexpensive method of barrier island protection (Mendelssohn, 1987). Vegetation programs cost significantly less than the various dredged material techniques currently in use. Hurricane impact research has also shown that dune and marsh vegetation are extremely effective at retarding coastal erosion. When vegetation is used in combination with nourishment or restoration projects, new and diverse barrier habitats can be rebuilt and restored. The costs for a typical dune building and vegetation project is $5-10 per linear foot of barrier island.

HOLOCENE GEOLOGIC FRAMEWORK

Four large sand shoals were formed in the retreat path of the Mississippi River delta plain during the Holocene transgression (Penland et al. 1989) (Figure 6). These sand bodies represent former shoreline positions of deltas associated with lower stillstands in relative sea level. Short periods of rapid relative sea level rise led to the transgressive submergence of these shorelines, which today can be recognized at the -10 m and -20 m isobaths on the Louisiana continental shelf. Trinity Shoal and Ship Shoal comprise the -10 m late Holocene shoreline trend. The Outer Shoal and the St. Bernard shoals make up the -20 m early Holocene shoreline trend. These sand bodies provide tremendous potential as sources of aggregate for shoreline erosion control. Scientifically, the shoals provide insight into the processes that control coastal evolution and shelf sand development under the conditions of eustacy and subsidence.

Relative sea level in the northern Gulf of Mexico during the late Wisconsinan lowstand fell to depths of -130 m below present sea level, exposing the continental shelf and producing a set of shelf-margin deltas (Berryhill 1986; Berryhill and Suter 1986; Kindinger 1989). Sediments were delivered to the Mississippi Fan through a submarine canyon; the youngest fan lobe was supplied by the Mississippi River between 10,000 and 25,000 yr B.P. (Coleman et al. 1983; Bouma et al. 1986; Mazzulo 1986), and represents the late Wisconsin lowstand systems tract (Van Wagoner et al. 1988).

During the 18,000 yr B.P. lowstand, the Mississippi River incised a trench across the Louisiana continental shelf. Together with tributary streams and subaerial weathering processes, an erosional unconformity was formed on the Pleistocene Prairie terrace, which is marked by a widespread oxidation surface (Fisk 1944). Between 18,000 to 9000 yr B.P., sediment from the ancestral Mississippi River was restricted to infilling the Mississippi Canyon. Between 9000 and 3500 yr B.P. the Mississippi River was no longer confined totally to the canyon, which allowed a series of shelf-phase delta plains to form on the outer- to mid-continental shelf during the Holocene transgression (Fisk and McClelland 1959; Boyd et al. 1988).

The sediment volume supplied by the Mississippi River to its delta plain appears to have been unable to keep pace with relative sea level rise during the Holocene transgression. Individual stillstand-coupled delta plains backstepped landward across the present continental shelf. The establishment of individual delta plains, built of smaller complexes through the delta switching process, indicates the existence of several periods during which the rate of sea level rise increased. As rates of relative sea level rise increased again,

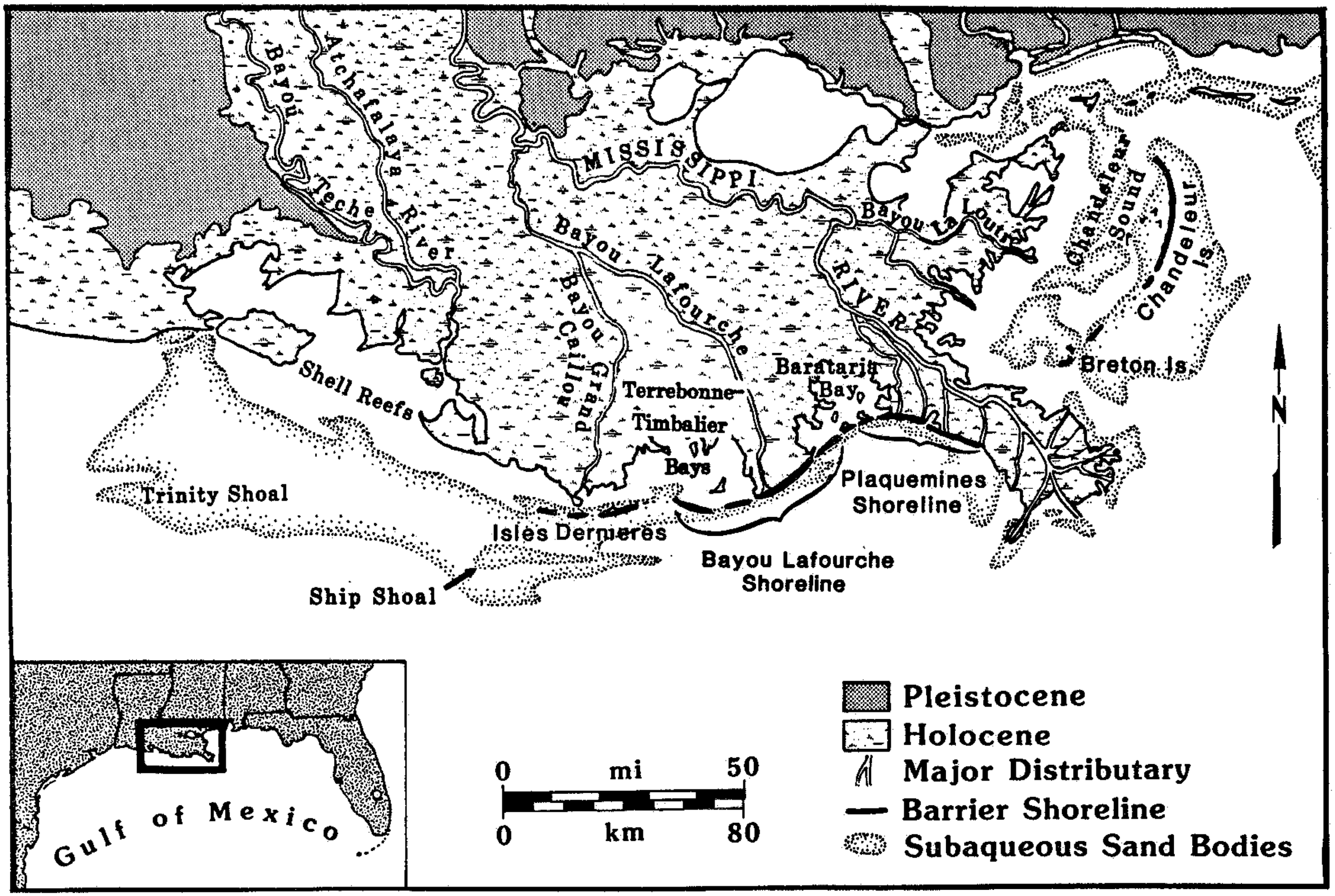


Figure 6. Location of the Holocene sand shoals offshore of the Mississippi River delta plain (from Frazier 1974).

the earlier Holocene shelf-phase delta plains were transgressed and submerged, producing large sand shoals from re-worked distributary mouth bar deposits, marking their former shoreline position. The Holocene shelf-phase delta plains progressively onlap the Pleistocene Prairie unconformity.

Each shelf-phase delta plain lies on a ravinement surface and consists of a regressive and transgressive component (Penland et al. 1988). The regressive component is built predominantly of distributary sands encased in prodelta muds and capped by freshwater marsh deposits. The second component of this shelf-phase delta sequence is transgressive and consists of lagoonal deposits overlain by a barrier shoreline or shelf sand body (Figure 7). The Outer Shoal and the St. Bernard Shoals are located along the -20 m isobath; this early Holocene shoreline trend is associated with the $\pm$9000 yr B.P. stillstand (Frazier 1974). Lying along the -10 m isobath, Trinity Shoal and Ship Shoal represent the late Holocene and early Holocene Mississippi River delta plains. The outer shelf region seaward of the early Holocene shoreline trend received little sediment supply after transgression, and now constitutes a condensed section. The end of the Holocene transgression is marked by the culmination of the eustatic rise in sea level about 3000 yr B.P., when the late Holocene delta plain shoreline retreated to the mouth of the Mississippi River alluvial valley. The shoreline of the Modern shelf-phase delta plain, which formed in association with the current stillstand, extends between Point Au Fer and Hewes Point. The exact timing of the eustatic highstand is debatable, but it appears to have begun around 3000 yr B.P. (Penland et al. 1988a). This position at the close of the Holocene transgression represents a maximum highstand of sea level (i.e., time of maximum flooding). Early and late Holocene sand shoals represent the transgressive depositional system of each of these shelf-phase delta plains.

TRINITY SHOAL GEOMORPHOLOGY

Trinity Shoal is the westernmost member of an inner-shelf shoal group offshore of south-central Louisiana (Figures 1 and 6). Located 40 km offshore of Cheniere au Tigre and Marsh Island, Trinity Shoal is a shore-parallel lunate shoal 30 km long and 5 km to 10 km wide that formed in association with the Teche delta about 3500 years ago. This shoal lies in 7 m to 10 m of water and has a relief of 2 m to 4 m. Figure 8 illustrates six north-south oriented bathymetric profiles across Trinity Shoal. These profiles also show the terrace morphology of Trinity Shoal. Shoal morphology can be divided into four zones: shoreface, back shoal, shoal, and ramp. The shoreface landward of Trinity Shoal represents a transitional zone between

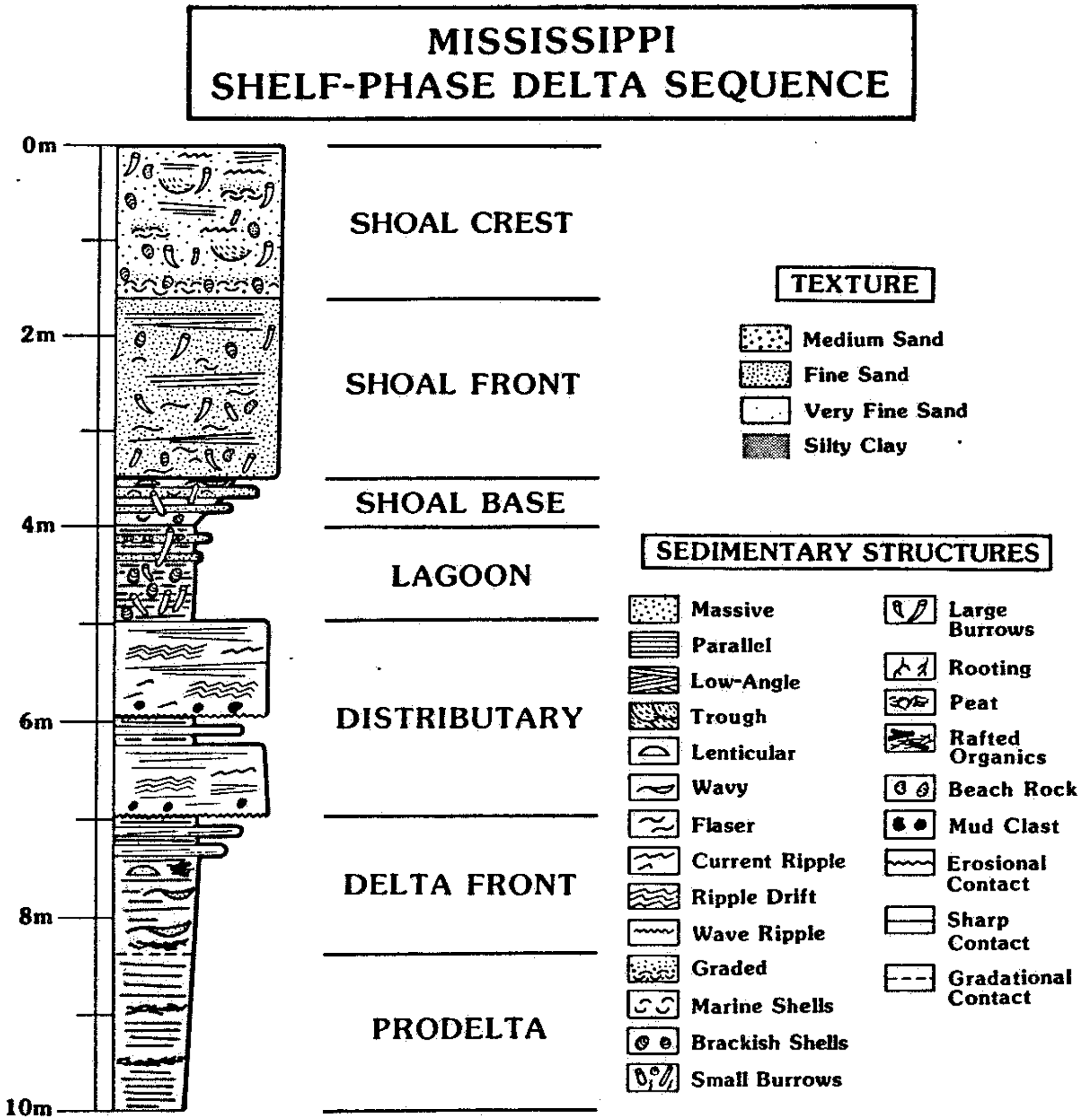


Figure 7. Generalized composite stratigraphic model for a transgressive Mississippi River shelf-phase delta plain (from Penland et al. 1988).

TRINITY SHOAL BATHYMETRIC PROFILES

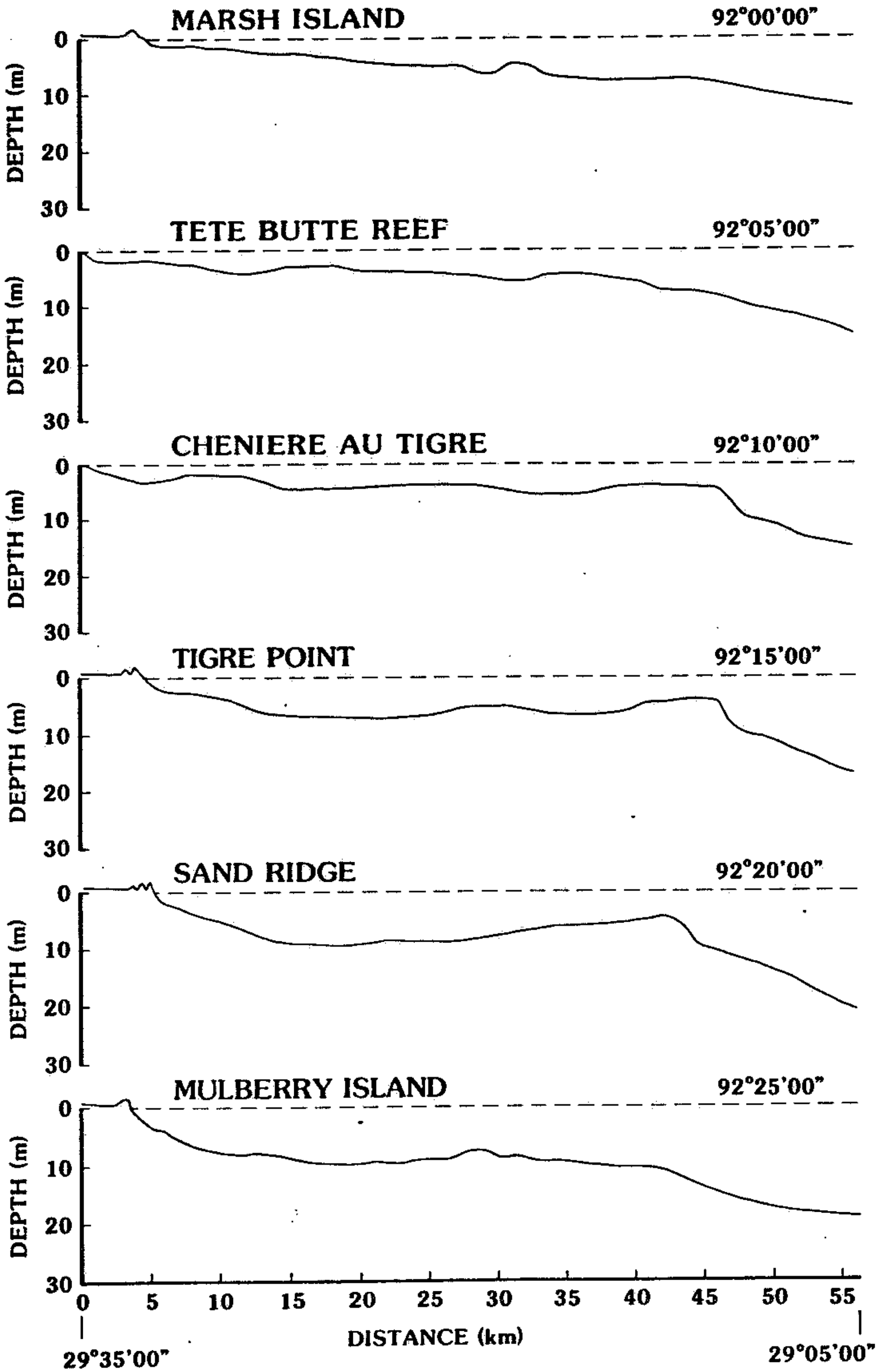


Figure 8. Six north-south bathymetric profiles across Trinity Shoal. The bathymetric profiles also illustrate the terrace morphology of Trinity Shoal.

the Mississippi River delta plain in the east near Marsh Island to the chenier plain near Cheniere au Tigre in the west. The Marsh Island shoreface is erosional with in situ and reworked, intertidally exposed shell reefs, of *Crassostrea* sp. and *Rangia* sp. Slopes on the Marsh Island shoreface range between 1:300 and 1:400. The Cheniere au Tigre shoreface varies from zones of active mud accumulation derived from the Atchafalaya River, to zones of shoreface retreat. Slopes on the chenier plain shoreface range from 1:400 to 1:500. The back shoal represents the zone between the crest of Trinity Shoal and the base of the shoreface. The landward slope of the back shoal is between 1:1800 and 1:2000. The crestline of Trinity Shoal is concave landward with seaward slopes of 1:1200 and 1:1400. The seaward slope of Trinity Shoal is relatively steep, with 1:800 to 1:1000 slopes. Together, the back shoal, shoal, and ramp represent the shelf expression of a transgressed barrier shoreline associated with the Teche delta complex. A comparison of historical hydrographic surveys of Trinity Shoal indicate that landward shoal migration has occurred. Trinity Shoal appears to retreat landward by erosion of the seaward shoal ramp with deposition on the back shoal. Rates of shoal retreat between 1887 and 1932 are less than 10 m/yr.

Surficial sediment on Trinity Shoal was mapped as very fine-grained sand by Krawiec (1966). Frazier (1974) mapped the surface lithofacies of Trinity Shoal as 100%-75% sand. The median phi diameter for sand ranged from 3.4 phi to 3.8 phi with secondary amounts of shell and organics. Krawiec (1966) concluded Trinity Shoal is composed of sands from a transgressive barrier shoreline associated with an abandoned Mississippi River delta.

TRINITY SHOAL GEOLOGY

Depositional Environments

Analyses of vibracores and seismic data resulted in the delineation of six distinct depositional environments. The regressive sediment environments include: (1) prodelta; (2) delta fringe; and (3) distributary channel. The transgressive sediment environments include: (1) lagoon; (2) barrier; and (3) shoal. Texture, primary physical structures, and sequence associations were used to characterize the depositional environment and sediment facies (Figures 7 and 9).

The prodelta environment was interpreted from core analysis as fine-grained laminated clay deposits that form the platform upon which the distributary network progrades. The delta fringe environment is a clay deposit that contains a coarsening-upward sequence of lenticular and wavy cross-beds of silt and sand.

SUBMERGED BARRIER ISLAND

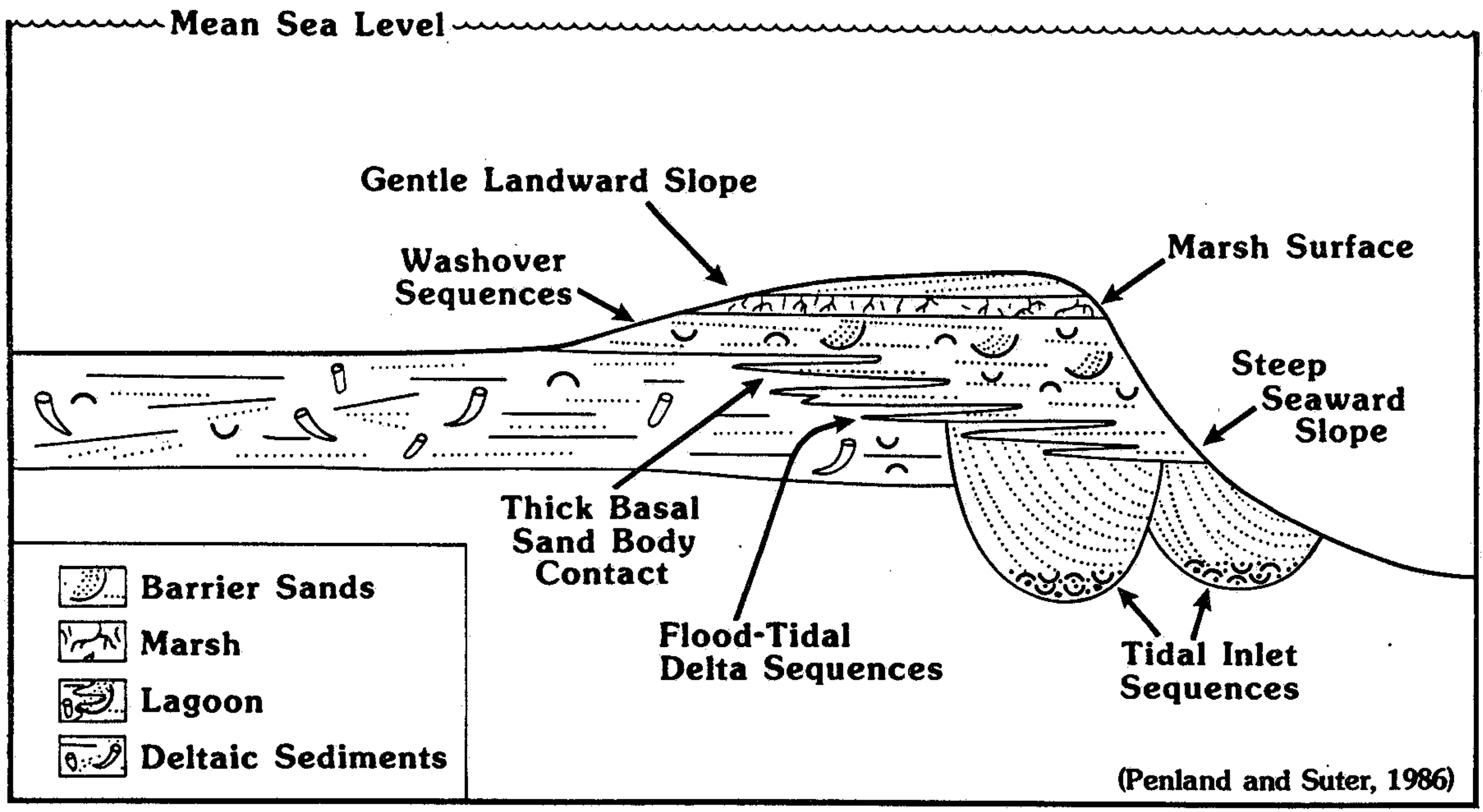


Figure 9. Schematic illustrating the sedimentary facies associations of submerged barrier islands.

Distributary channel deposits are composed of channel and levee sand as well as the fine-grained fill that seals the channel.

The shoal environment is represented by the marine sand body that caps Trinity Shoal. Massive in appearance, the shoal environment is composed of a marine sand body derived from reworking the underlying barrier facies. This sand facies contains faint horizontal and planar bedding, mud-filled burrows, and shell fragments throughout. It is a more homogenous sand body, with no inclusions of wavy or lenticular mud bedding, and a mean grain-size of 3.29 phi (Table 2). The percent sand is greater than 90% and is very well to well sorted. In contrast, the barrier environment is represented by recurved spit, tidal inlet, washover, sand sheet, and aeolian environments of deposition. The typical barrier sequence coarsens-upward and represents the transgressive contact between the lagoon, flood-tidal delta, and washover deposits of the barrier island system. The facies of the barrier environment contain a variety of burrows throughout, sandy/shelly storm bedding, discrete shells, and lenticular, wavy, and small scale cross-beds. The mean grain-size of the barrier sub-environments is 3.19 phi, and is moderately to well sorted (Table 2). The lagoon environment is a coarsening-upward sequence of interbedded muds with silt and sandy storm beds or washover deposits. Primary physical structures include small to large burrows, wavy and lenticular silt and sand beds, and shell fragments throughout. Figures 10 to 15 illustrate the sedimentary textural parameters in terms of percent sand for the 30 Trinity Shoal vibracores analyzed for this study. Sediment samples were obtained from the vibracores and used for analysis of grain size for transgressive and regressive facies associated with Trinity Shoal (Table 2).

Cross-Sections

Seismic profiles and vibracore logs (Figure 16) were integrated to build five stratigraphic dip and five stratigraphic strike cross-sections. Dip cross-sections depict the Trinity Shoal sand body rapidly thinning from the west to the east (Figures 17 to 21). Cross-sections A - A' (Figure 17), B - B' (Figure 18), and C - C' (Figure 19) illustrate the interpreted depositional environments and facies associations. The combined thickness of the shoal and barrier environments exceed 8 m. The barrier sand body pinches out by cross-section E - E' (Figure 21) and a 1 m to 2 m thick shoal sand body blankets lagoonal mud further to the east. The combined width of the shoal and barrier environments of Trinity Shoal varies from 2 km to 4 km.

VIBRACORE SAMPLE NUMBER	DEPTH IN CENTI-METER	CALCULATION OF MOMENT MEASURE STATISTICS				CALCULATION OF FOLK STATISTICS				CALCULATION OF INMAN STATISTICS				TEXTURAL STATISTICS			
		Mean Size	Sorting	Skewness	Kurtosis	Mean Size	Sorting	Skewness	Kurtosis	Mean Size	Sorting	Skewness	Kurtosis				
TS-86-03	10	3.41	.38	-.85	3.98	3.43	.34	.18	.83	3.46	.36	.19	.42	sand	v. well sorted	fine skewed	platykurtic
TS-86-03	300	3.62	.35	-1.48	5.48	3.61	.33	-.18	1.04	3.59	.34	-.22	.62	sand	v. well sorted	coarse skewed	mesokurtic
TS-86-04	10	3.80	.36	-.88	3.20	3.83	.37	.05	1.12	3.85	.36	.14	.77	muddy sand	well sorted	near symmetrical	leptokurtic
TS-86-04	250	3.58	.55	-1.46	2.68	3.61	.53	-.26	1.42	3.59	.45	-.19	1.28	muddy sand	mod. well sorted	coarse skewed	leptokurtic
TS-86-06	05	3.28	.54	-1.31	2.80	3.37	.49	-.06	1.56	3.40	.38	.20	1.54	sand	well sorted	near symmetrical	very leptokurtic
TS-86-06	325	3.75	.37	-1.91	7.32	3.78	.32	.00	1.47	3.78	.26	.07	1.45	muddy sand	v. well sorted	near symmetrical	leptokurtic
TS-86-07	10	3.38	.36	-1.04	4.92	3.40	.32	.23	.85	3.43	.34	.21	.40	sand	v. well sorted	fine skewed	platykurtic
TS-86-07	250	3.45	.35	-1.24	6.88	3.46	.32	.12	.75	3.48	.36	.12	.33	sand	v. well sorted	fine skewed	platykurtic
TS-86-08	05	3.35	.30	-.07	4.09	3.36	.29	.27	1.10	3.38	.30	.21	.54	sand	v. well sorted	fine skewed	mesokurtic
TS-86-08	305	3.32	.68	-1.30	.83	3.44	.60	-.33	1.50	3.42	.47	-.16	1.56	sand	mod. well sorted	v. coarse skewed	very leptokurtic
TS-86-09	100	3.19	.48	-.74	1.37	3.21	.49	-.10	1.17	3.20	.49	1.06	.68	sand	well sorted	coarse skewed	leptokurtic
TS-86-09	300	3.35	.45	-.76	.84	3.35	.46	-.16	.85	3.34	.49	-.13	.43	sand	well sorted	coarse skewed	platykurtic
TS-86-15	10	3.05	.44	-.63	2.61	3.05	.42	-.07	1.04	3.04	.40	-.12	.83	sand	well sorted	near symmetrical	mesokurtic
TS-86-17	10	3.27	.46	-.66	.61	3.28	.48	-.11	1.03	3.27	.49	-.05	.56	sand	well sorted	coarse skewed	mesokurtic
TS-86-17	280	3.55	.40	-1.98	6.68	3.57	.36	-.32	1.00	3.54	.36	-.25	.63	sand	well sorted	v. coarse skewed	mesokurtic
TS-86-18	10	3.53	.37	-1.35	4.89	3.54	.33	-.17	.76	3.52	.37	-.16	.34	sand	v. well sorted	coarse skewed	platykurtic
TS-86-18	180	3.45	.42	-1.65	4.47	3.49	.40	-.24	.97	3.47	.39	-.14	.73	sand	well sorted	coarse skewed	mesokurtic
TS-86-21	10	3.05	.32	-.29	2.27	3.04	.32	-.13	.76	3.03	.35	-0.13	.34	sand	v. well sorted	coarse skewed	platykurtic
TS-86-21	95	3.17	.40	-.29	2.70	3.15	.38	-.08	1.40	3.13	.34	-.21	1.02	sand	well sorted	near symmetrical	leptokurtic
TS-86-23	10	3.40	.53	-.64	1.42	3.45	.52	.13	1.26	3.49	.46	.27	1.11	muddy sand	mod. well sorted	fine skewed	leptokurtic
TS-86-23	230	3.53	.60	-1.24	1.07	3.54	.59	-.39	1.42	3.47	.52	-.39	1.08	muddy sand	mod. well sorted	v. coarse skewed	leptokurtic
TS-86-25	20	2.77	.85	.02	-1.12	2.76	.89	-.02	.73	2.74	.98	-.07	.35	sand	moderately sorted	near symmetrical	platykurtic
TS-86-29	10	3.35	.43	-1.14	4.21	3.39	.39	.09	1.24	3.43	.35	.24	.96	sand	well sorted	near symmetrical	leptokurtic
TS-86-29	250	3.48	.33	-.26	3.07	3.47	.33	.15	.75	3.49	.36	.14	.33	sand	v. well sorted	fine skewed	platykurtic
TS-86-30	05	2.94	.54	-.59	.32	2.94	.54	-.35	1.09	2.88	.52	-.35	.77	sand	mod. well sorted	v. coarse skewed	mesokurtic

*NOTE: Measurements are in "phi" units.

Table 2. Grain texture analyses from the transgressive shoal and barrier deposits, Trinity Shoal.

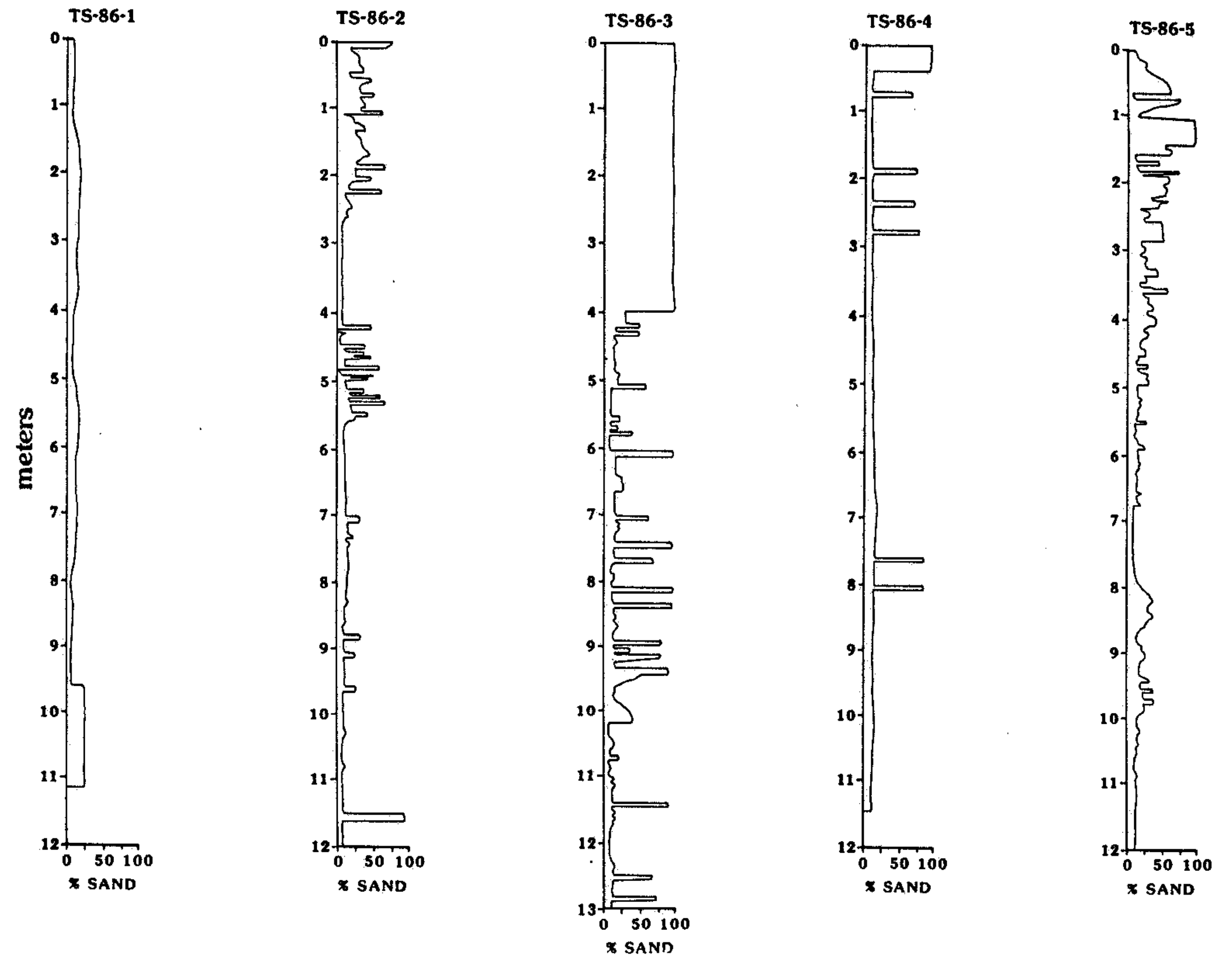


Figure 10. Sedimentary textural descriptions showing percent sand for Trinity Shoal vibracores TS 1 to TS 5.

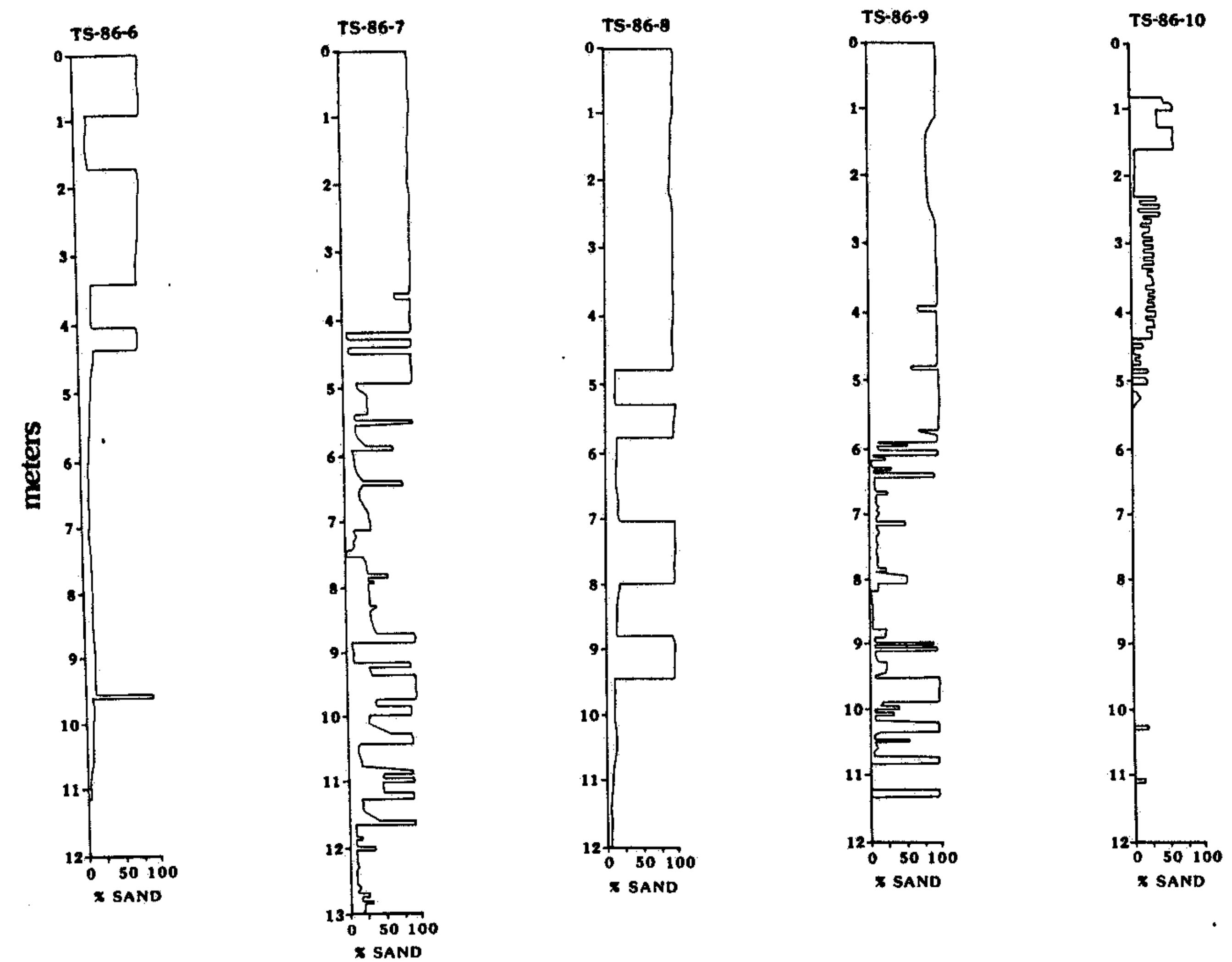


Figure 11. Sedimentary textural descriptions showing percent sand for Trinity Shoal vibracores TS 6 to TS 10.

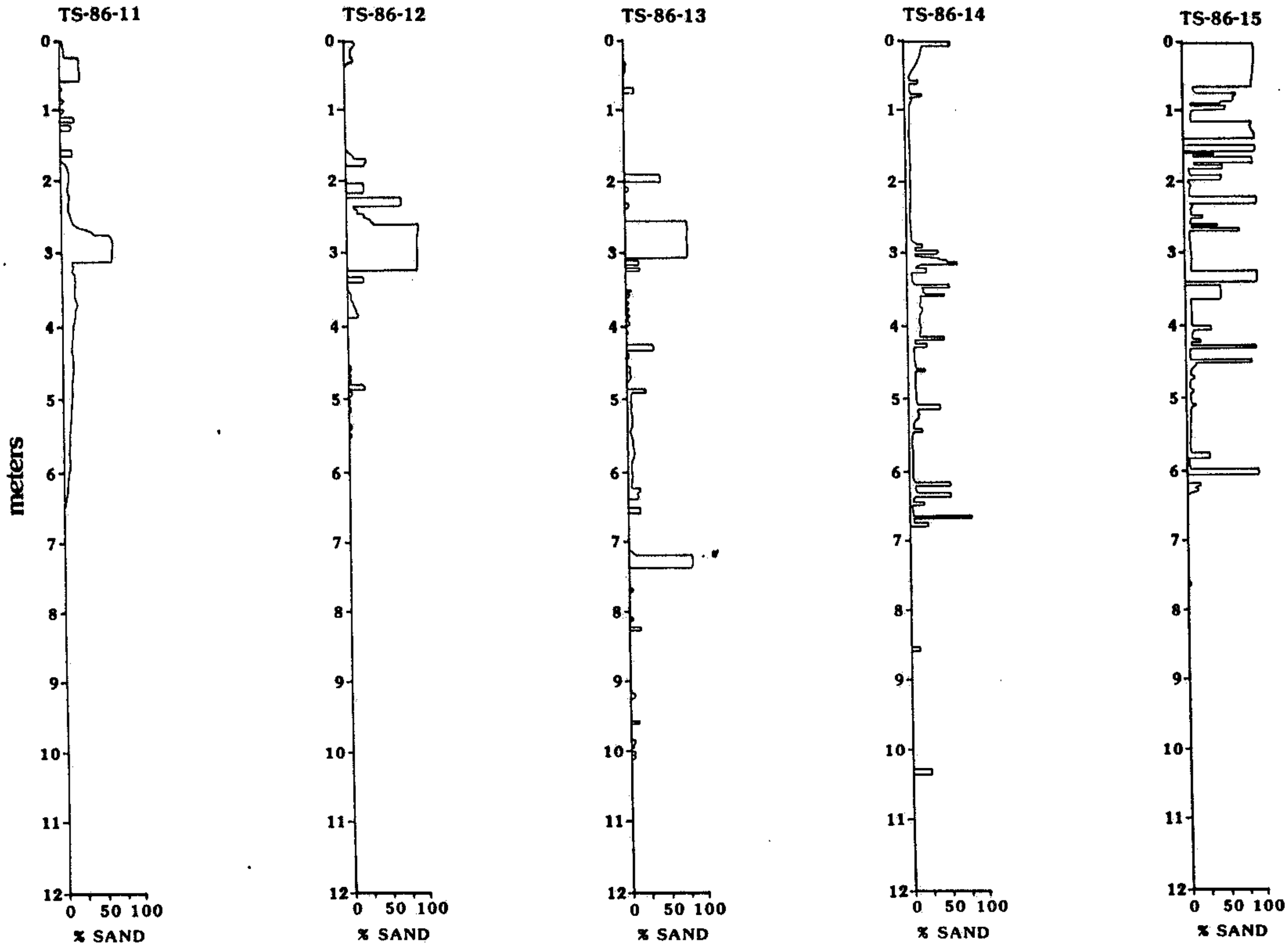


Figure 12. Sedimentary textural descriptions showing percent sand for Trinity Shoal vibracores TS 11 to TS 15.

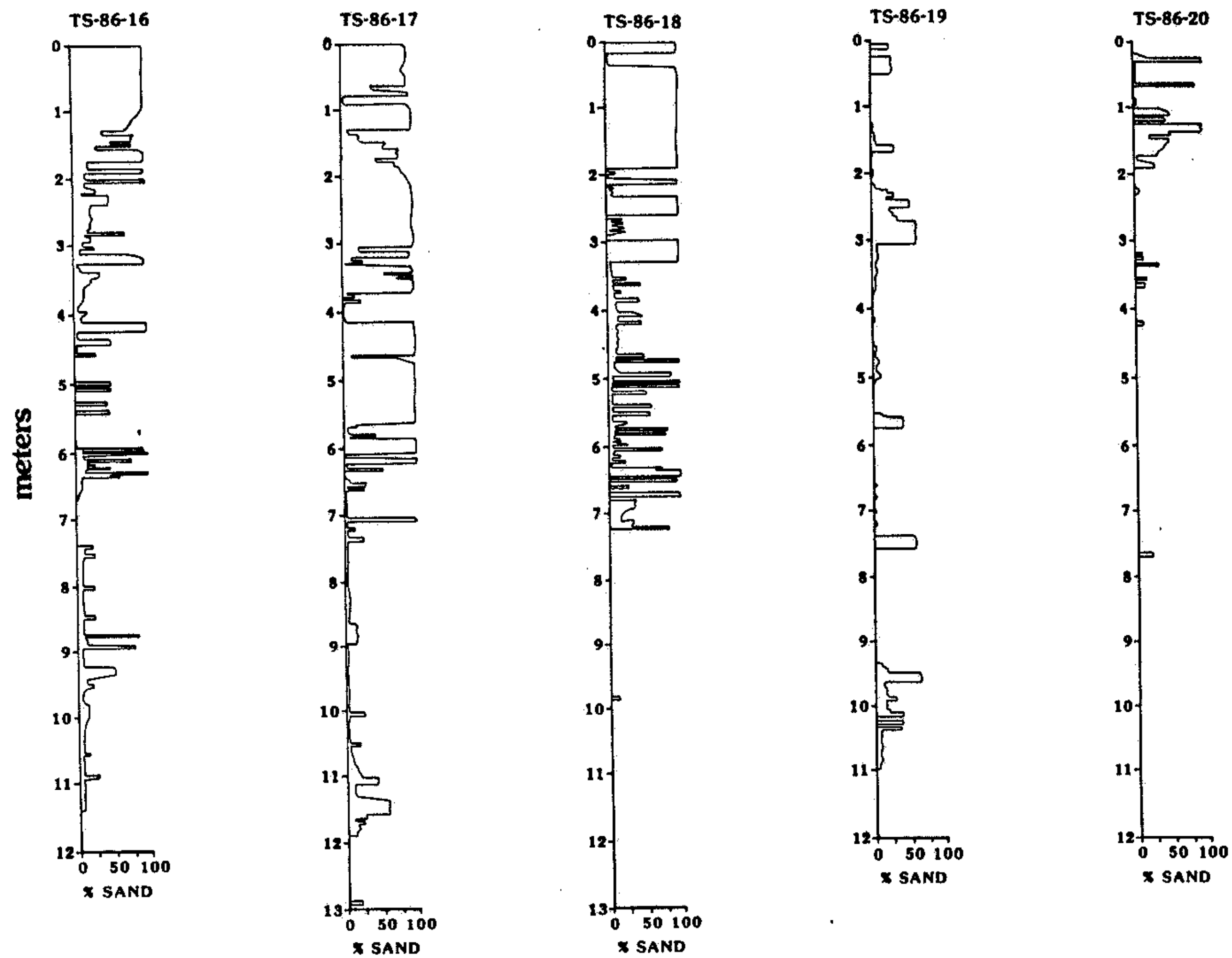


Figure 13. Sedimentary textural descriptions showing percent sand for Trinity Shoal vibracores TS 16 to TS 20.

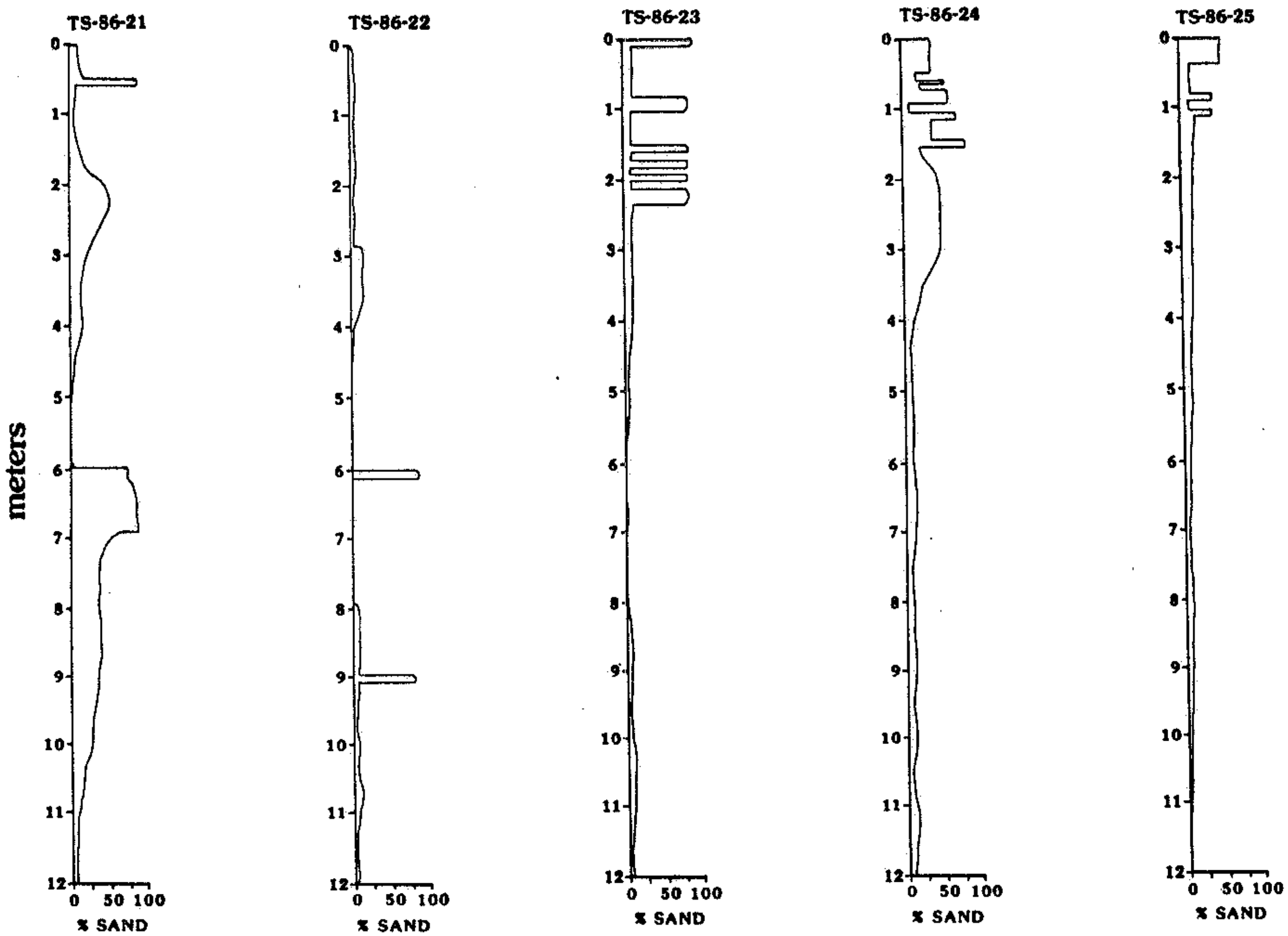


Figure 14. Sedimentary textural descriptions showing percent sand for Trinity Shoal vibracores TS 21 to TS 25.

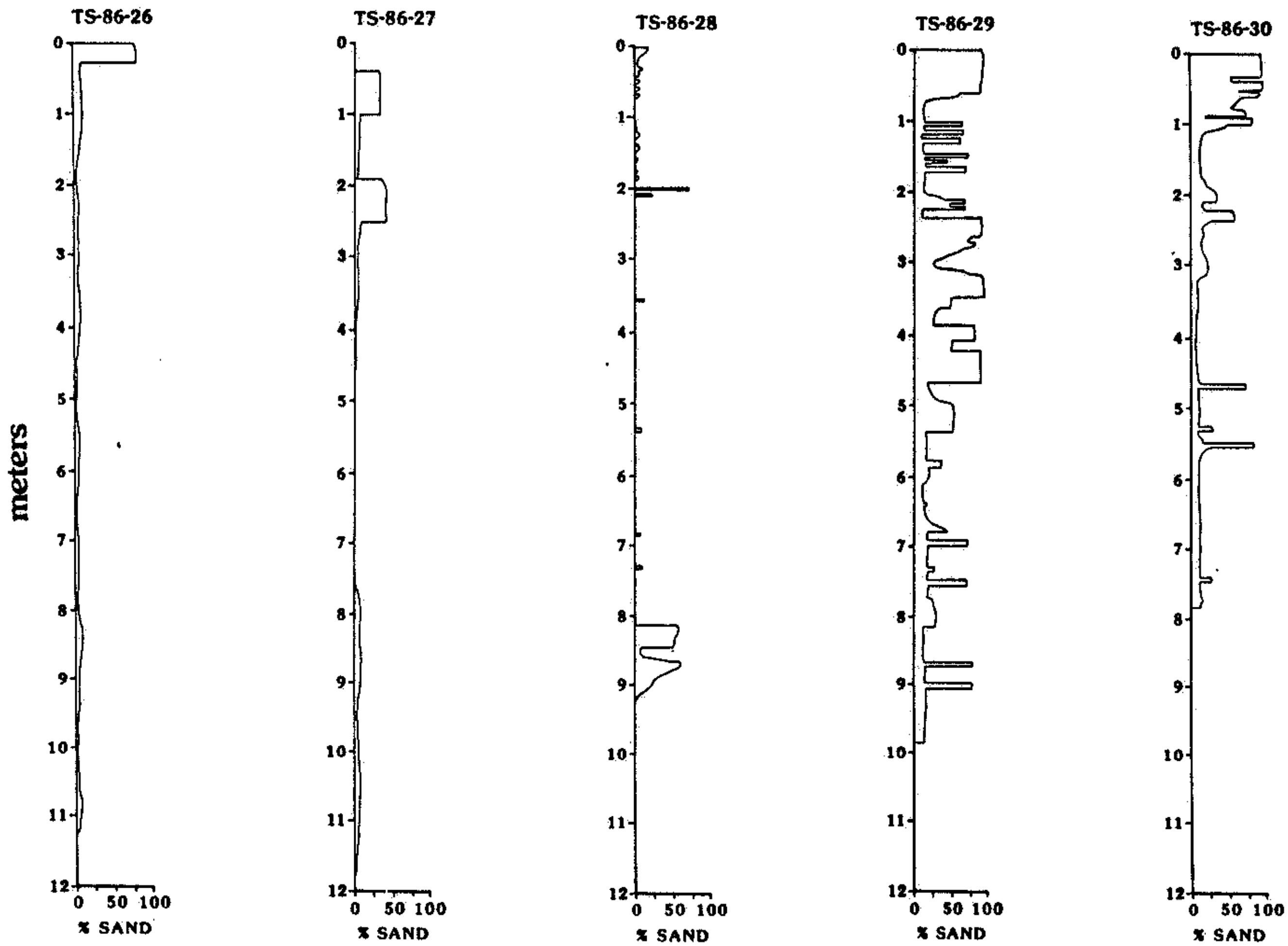


Figure 15. Sedimentary textural descriptions showing percent sand for Trinity Shoal vibracores TS 26 to TS 30.

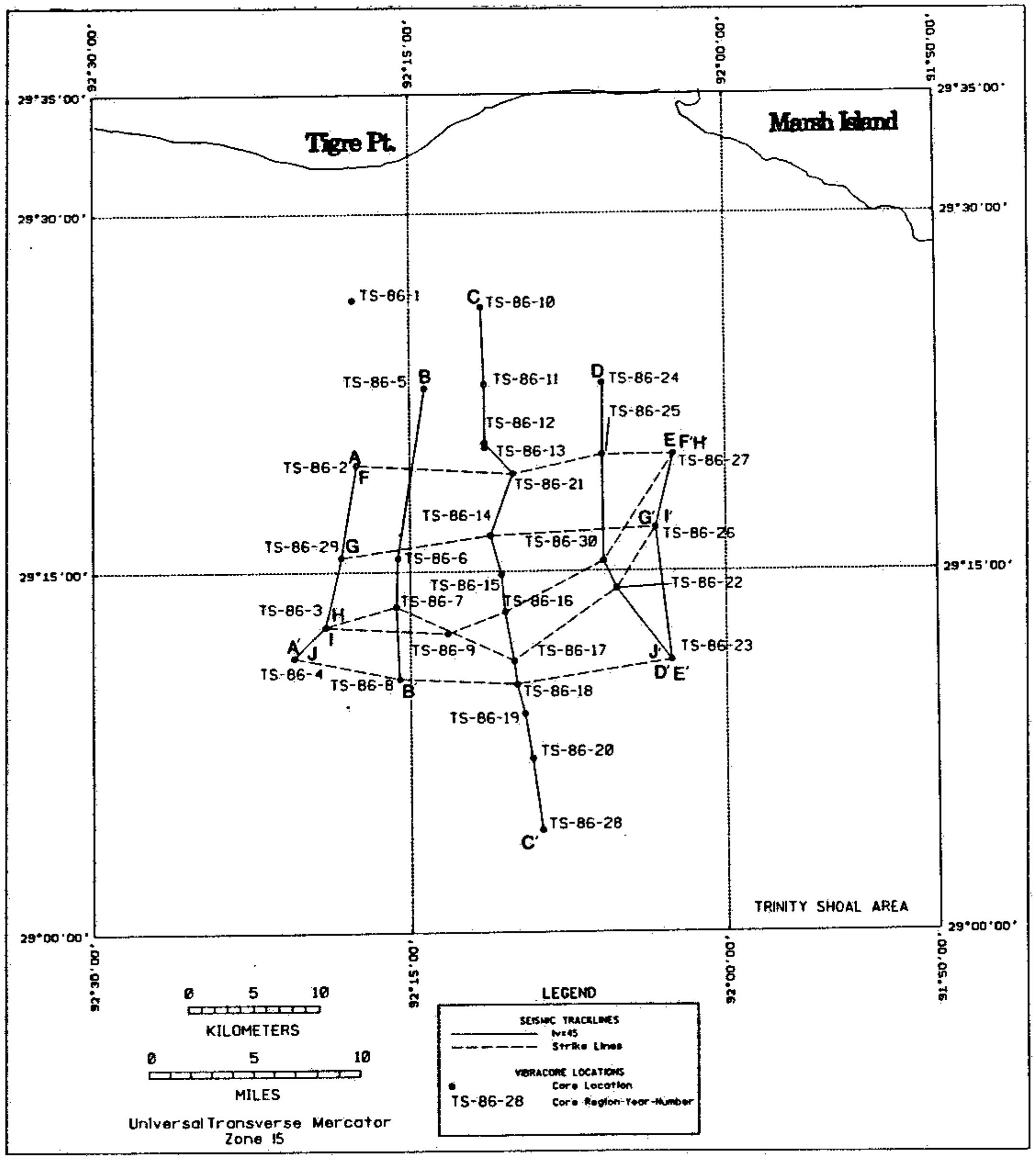


Figure 16. Vibracore locations and stratigraphic cross-sections, Trinity Shoal.

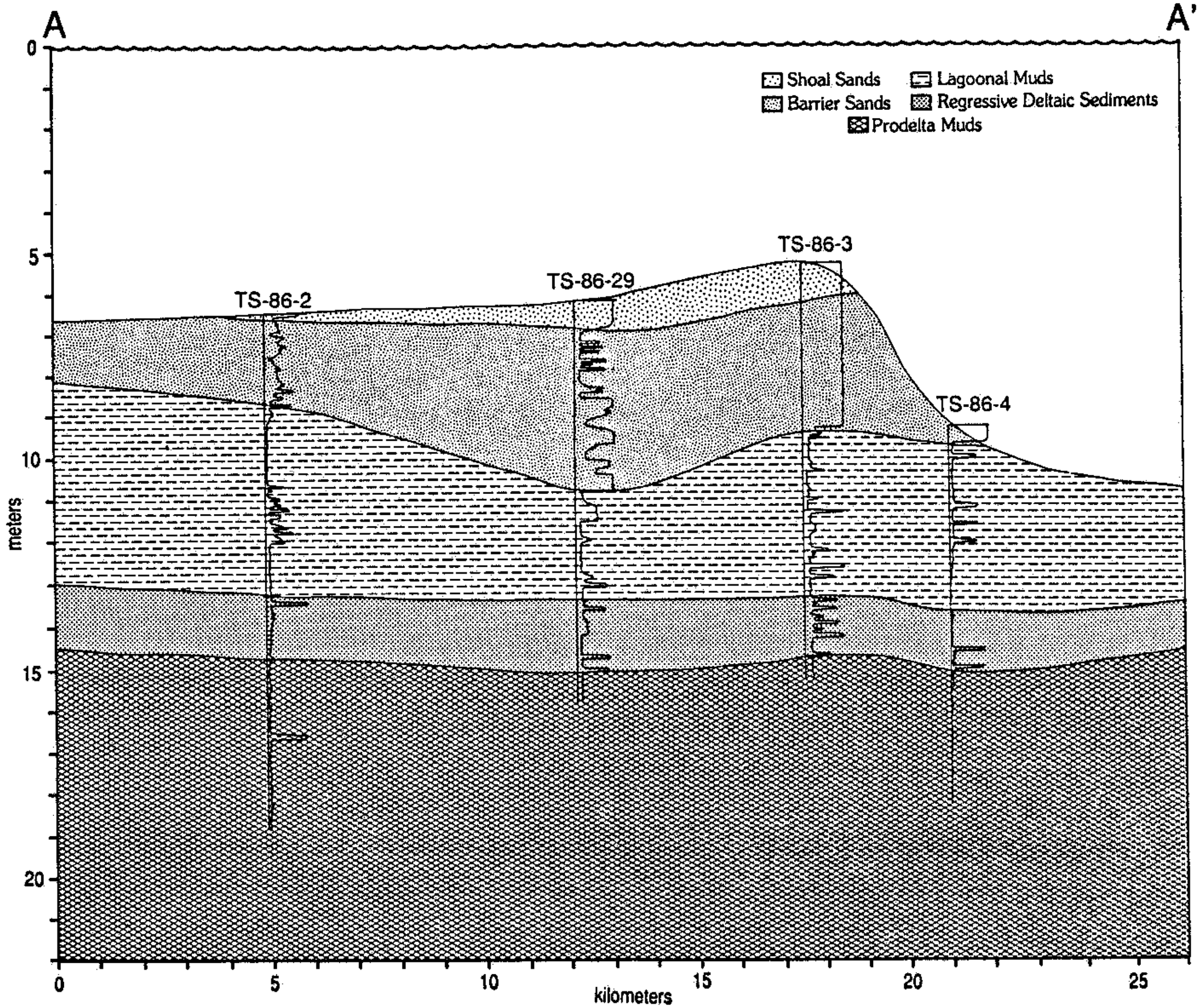


Figure 17. Stratigraphic dip cross-section A - A', Trinity Shoal.

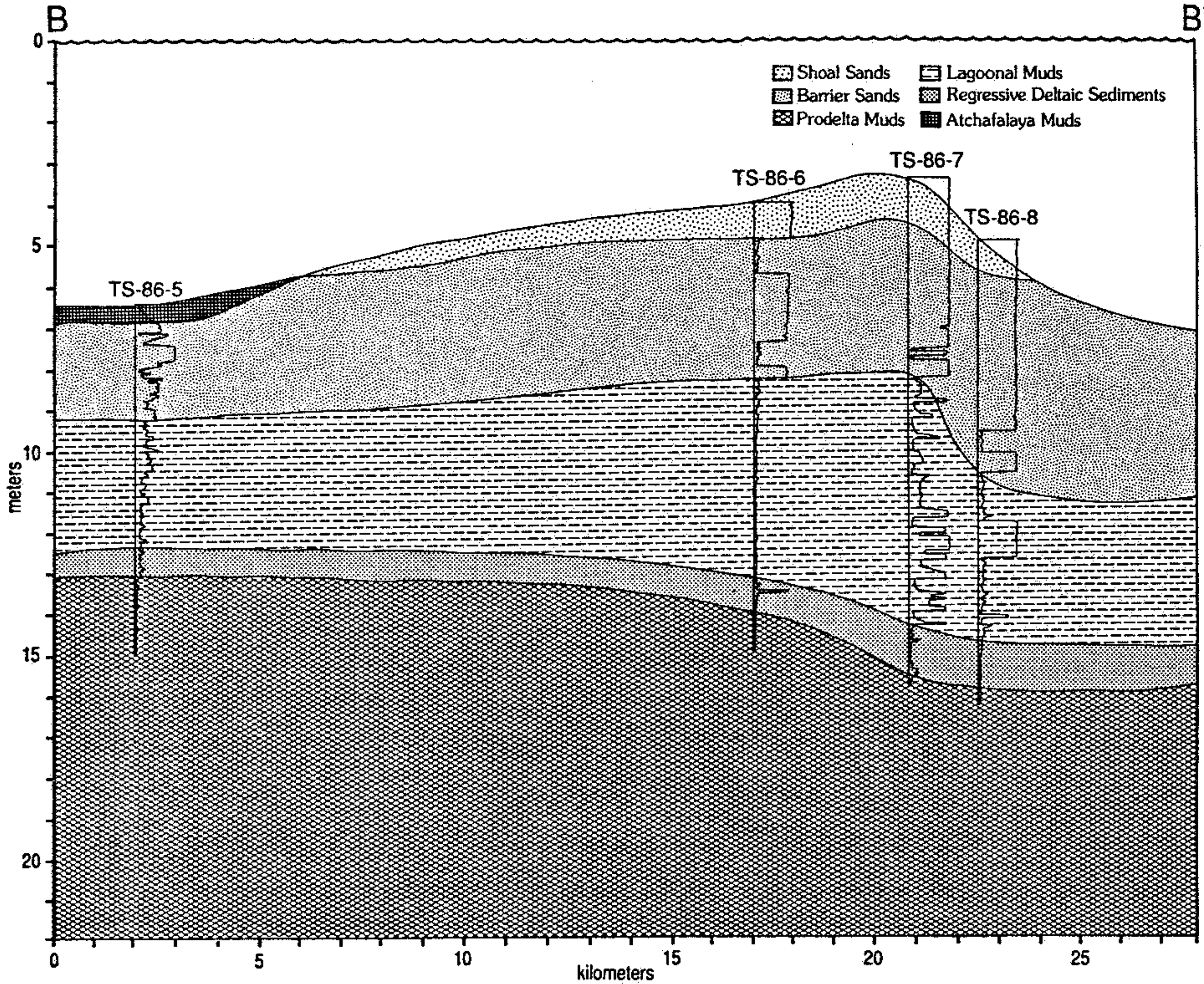


Figure 18. Stratigraphic dip cross-section B - B', Trinity Shoal.

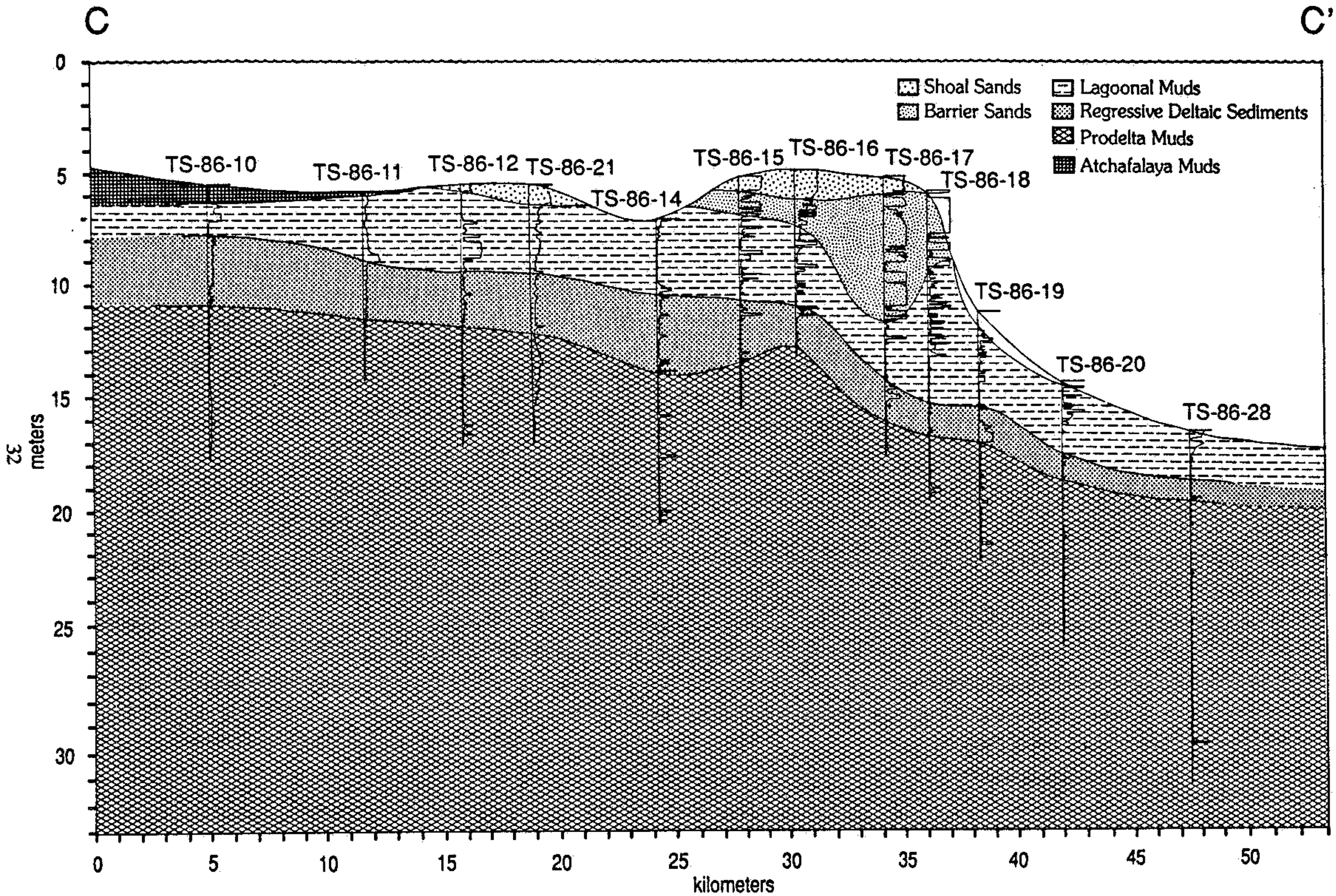


Figure 19. Stratigraphic dip cross-section C - C', Trinity Shoal.

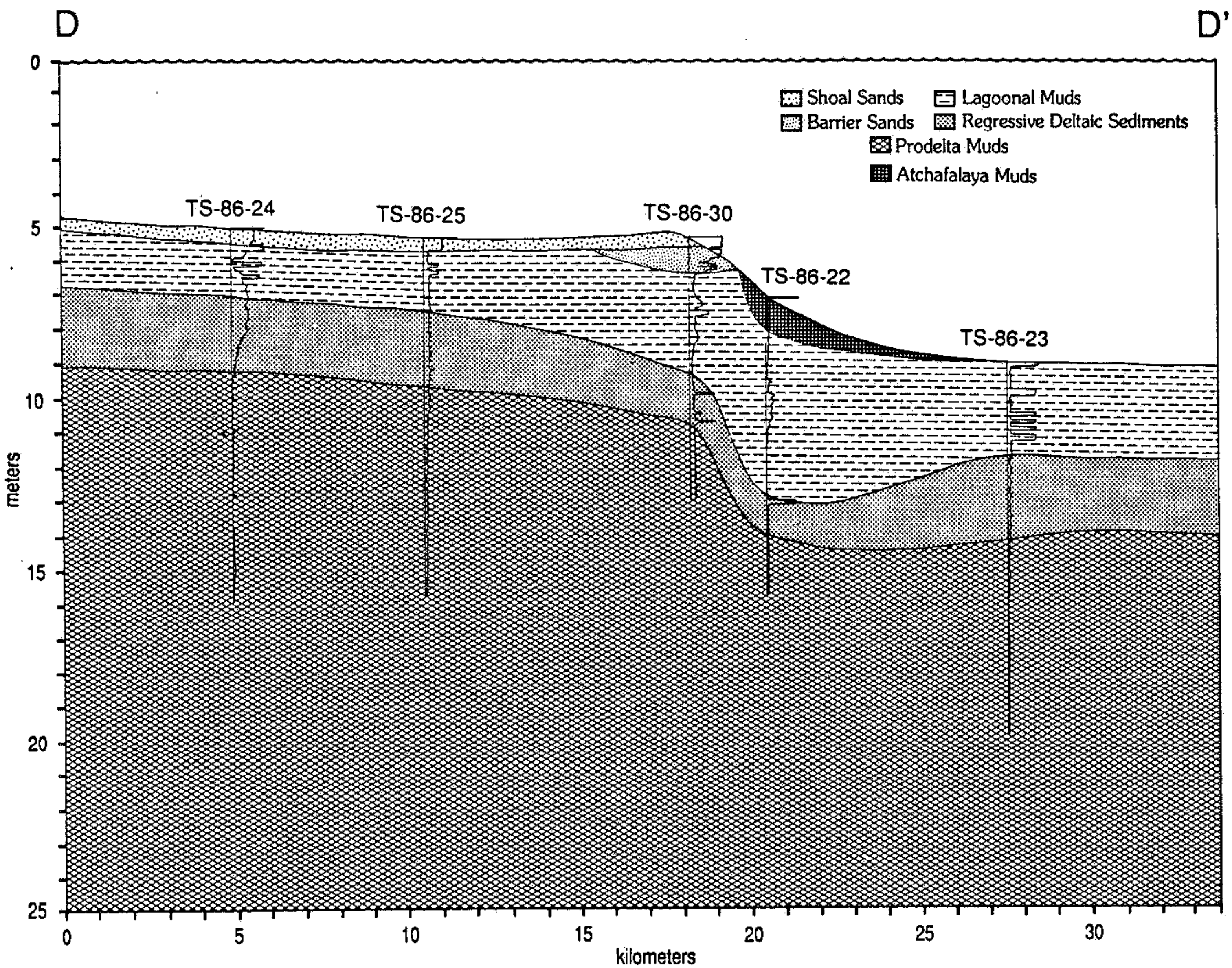


Figure 20. Stratigraphic dip cross-section D - D', Trinity Shoal.

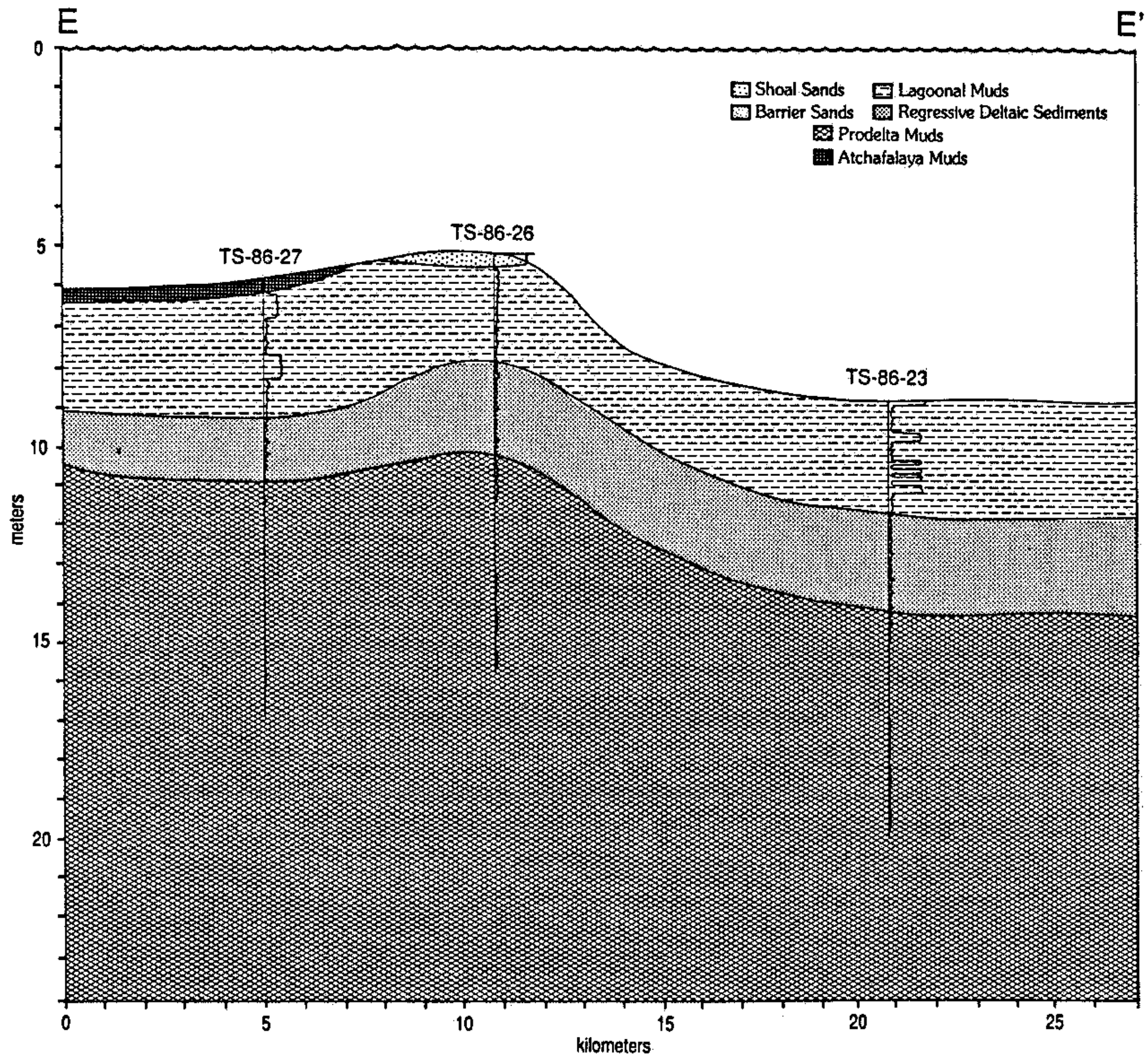


Figure 21. Stratigraphic dip cross-section E - E', Trinity Shoal.

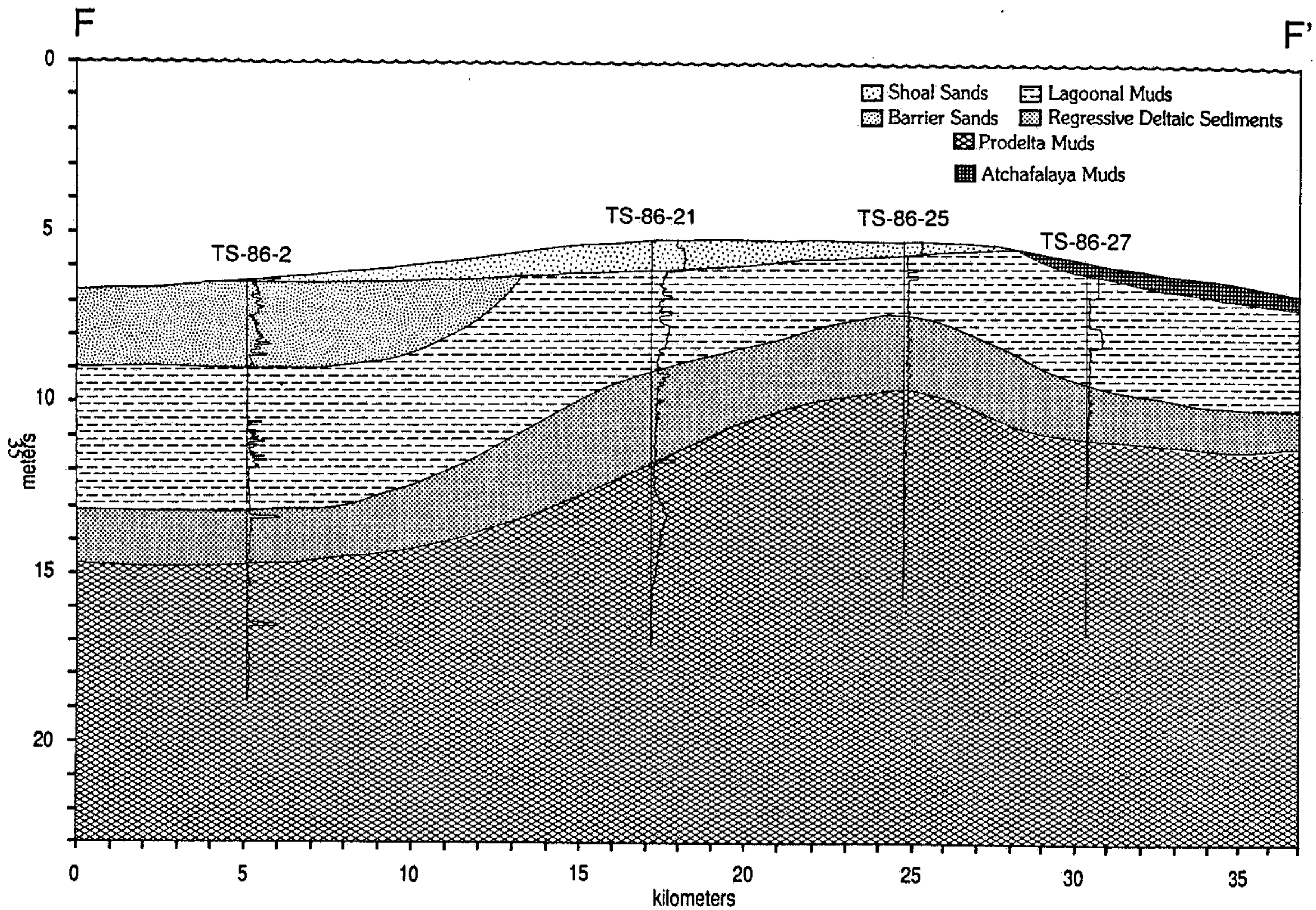


Figure 22. Stratigraphic strike cross-section F - F', Trinity Shoal.

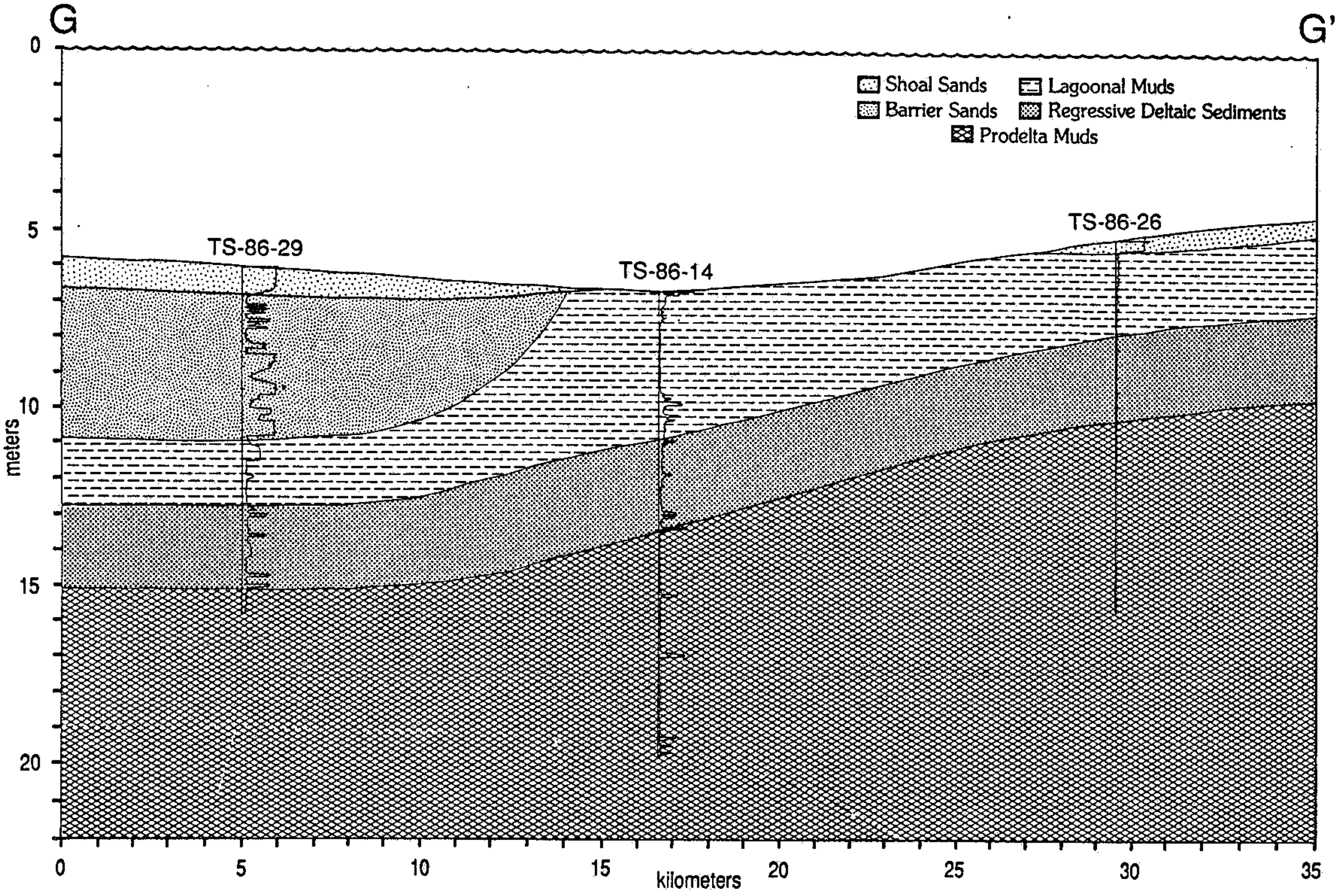


Figure 23. Stratigraphic strike cross-section G - G', Trinity Shoal.

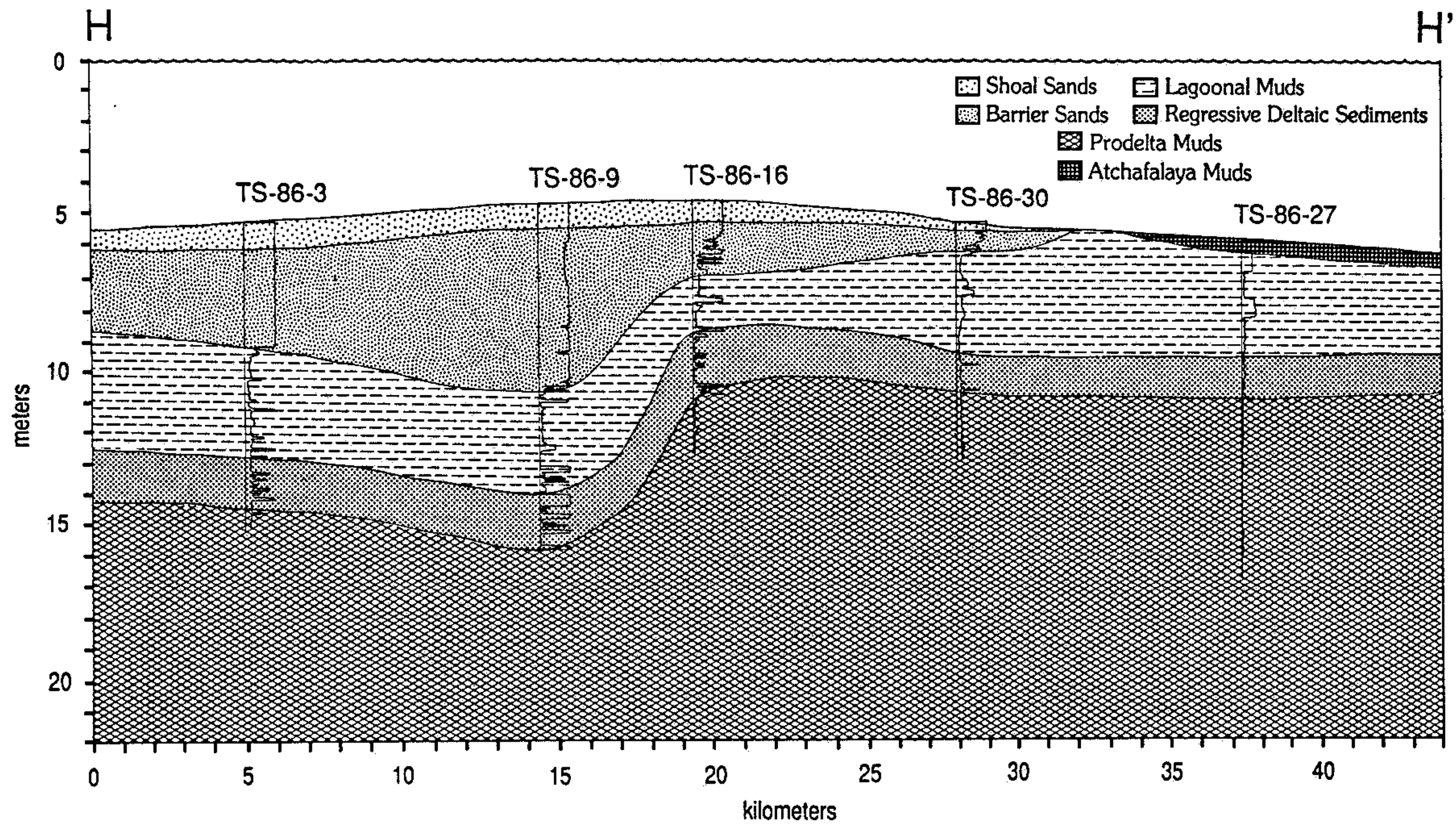


Figure 24. Stratigraphic strike cross-section H - H', Trinity Shoal.

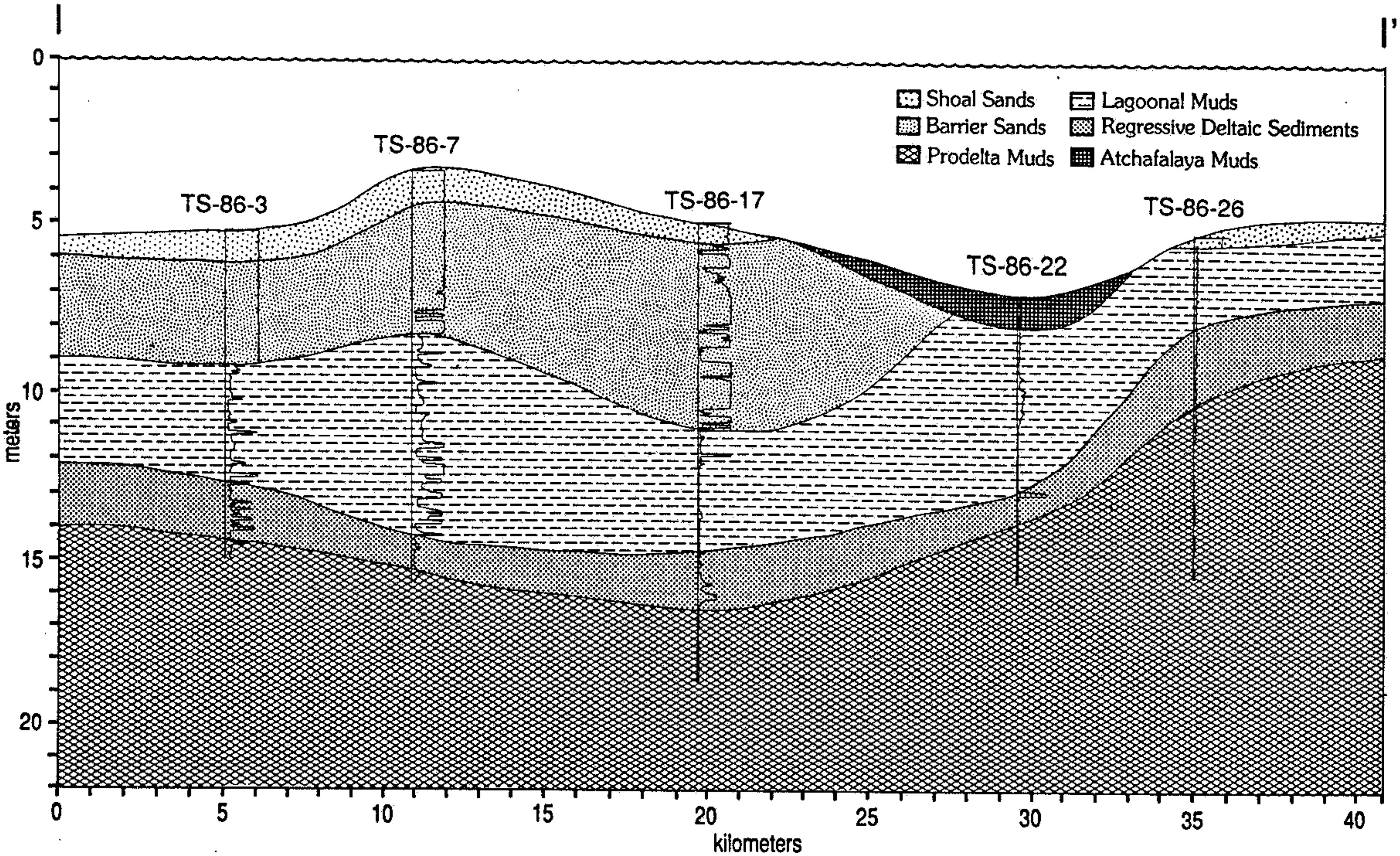


Figure 25. Stratigraphic strike cross-section I - I', Trinity Shoal.

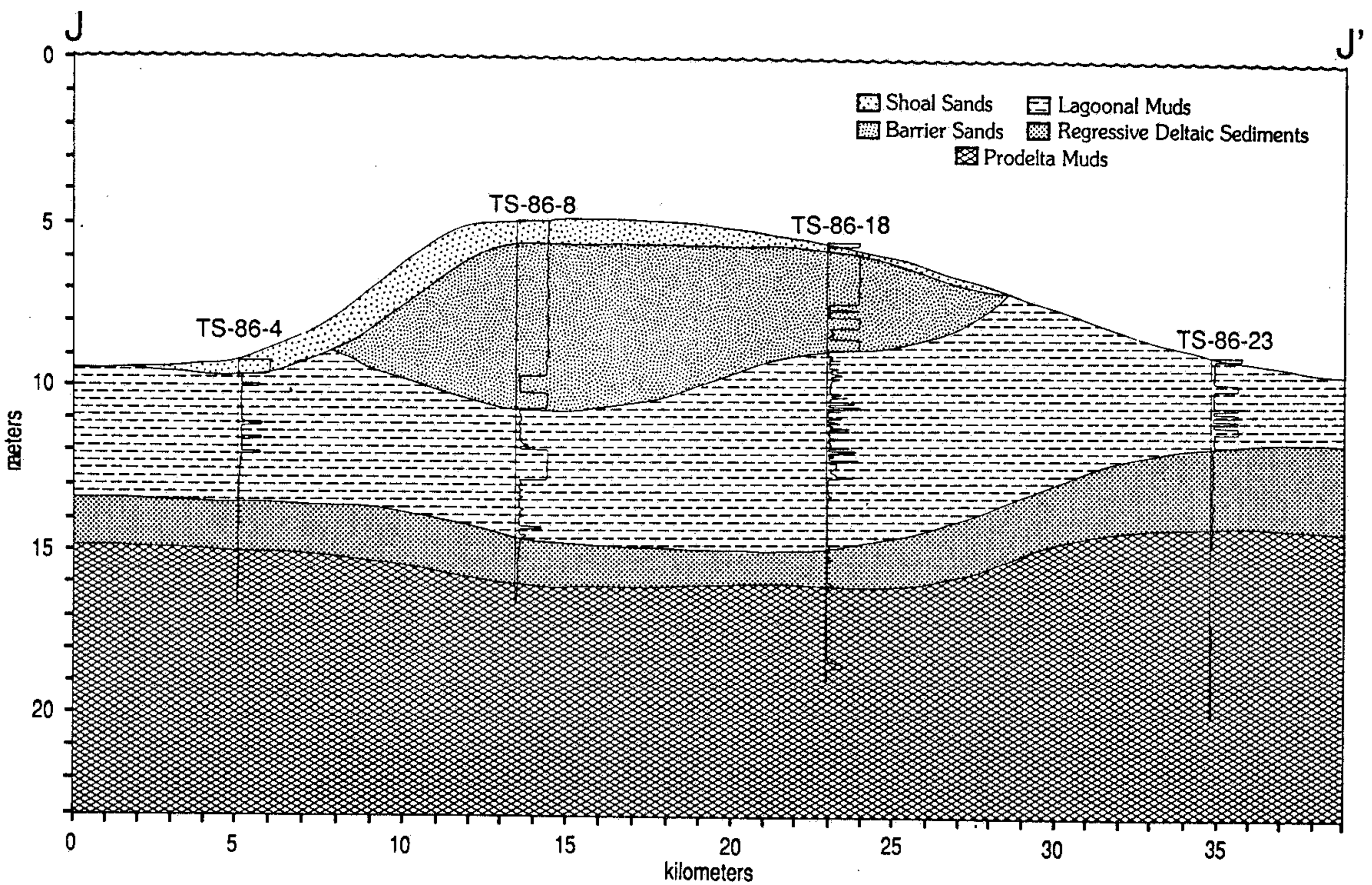


Figure 26. Stratigraphic strike cross-section J - J', Trinity Shoal

Strike cross-sections depict the Trinity Shoal sand body rapidly thinning to the east (Figures 22 to 26). Cross-sections H - H' (Figure 24), I - I' (Figure 25), and J - J' (Figure 26) illustrate the thickest portion of Trinity Shoal. Lagoonal mud form a persistent blanket throughout the area. Total shoal length is greater than 35 km and maximum width is about 32 km. The geometry of Trinity Shoal suggests it is a reworked sand body derived from the Mississippi River's Late Holocene Teche delta complex. The shoal sand body forms a thin 1 m to 2 m layer overlying the core of the barrier deposits to the west and the lagoonal mud to the east.

Isopach Mapping

Figure 27 is an isopach map of the combined shoal and barrier environments of Trinity Shoal. Seismic profiles were correlated with vibracores in order to calibrate the seismic facies with the shoal and barrier environments interpreted from core analysis. Seismic facies interpreted as representing shoal and barrier environments were then mapped throughout the study area. The Trinity Shoal isopach (Figure 27) shows a westward-skewed sand body wrapping around the western margin of the Mississippi River's Late Holocene delta plain. The thickness of the shoal and barrier deposits ranges from 0 to 8+ m. The thickest portion of the shoal and barrier deposit occurs on the southern or seaward flank of Trinity Shoal. This portion of the shoal also represents the highest quality and concentrated volume of sand within the entire area. Shoal and barrier sand thickness patterns trend in a general east-west direction across the study area.

The approximate total volume of sand contained within Trinity Shoal was determined by calculating the area between each 2 m contour using the following formula: Volume = Area 1 - Area 2 / 2 (Thickness). The total volume of sand contained within the shoal and barrier environments was calculated at about 2 billion m^3. The volume of sand between contours is about 1.1 billion m^3 for the 0 m to 2 m interval, 0.6 billion m^3 for the 2 m to 4 m interval, 241 million m^3 for the 4 m to 6 m interval, 65 million m^3 for the 6 m to 8 m interval, and 3 million m^3 for the 8 m to 10 m contour interval. By extending seismic and vibracore coverage to the west of the present grid, the true areal extent and volume of sand contained within the shoal may be better delineated.

CONCLUSIONS AND RECOMMENDATIONS

Louisiana is currently experiencing the highest rates of shoreline retreat and wetland loss in the United States. The process of land loss and change typically occurs through conversion of vegetated wetlands

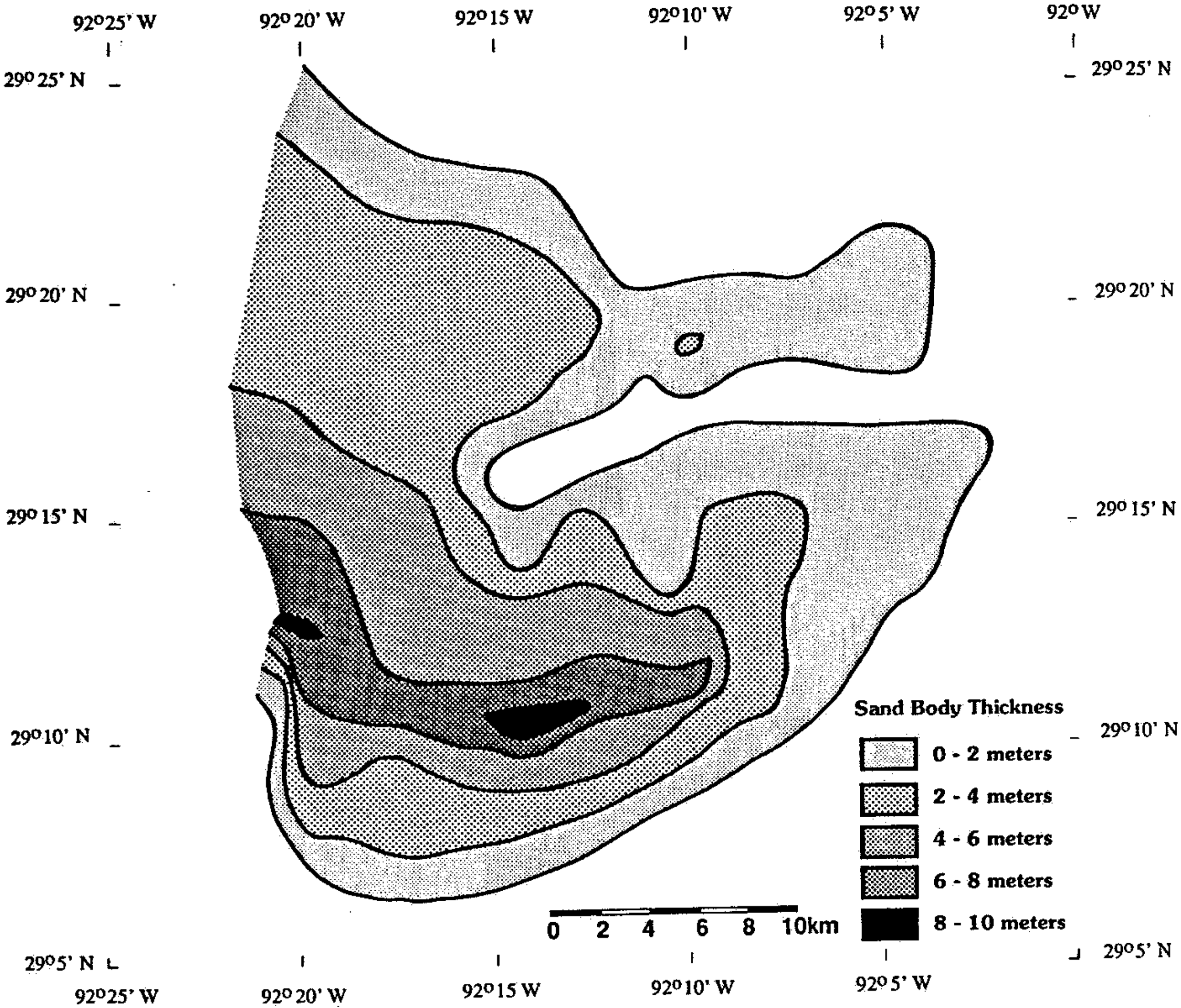


Figure 27. Isopach map of the transgressive shoal and barrier deposits, Trinity Shoal.

to an estuarine water body, followed by barrier island destruction and development of open-water conditions. Barrier island erosion occurs through shoreface erosion, tidal inlet development, and subsidence; wetlands and estuaries deteriorate by pond development, bay expansion, sediment loss, devegetation, and relative sea level rise. Human impacts are an important, but secondary component of coastal erosion and wetland loss. However, their effect may be primary for any given system, but they are difficult to establish.

A comprehensive management plan is recommended which uses beach and shoreface nourishment, barrier restoration, vegetation, coastal structure modification, and regularly-scheduled maintenance programs. These techniques are in line with natural geologic processes and are more cost-effective than conventional projects that seek engineering solutions to geologic problems.

Barrier island restoration and beach replenishment projects require large amounts of construction aggregate for beach, dune, and back-barrier building. Trinity Shoal has tremendous potential as a source of aggregate for shoreline erosion control. The shoal's transgressive sand facies offer the best source of material for coastal erosion control projects in terms of volume and quality, with a calculated volume of 2 billion m^3 based on our analysis of the current data base. However, seismic grid and vibracore locations were chosen based on existing public nautical and bathymetric charts. Data interpretation and mapping has revealed Trinity Shoal extends further to the west than shown on the published maps. We therefore recommend extending seismic and vibracore coverage to the west of the present grid in order to determine the true areal extent, thickness patterns, and total volume of quality sand in Trinity Shoal. Further study of the Holocene shoals on the Louisiana continental shelf will also provide greater insight into the processes that control coastal evolution and shelf sand development under the conditions of eustacy, subsidence, and other geologic processes.

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