

CHAPTER 3

SEDIMENTS OF THE GULF OF MEXICO

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3.1 INTRODUCTION

The Gulf of Mexico is a Mediterranean-type sea with limited fetch and low tidal ranges (microtidal) throughout. This basin is somewhat like a miniature ocean in that it contains all of the main bathymetric provinces of an ocean along with a complicated coastal zone (Figure 3.1). This chapter will consider the overall nature of the basin with emphasis on the sediments it contains. The discussion will be restricted to surface sediments and only to Holocene sediments where subsurface materials are included.

The Gulf of Mexico is a unique basin on the globe. It is located in the low, mid-latitudes and extends over multiple climatic zones. It includes regions where huge volumes of terrigenous sediments are delivered and others where terrigenous sediments are generally absent. The nature and distribution of sediments in the shallow Gulf margin have been controlled largely by the rise and fall of sea level during the waxing and waning of Quaternary glaciers. During that time, the shoreline migrated across virtually the entire continental margin, as we know it today. This has also had an influence on the sediments in the deep Gulf, from the continental slope to the abyssal plain.

The greatest terrigenous sediment supply is at the Mississippi Delta; next in volume is the Texas coast where numerous rivers cross the coastal plain regardless of the position of the shoreline. The northeast Gulf has also experienced a significant amount of terrigenous sediment influx. Similar sediment delivery along the coast of Mexico has occurred in the area south of Laguna Madre and north of Campeche Bay, but the sediment is different because of the extensive volcanic source rocks. There is virtually no sediment currently being delivered, nor has there been in the past, from the Florida Peninsula and the Yucatán Peninsula; both have been carbonate platforms throughout their existence. There is a veneer of terrigenous sediment on the Florida mainland, but the lack of well-developed drainage keeps it from being transported to the coast.

The deep Gulf environments are fairly similar to those of the world's oceans. The surface is rather flat with local relief of only a few meters. The sediments are a combination of fine terrigenous sediments and biogenic sediments contributed by various planktonic organisms. The terrigenous sediments are nearly all clay minerals that have come from the northern provinces of the Gulf States. The biogenic sediments are mostly foraminifera with some diatoms. The sediments are delivered to their sites of accumulation differently. Much of the terrigenous sediment comes to the abyssal plain via sediment gravity processes—especially turbidity currents. A small portion of the terrigenous sediment and all of the biogenic sediment settle through the water column.

The sediment on the continental slope typically is delivered in pulses or events by sediment gravity phenomena. Much of this occurred during low sea-level stages during the Quaternary. During these conditions, large streams that carried sediment extended across what is now the continental shelf, but was then the coastal plain. The mouths of these rivers were at, or near, the

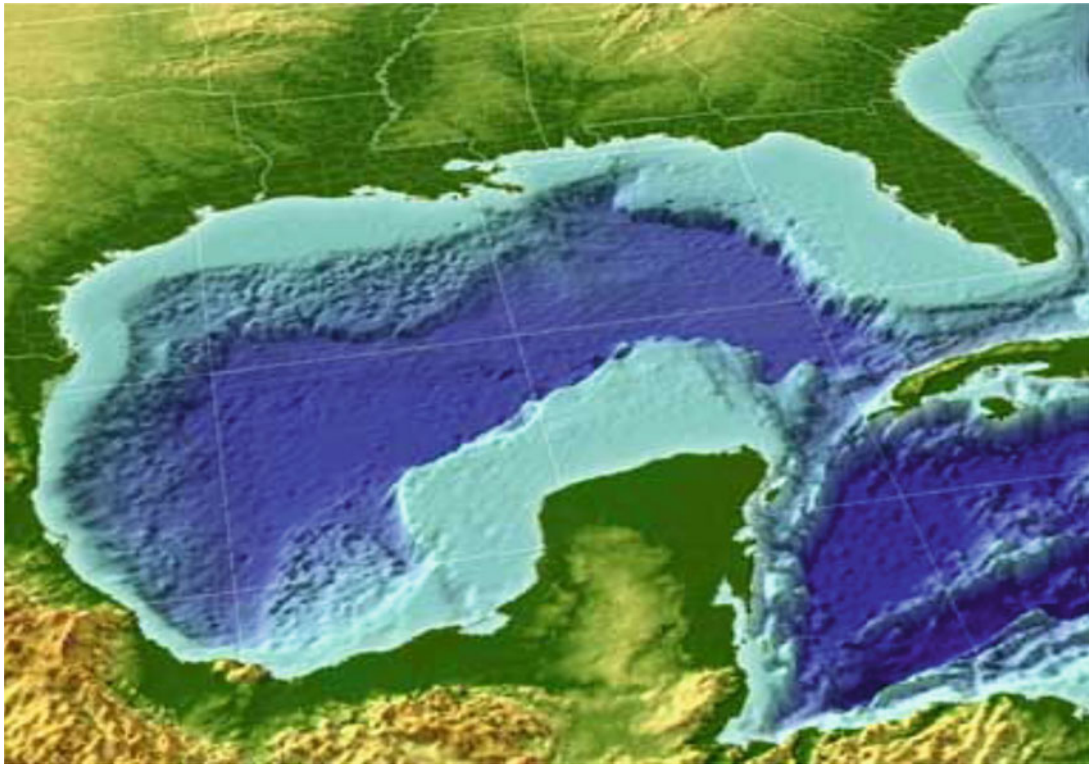


Figure 3.1. General topographic and bathymetric map of the Gulf of Mexico region (from Mertzsohn et al. 2015).

slope-shelf break where sediment was discharged. Instead of developing deltas, as happens under present conditions, the sediment was transported down the relatively steep slope with some coming to rest on this surface and most making its way to the sediment fans and the deep abyssal environment.

The continental shelf is presently composed of a combination of modern sediments, delivered since sea level reached its present or near its present position, and sediments that were deposited during sea-level lowstands when this surface was accumulating mostly fluvial sediments in channels or floodplain deposits. Most of the inner shelf surface is now composed of modern sediments; much of the outer half of the shelf is relict sediments deposited in depositional environments different than those present.

Modern sediments delivered during present sea-level conditions currently dominate coastal environments. There are also sediments in these environments that are produced within the environment that they occupy as biogenic skeletal material. Because of the development and concentration of the population around modern coastal environments, these sediments tend to be polluted at some level.

In summary, the sediments of the Gulf of Mexico range widely in all respects. The following discussions will provide an introduction to their character and distribution.

3.2 BATHYMETRIC PROVINCES

The Gulf of Mexico (Figure 3.2) has a surface area of about 1.5 million square kilometers (km^2) (579,000 square miles [mi^2]), and 20 percent (%) of its area has a depth greater than 3,000 meters (m) (9,800 feet [ft]). The continental slope comprises 20 % of the Gulf, and the

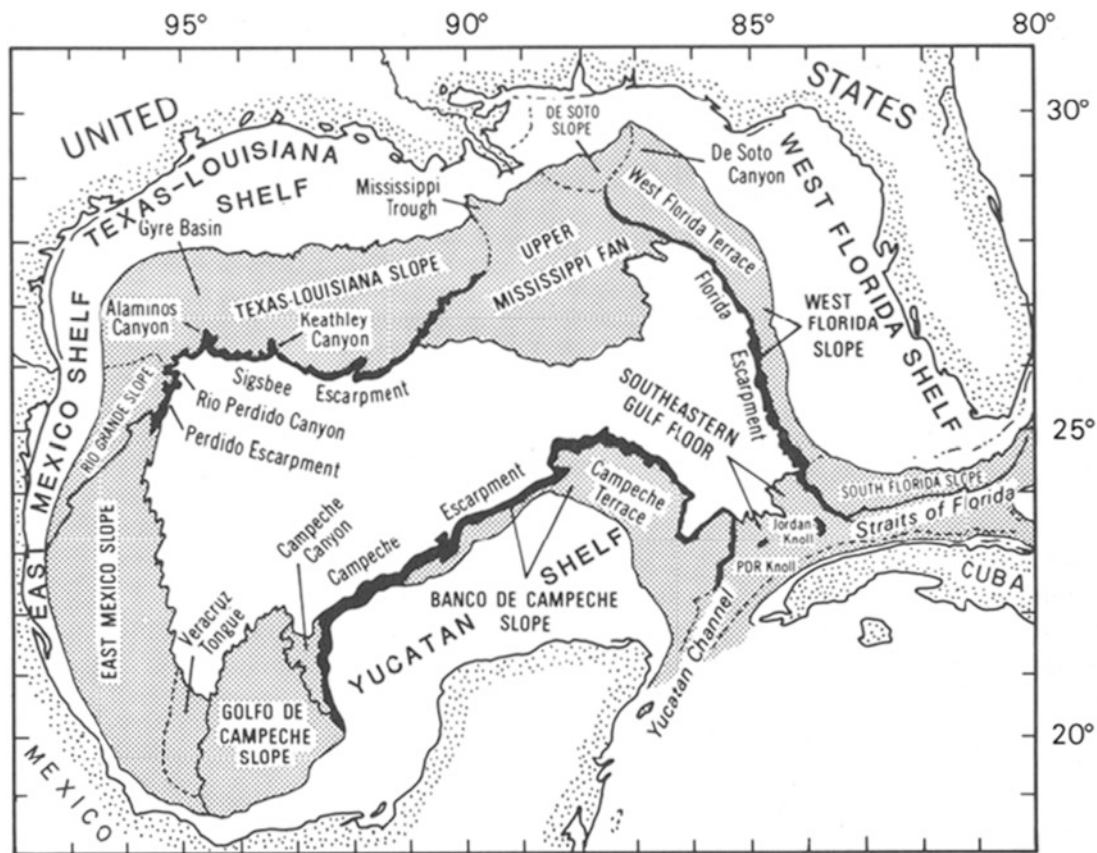


Figure 3.2. Physiographic map showing the major provinces of the Gulf of Mexico (from Martin and Bouma 1978). AAPG©[1978], reprinted by permission of the AAPG whose permission is required for further use.

continental shelf comprises 22 %. The coastal zone out to a depth of 20 m (65.6 ft) comprises 38 % of its area. Mean water depth of the Gulf is 1,615 m (5,299 ft), and the water volume of the Gulf is approximately 2.4 million cubic km (km^3) (584,000 cubic mi [mi^3]).

The shape of the basin is basically a simple cup with thick sediment sequences. It dates from Late Triassic time, about 150 million years ago. Sea level has experienced considerable change since that time as crustal plates have moved over the earth's surface. The time of highest sea level was during the Cretaceous Period, about 75 million years ago. The time of lowest sea level was only about 20,000 years ago when it was about 120–130 m (395–425 ft) below its present level (Salvador 1991). For purposes of this chapter, the Gulf will be divided into two provinces: terrigenous and carbonate (Uchupi 1975). These terms refer to the type of sediments that characterize each of the provinces (Figure 3.2). Terrigenous sediments are derived from land through river runoff, and carbonate sediments are precipitated in the Gulf generally as skeletal material (primarily from invertebrates) or as direct precipitates. These will be discussed in detail later in the chapter.

The physiography of the Gulf basin has been controlled by numerous geologic phenomena. They include (1) rifting, (2) subsidence, (3) development of carbonate platforms, (4) Gulf-wide changes in sea level, (5) formation of salt domes, (6) gravity slumping, and (7) sediment gravity flows (Bryant et al. 1991).

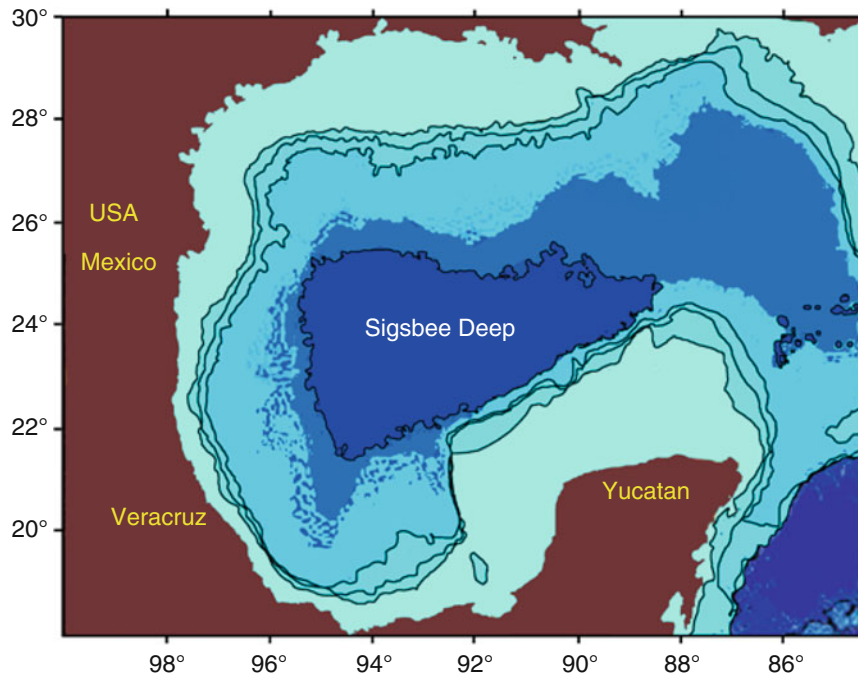


Figure 3.3. Map showing the location and extent of the Sigsbee Deep in the dark outlined area near the center (courtesy of Universidad Nacional Autonoma de Mexico).

3.2.1 Sigsbee Abyssal Plain

Much of the abyssal plain portion of the Gulf is called the Sigsbee Deep (Figure 3.3). It lies in the central portion of the basin and reaches a maximum depth of 3,750–4,384 m (12,300–14,383 ft) depending on which author you read (Turner 1999). This area is one of the flattest places on earth. Its surface slope is 1:10,000 and smooth (Bryant et al. 1991) except for the Sigsbee Knolls, which are diapiric salt domes that represent the only significant relief on this surface.

3.2.2 Mississippi Fan (Cone)

The Mississippi Fan (cone) is a deepwater feature (Figure 3.4) that extends from the outer continental margin off the mouth of the Mississippi River to the abyssal plain (Sigsbee Deep). It lies between the Mississippi Trough and the De Soto Canyon. This fan covers 300,000 km² (116,000 mi²) (Twichell 2011). The Sigsbee Escarpment, the margin of the Jurassic Luann salt, is on the northwest edge of the fan. The Mississippi Canyon is the sediment's main pathway to the fan. On its southeastern edge, it grades into the Florida abyssal plain.

This huge accumulation of sediment (Figure 3.5) was developed primarily during Pleistocene time and is linked to the rise and fall of sea level resulting from expansion and contraction of ice sheets on the continents (Bryant et al. 1991). It has been calculated that during the Pleistocene lowstands of sea level, the rate of sediment delivery was about 13 times what it is now (Perlmutter 1985). Now sediment is being transported to the fan very slowly. When the course of the Mississippi River moved to the east late in the Quaternary, the Mississippi Canyon was removed as a major conduit of sediment to the fan.

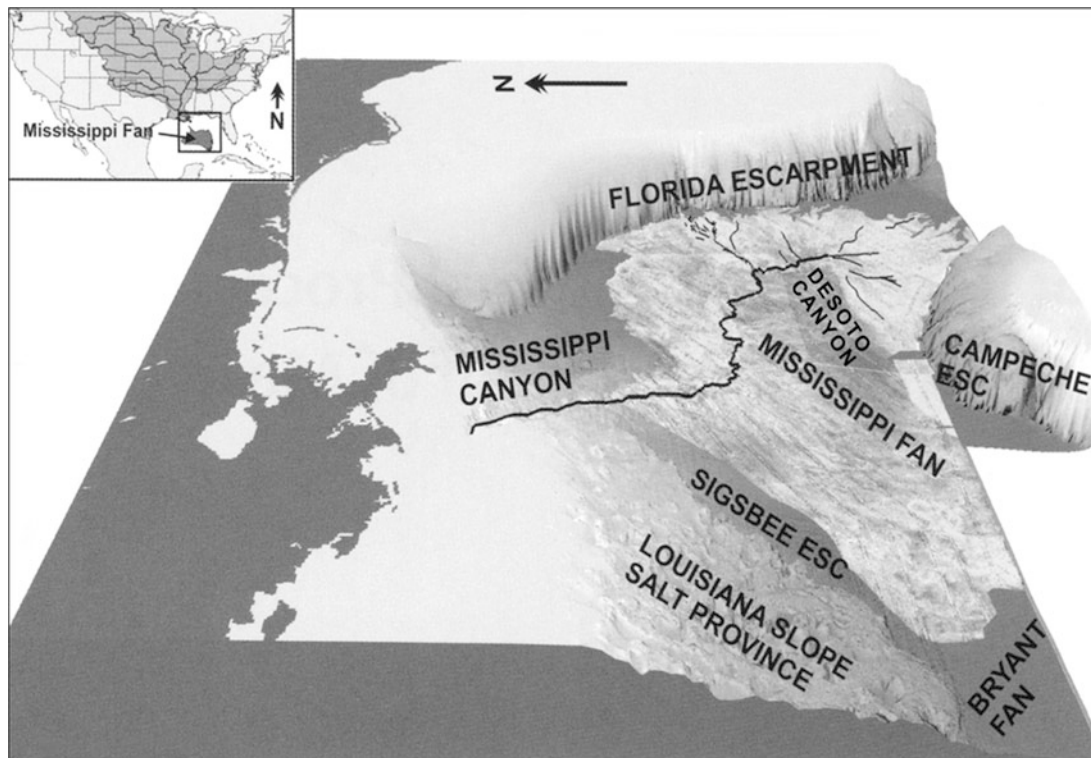


Figure 3.4. A three-dimensional schematic diagram of some of the major deepwater provinces in the Gulf of Mexico (from Twichell 2011).

3.2.3 Continental Slope

There is a range of morphologies on the continental slope. The aforementioned Florida Escarpment is very steep and has modest relief on the underlying carbonate strata of Mesozoic Age. The Yucatán Platform is similar. Much of the slope comprises small basins that are produced by the movement of salt, typically in diapiric fashion. The basins are 10–12 km (6.2–7.5 mi) in diameter with relief of 150–300 m (490–980 ft) (Bryant and Liu 2000). There are about 90 of these small basins.

The De Soto submarine canyon crosses the continental slope at the western end of the Florida Platform (Figure 3.4). Data show that this canyon is very old, and it has not received significant sediment accumulation since the latter part of the Cretaceous Period (Bryant et al. 1991). By contrast, the Mississippi Canyon (Figure 3.5) is one of the youngest such physiographic features in the Gulf of Mexico having been formed in the late Quaternary. It was also filled with sediment in a rather short time.

From the western edge of the Mississippi Canyon across the Texas slope, the surface of the continental slope is quite complex with abundant salt and shale diapiric structures that have relief of tens of meters (Figure 3.6). The Rio Grande slope is complicated by multiple structural ridge systems. Farther to the south, salt diapiric systems interact with these ridge systems and further complicate the bathymetry (Bryant et al. 1991). Proceeding into the Bay of Campeche, the nature of the slope becomes similar to that off the coasts of Texas and Louisiana with complex salt diapirs.

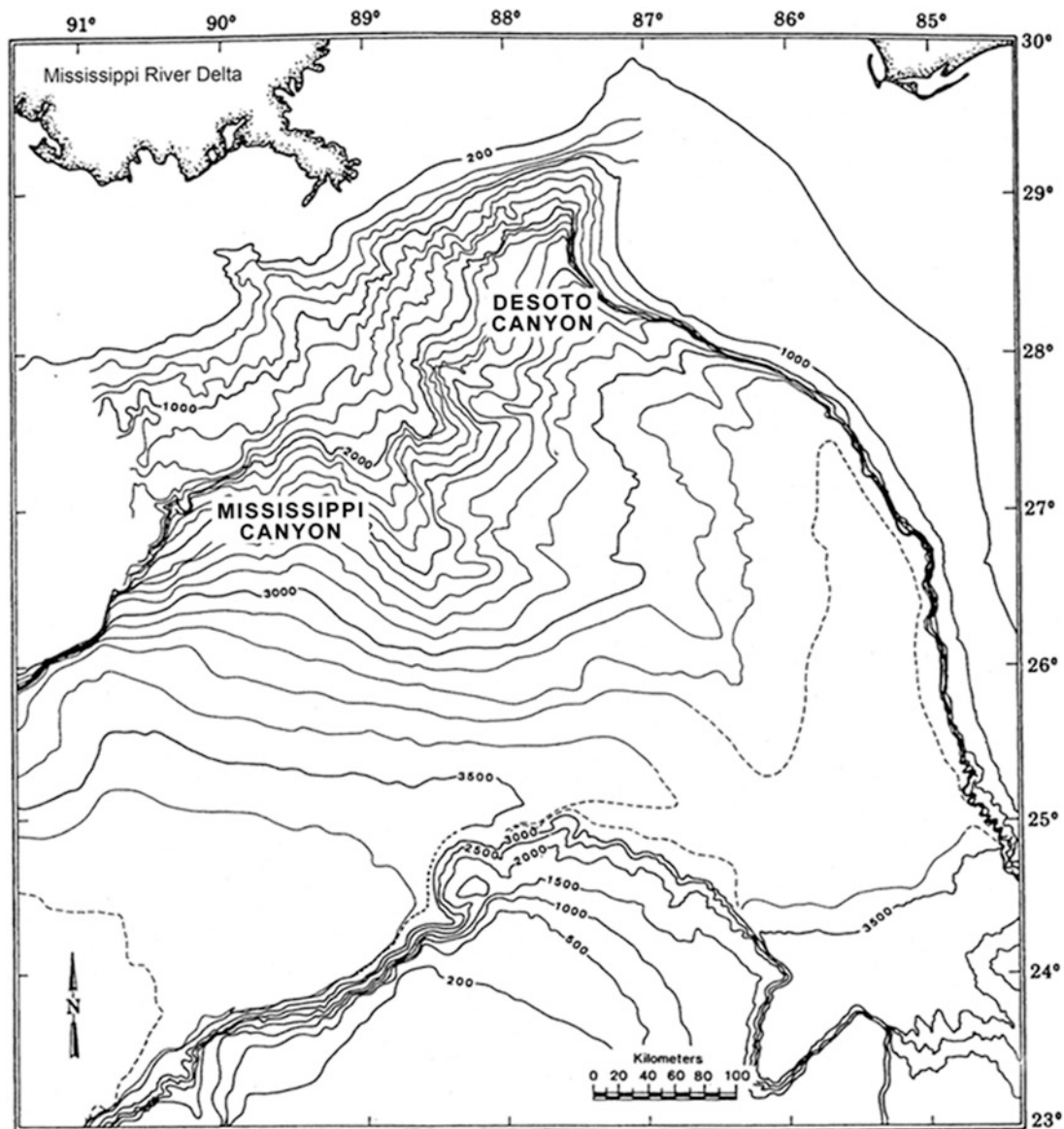


Figure 3.5. Bathymetric map of the Mississippi Fan. Reprinted from Bouma et al. 1985, Chapter 21-Mississippi Fan, Gulf of Mexico (AH Bouma, CE Stelling, JM Coleman), p. 144, with permission of Springer.

3.2.4 Continental Shelf

The continental shelf of the Gulf of Mexico displays a range of morphologies depending on the framework geology. The shelf adjacent to the Florida Peninsula is the widest and has the lowest gradient. This shelf is the submarine extension of the Florida Platform, a thick accumulation of limestone that extends back to the Jurassic Period. Its present expression is as a limestone surface with scattered carbonate and terrigenous sediment. It extends more than 500 km (300 mi) and is more than 150 km (93 mi) wide along the 75-m (245-ft) isobaths (Hine and Locker 2011). The maximum width is 240 km (149 mi). The gradient ranges from 0.2 to 4.0 m per km (m/km) (0.67–1.25 ft/mi) overall but is steeper (6–9 m/km) (20–30 ft/mi) in the

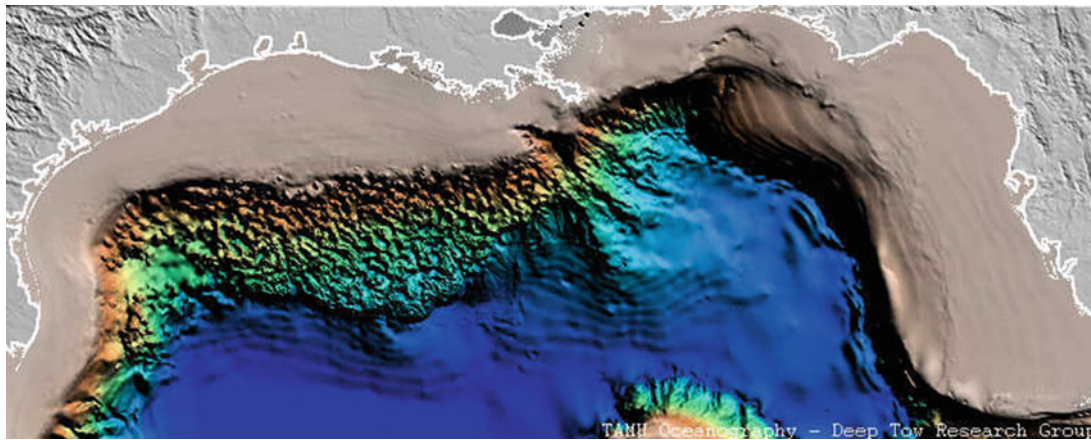


Figure 3.6. A schematic map of the continental slope of the northern Gulf of Mexico in the context of the continental shelf and the deep Gulf basin (courtesy of Texas A&M University, Deep Tow Research Group).

nearshore area. This shelf essentially terminates at De Soto Canyon on the north and at the Portales Terrace on the south. The Florida Escarpment (Figure 3.7) is at the edge of the shelf and is one of the steepest submarine slopes in the world at a slope of 45° (Bryant et al. 1991).

The shelf in the northeastern Gulf is narrower and steeper with numerous shelf ridges (Figs. 3.8 and 3.9) and relict deltas (Hine and Locker 2011). The fabric of this relief trends northwest–southeast. The shelf bathymetry in this part of the Gulf reflects the combination of the numerous cycles of sea-level change along with the dominance of fluvial influence. The De Soto Canyon (Figure 3.2) is the largest physiographic feature off the Florida panhandle. Its headland extends to within 25 km (15.5 mi) of the shoreline. The shelf widens to about 100 km (62 mi) on either side (Hine and Locker 2011).

There is essentially no continental shelf around the Mississippi Delta; the active delta extends across the shelf. The shelf to the west of the delta is rather similar along the entire Texas coast. It is wide, has low relief, and has a moderate gradient between that of the northeast Gulf and west Florida. There are many relict reefs and knolls on the Texas shelf that provide several meters of relief on an otherwise rather flat surface. The crests of salt domes that have protruded upward through younger Mesozoic and Cenozoic strata provide some relief on the east Texas shelf.

Moving to the west, the Louisiana and Texas shelf is broad and flat with a width that ranges from 32 to 90 km (20–56 mi) (Bryant et al. 1991). It is scattered with relict reefs and salt dome diapirs off Louisiana and east Texas. There are also numerous filled fluvial channels that developed during Quaternary lowstands of sea level.

A major change in the bathymetry of the Texas shelf occurs near the middle, what is commonly called the Coastal Bend. Here there is a gradual transition from shelf bathymetry to the slope in distinct contrast to the relative abrupt change in bathymetry between these two provinces on the remainder of the Texas shelf (Figure 3.10). This zone lies between the ancestral deltas of the Rio Grande River to the south and the Brazos–Colorado delta to the north.

Around the west Gulf shelf off Mexico there is a major narrowing of this province from about 80 km (50 mi) at the Rio Grande to less than 10 km (6.2 mi) off the volcanic province near Veracruz, Mexico. There is a marked widening of the shelf toward the Yucatán Peninsula. Salt diapirs are an influence west of the Campeche Bank (Bryant et al. 1991).

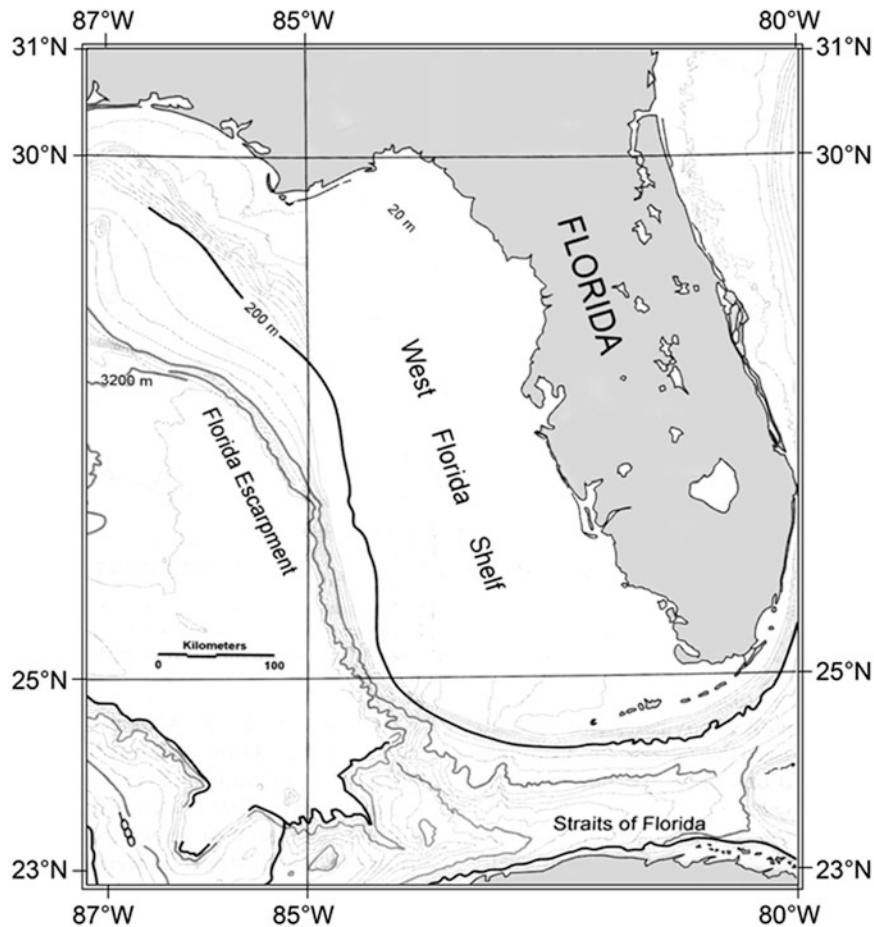


Figure 3.7. The Florida shelf and escarpment that forms the west margin of the Florida Platform (Hine et al. 2003b). Reprinted from *Marine Geology*, Vol 200, Hine AC et al., The west-central Florida inner shelf and coastal system: A geologic conceptual overview and introduction to the special issue, Figure 3, Copyright 2003, with permission from Elsevier.

The shelf along the Mexican mainland is similar to that in the northwest Gulf but is generally not as wide. It is gently sloping and has little relief on it. Like the Florida shelf, the slope on three sides of the Yucatán shelf is steep—up to 35°. Because the northern coast of Cuba is adjacent to the Florida Straits, it also has a narrow and relatively steep shelf.

3.2.4.1 Relict Sediment Cover

On most of the shelf, the relief of the relict sediment cover is limited to shore-parallel quartz sand sediment bodies that are interpreted as being relict barriers that were abandoned during rapid sea-level rise in the Pleistocene era. Most are late Pleistocene or Holocene in age, but some might be older. There are relict Quaternary reefs along various isobaths, particularly offshore of Texas. The relict cover is dominated by lowstand depositional environments such as fluvial channels, floodplains, and deltas (Anderson and Fillon 2004).

Another important component of the shelf is the presence of these relict barrier islands. They are distributed around the entire Gulf of Mexico but with various relationships to the modern sediment blanket. On the Florida shelf, these relict barriers are small and rest primarily on limestone bedrock (Figure 3.11).

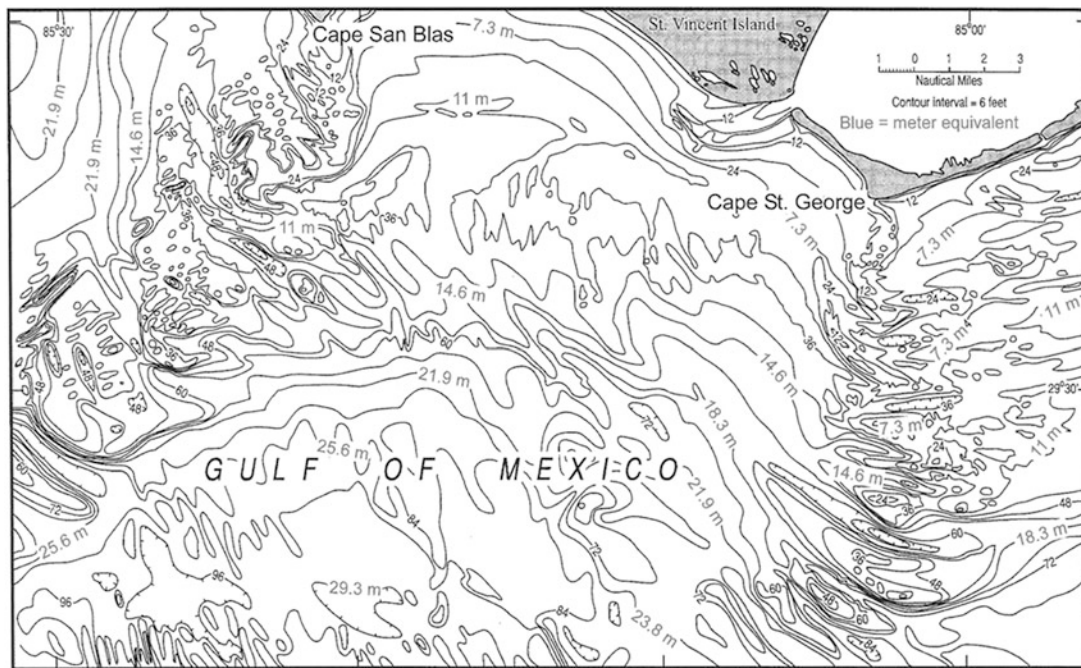


Figure 3.8. Bathymetric map of a portion of the continental shelf off the panhandle of Florida showing considerable relief of linear features that are sand bodies reworked from fluviodeltaic sediments of Quaternary sea-level lowstand deposition (from McBride et al. 2004; reprinted with permission from the Society for Sedimentary Geology).

Similar sand bodies are present off the panhandle coast of Florida and have been described in McKeown et al. (2004). Further west on the shelf, much larger relict sand bodies are present on the Louisiana shelf. The largest of these is the Ship Shoal (Figure 3.12). These relict sand bodies are the sites of possible nourishment sand for the Louisiana coast.

Similar sediment bodies are also present on the Texas coast. From east to west, they are the Sabine Bank, Heald Bank, and Freeport Rocks. All of these relict sediment bodies (Figure 3.13) represent coastal accumulations of sand and shell material that were deposited during slow-downs or stillstands of the Holocene sea-level rise (Rodriguez et al. 1999).

3.2.4.2 Modern Sediment Cover

On the west Florida shelf, the modern sediment cover displays essentially no relief on the shelf surface except for the above-described sand bodies. The surface of the shelf throughout most of its extent is the pre-Quaternary carbonate strata with sinkholes and karstic terrain—both widespread and abundant. The Yucatán shelf of Mexico is similar. The rest of the northern Gulf shelf is a mixture of relict and modern sediment surfaces. The continental shelf around the Yucatán Platform is in some ways similar to that in Florida. It is up to 240 km (150 mi) wide on the north but quite narrow on the east. The surface is scattered with karstic features and reefs (Logan et al. 1969).

The shelf in Cuba is unlike the rest of the Gulf of Mexico because it is a collision area. The Caribbean plate moved into this region pushing between the North American and South American plates. As a result, this margin is narrow with high relief and numerous structural components including faults.

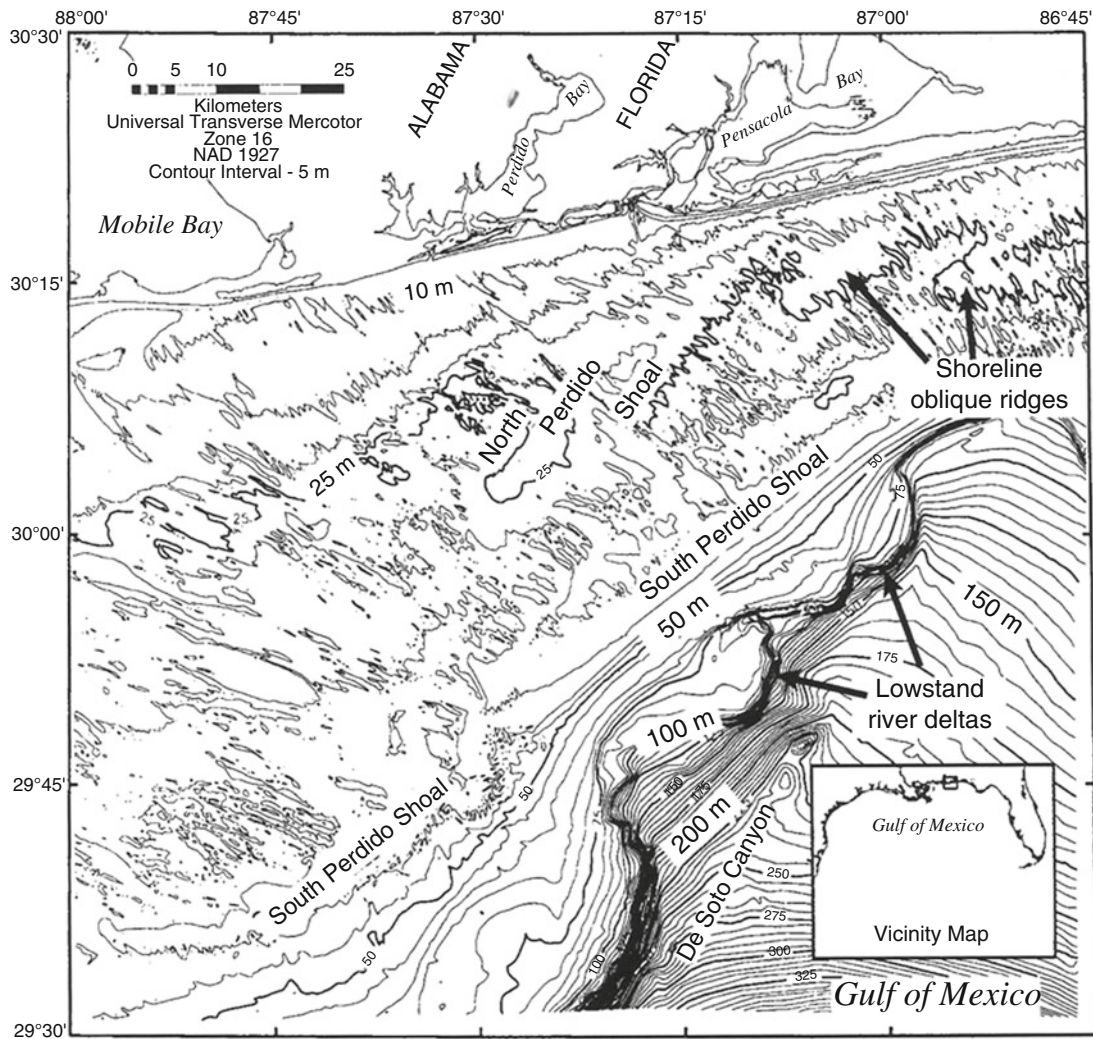


Figure 3.9. Bathymetric map off the northern Gulf Coast with considerable relief caused by northwest–southeast trend (from McBride et al. 2004: reprinted with permission from the Society for Sedimentary Geology).

3.2.5 Coastal Environments

3.2.5.1 Beach and Nearshore Zone (Barrier Islands)

Barrier islands and their contained beaches are extensive around the Gulf Coast. These barriers are young; some are only decades old, and the oldest is about 7,000 years old. Their size tends to be related to the abundance of sediment. They range from only a kilometer (0.6 mi) or so to 150 km (93 mi) in length. The relief may be up to 15 m (49 ft). Most of these barriers are wave dominated, but there are also mixed-energy barriers, most of which are on the Florida coast. The surf zone, just offshore of the beach, is commonly characterized by longshore bars and intervening troughs (Davis and FitzGerald 2003), the number of which is the result of bottom gradient and sediment availability. This zone is the most dynamic of the entire Gulf in that waves and currents are continuously present and ever changing.

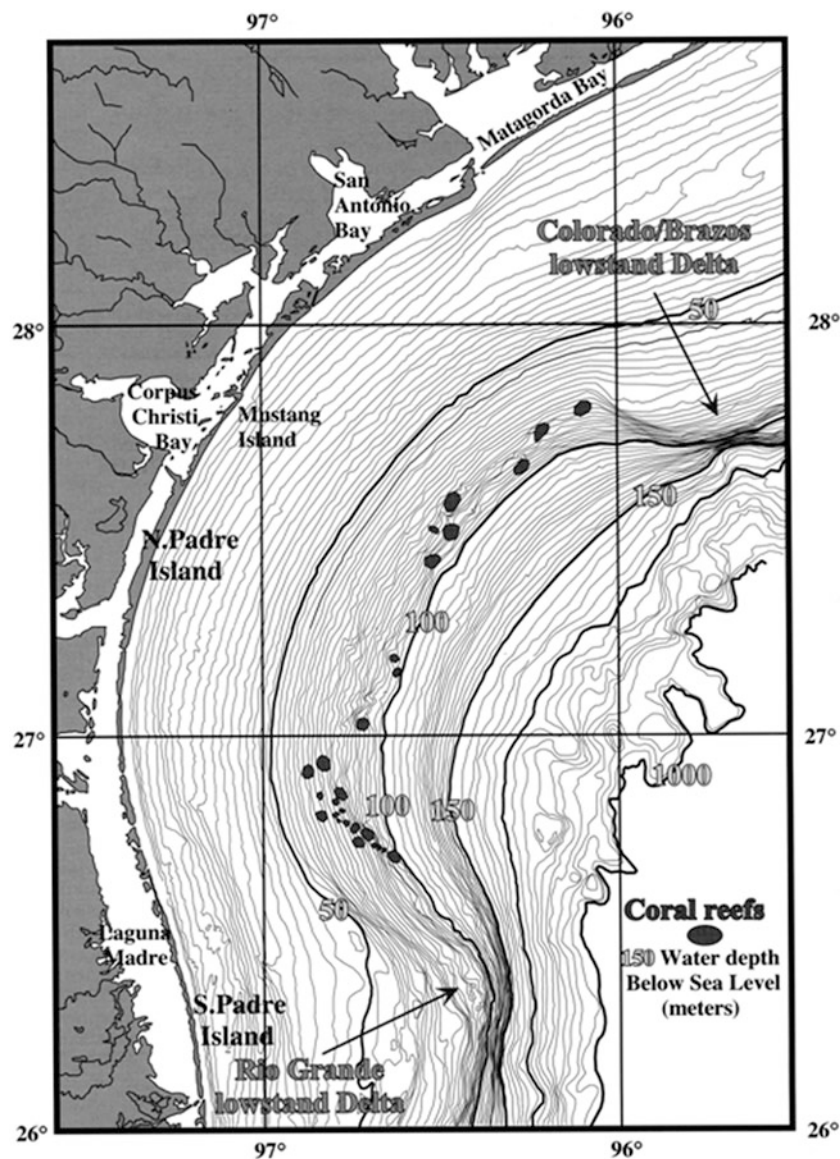


Figure 3.10. Bathymetric map of the shelf in the central and south Texas continental margin where there is a major change in the surface configuration. To the north and south, the bathymetry is as expected with a smooth shelf and a change to a steep slope. The central area is quite different with an embayment and multiple coral reefs (from Berryhill 1987). AAPG © [1987], reprinted by permission of the AAPG whose permission is required for further use.

3.2.5.2 Dunes

Most of the Gulf Coast is surrounded by sand dunes. The dunes result primarily from onshore wind blowing over the dry beach. These dunes range widely in size depending on the availability of sediment. The largest tends to be on the panhandle of Florida, the Matagorda Peninsula, and Padre Island, Texas. In parts of the Gulf Coast, dunes are completely absent, primarily in the southwestern and Big Bend parts of Florida.

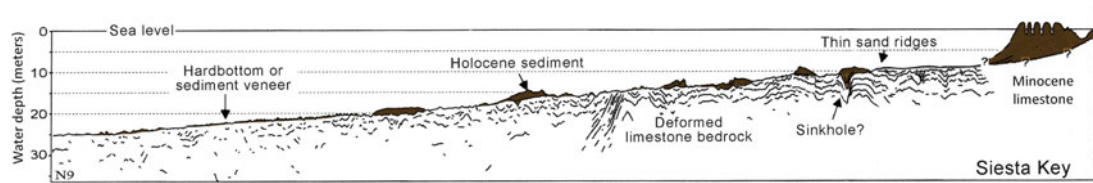


Figure 3.11. Interpreted seismic profile from the inner continental shelf of Florida showing the presence of small sediment bodies (*black*) that are interpreted as relict barrier island sand bodies (Locker et al. 2003). Reprinted from Marine Geology, Vol 200, Locker SD et al., Regional stratigraphic framework linking continental shelf and coastal sedimentary deposits of west-central Florida, Figure 3, Copyright 2003, with permission from Elsevier.

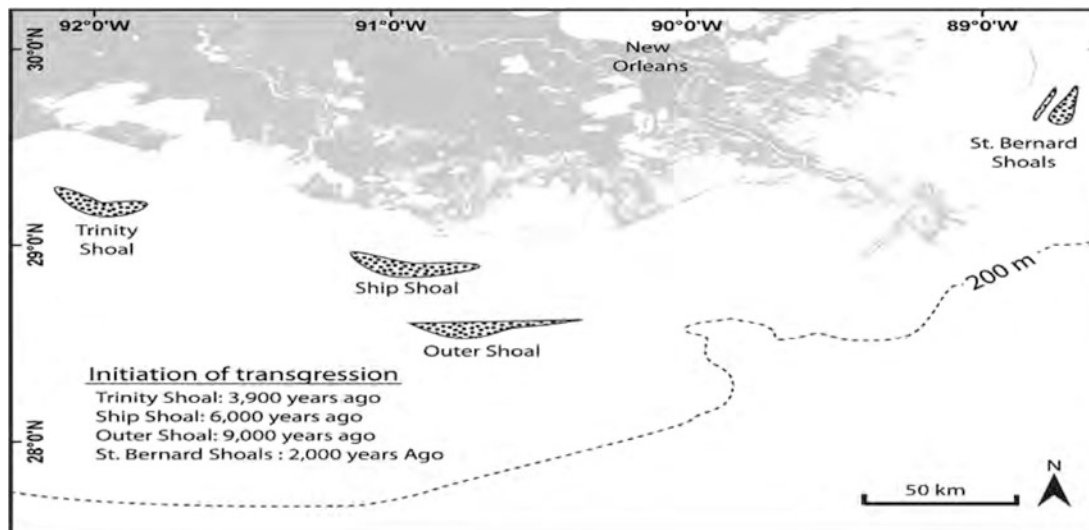


Figure 3.12. Major relict sand bodies on the Louisiana continental shelf. These huge sand bodies are potential nourishment material for the Louisiana coast (from Rogers and Kulp 2009).

3.2.5.3 Tidal Inlets

Breaks in the numerous barrier islands around the Gulf are tidal inlets where considerable tidal flux is transported during each tidal cycle. The volume of water transported through these inlets ranges among four orders of magnitude depending on the size of the estuaries (Davis 1988). The depth of the inlets ranges from only 1 m (3.3 ft) to more than 30 m (98 ft). Inlets tend to have large sediment accumulations at both the Gulf side (ebb-tidal deltas) and the landward side (flood-tidal deltas). The size of the inlet tends to be directly related to the tidal prism (water budget) that passes through the inlet during an individual tidal cycle. Inlets of the Gulf Coast range from tide-dominated through mixed-energy to wave-dominated. Small unstable inlets have closed over historical time, and hurricanes have generated new ones. In general, little sediment is passing from estuaries into the Gulf.

3.2.5.4 Wetlands

Coastal wetlands are widespread along the many coastal bays on the Gulf of Mexico. In the low latitudes—generally south of about 30°—wetlands are dominated by mangroves: red

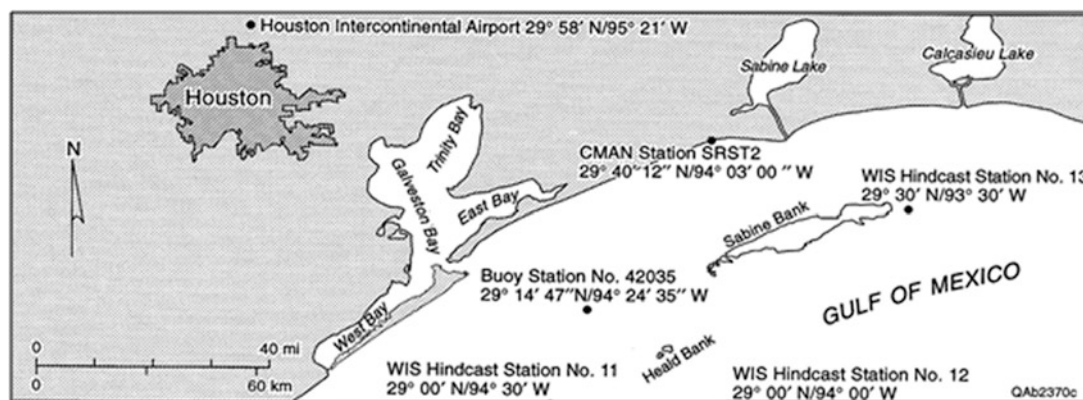


Figure 3.13. Locations and geography of Sabine and Heald Banks on the east Texas shelf. These are relict barrier islands similar to those off Louisiana (from Morton and Gibeaut 1995).

(*Rhizophora mangle*), black (*Avicennia germinans*), and/or white (*Laguncularia racemosa*). Some marsh grass can also be present. North of that latitude, the wetlands are dominated by salt marsh with cordgrass (*Spartina*) and rushes (*Juncus*) being the dominant vegetation. These wetlands extend over only a few tenths of a meter of elevation due to the small tidal range throughout the Gulf. The combination of dammed rivers, hurricanes, and sea-level rise has caused a tremendous reduction in the area of wetlands on the Gulf Coast, especially along the northern coast.

3.2.5.5 Estuaries

The Gulf of Mexico is surrounded by many estuaries; however, they are small and scarce on the Yucatán coast. These estuaries are the result of flooding of drainage systems that were incised during lowstands of sea level during the Quaternary Period when there were multiple cycles of sea-level rising and falling in response to the advance and retreat of glacial ice sheets. Estuaries may have a single river or multiple rivers emptying into them. These coastal water bodies are generally brackish and shallow, typically less than 5 m (16.4 ft) deep. Sediments in these coastal bays are dominated by mud.

3.2.5.6 Lagoons

The term lagoon is used to separate those coastal bays that have essentially no freshwater input or tidal flux from those that do (estuaries). Along the Gulf Coast, there are a few lagoons, most prominent of which are Baffin Bay and Laguna Madre of Texas. Smaller examples are also present on the coast of Mexico (Laguna Madre, Alvarado, Celestún) (Carranza-Edwards 2011).

Baffin Bay is a drowned fluvial system that was active in an earlier time when the climate in this area was much wetter. Laguna Madre is a long, shore-parallel coastal bay that reaches salinities near 100 parts per thousand (ppt) in some isolated areas. Both are quite shallow.

3.3 GENERAL CHARACTERISTICS OF SEDIMENTS

In this section, each major category of Gulf of Mexico sediment will be discussed in general, and then the sediments of all environments within the Gulf will be addressed. Because of the extensive geography being considered, some generalities will need to be presented. Every square meter of the Gulf floor, at all depths, contains some sediment (Figure 3.14).

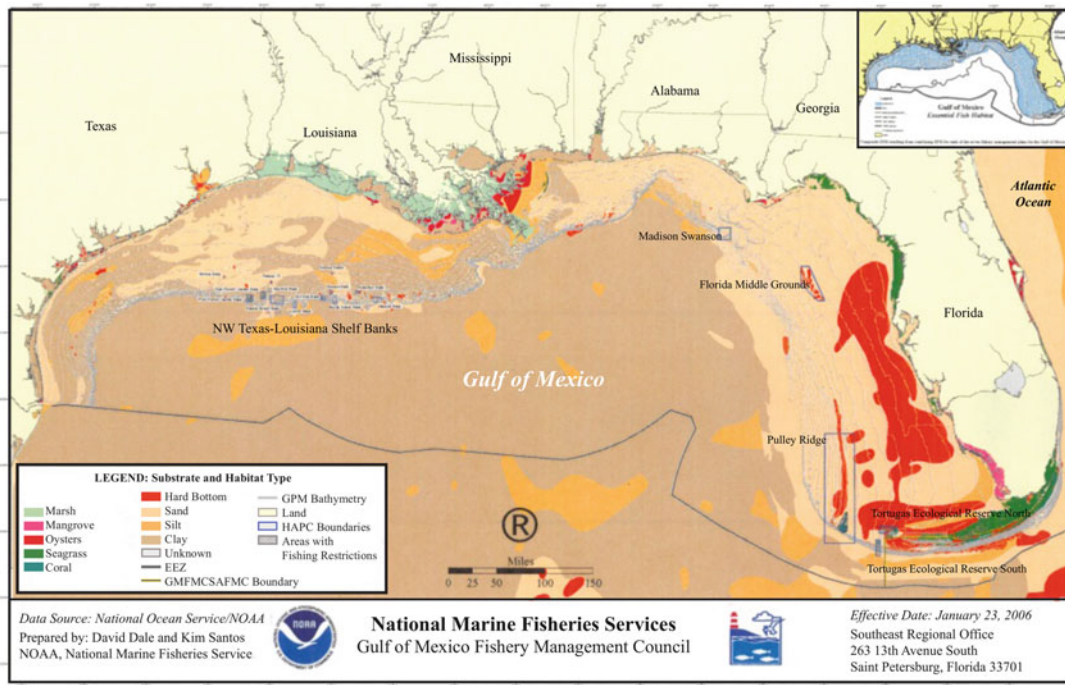


Figure 3.14. Map of the bottom surface sediment throughout the northern Gulf of Mexico (from NOAA).

Table 3.1. Percentage Range of the Constituents of Detrital Sand and Silt in Cores Taken from the Gulf of Mexico (from Davies and Moore 1970).

Category	Percent Range	Category	Percent Range
Quartz	1–67	Matrix (clay minerals)	1–72
Feldspar	0–7	Carbonate grains	2–75
Mica	0–4	Glass	0–83
Rock fragments	0–22	Accessories	0–6
Iron oxide grains	0–18		

Some of the dominant constituents (Table 3.1) can be associated with geographic areas. For example, the carbonate-rich sediments are typically associated with the Florida and Yucatán platforms. The glass fraction is associated with the area of Mexico near Veracruz where volcanic source rocks are abundant, and the mud (matrix) is most common in the deep basin, estuaries, and deltas.

3.3.1 Terrigenous Sediments

The term *terrigenous* comes from the Greek roots of *terra*, meaning land, and *genesis*, meaning origin. These sediments originate on land. They are eroded, transported by river systems to the coast, and become most of the Gulf of Mexico floor including all environments from the coast to the deep regions. Terrigenous sediments almost exclusively comprise silicate minerals. These are minerals that have their core in the elements silica and oxygen, with the relative abundance of each depending on the family within the silicate mineral spectrum. The most basic of these is quartz (SiO₂), which is one of the two most abundant terrigenous

minerals in the Gulf. Quartz is very resistant to chemical erosion and is quite durable physically. As a result, quartz is able to withstand the rigors of erosion and transportation over long periods of time and distances of travel.

The other very abundant terrigenous species are clay minerals. Clay minerals are termed *layered silicates* because their crystallography causes them to split into thin sheets. Mica is an excellent example of a layered silicate. Most of the clay minerals are the weathering products of other minerals such as feldspars. There are multiple clay minerals depending on the number of layers in their crystal structure and the types of elements that are combined with the silicate structure. They include iron (Fe), aluminum (Al), magnesium (Mg), potassium (K), calcium (Ca), and sodium (Na).

It is possible to make some generalizations about the distribution of clay mineral species in the Gulf Basin. Four clay mineral species can be found in the basin: smectite, illite, kaolinite, and chlorite. Because of the range of clay mineral species over multiple physiographic provinces, it is best to consider their general distribution here. Smectite, which is the most common of the four, is relatively low in concentration on the shelf of Alabama and Florida. Illite is the next most common species in the Gulf; however, illite abundance shows a decrease from the shelf into the deep basin. Kaolinite decreases from east to west and is generally low on the central and western parts of the Gulf. Chlorite is the least abundant throughout the basin, less than 20 % in all environments (Wade et al. 2008).

The other two most common elements of terrigenous sediments are feldspar (a potassium silicate) and rock fragments (small pieces of rock of many compositions that comprise multiple mineral grains). Other resilient terrigenous mineral grains occur in very small percentages in sand. These are commonly called accessory minerals or heavy minerals (Figure 3.15), and most

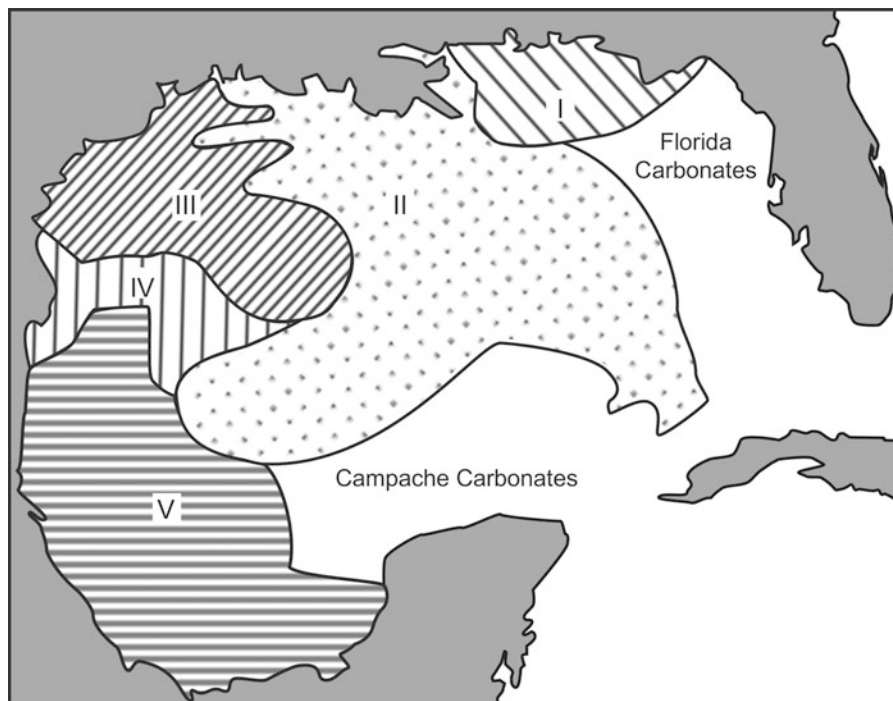


Figure 3.15. General map of heavy mineral group distribution in the Gulf of Mexico (from Davies and Moore 1970: reprinted with permission from The Journal of Sedimentary Research). Province I is from the Appalachians; kyanite and staurolite dominate. Province II is from the Mississippi River; augite, hornblende, and epidote dominate. Province III is from Central Texas with hornblende and epidote dominating. Province IV is Rio Grande; epidote, augite, and hornblende are dominant, and Province V is in Mexico; little is known about the heavies in Province V.

have a density (specific gravity) higher than quartz and feldspar. They include garnet, magnetite, zircon, limonite, rutile, and a few others.

3.3.2 Biogenic Sediments

The Gulf of Mexico is replete with organisms, many of which have skeletal components that contribute to the sediment. There are three categories of skeletal components: calcium carbonate, phosphatic skeleton, and siliceous materials. By far the most common is the calcium carbonate exoskeleton of invertebrates. Phosphatic skeleton is from fish, and siliceous material is small single-celled organisms and sponge spicules.

3.3.2.1 Calcium Carbonate

Many invertebrates have various types of skeletons of calcite, high-magnesium calcite, and aragonite. These compounds are all various types of calcium carbonate with some variation in crystallography and composition. They range from single-celled organisms to large invertebrates, including coral colonies and calcified green and red algae. In some of these organisms, such as gastropods (snails), the entire intact skeleton is included in the sediment. In others, such as echinoderms (starfish, sea urchins), the skeleton disarticulates and may become dozens of individual pieces. Regardless of size, the skeletal material can become a significant part of the sediment. In some places, such as the Florida Keys or the Yucatán Peninsula, the entire composition of the sediment may be skeletal carbonate (Figure 3.16). These carbonate exoskeletons are typically broken by waves, currents, and even by other organisms. Their abundance in

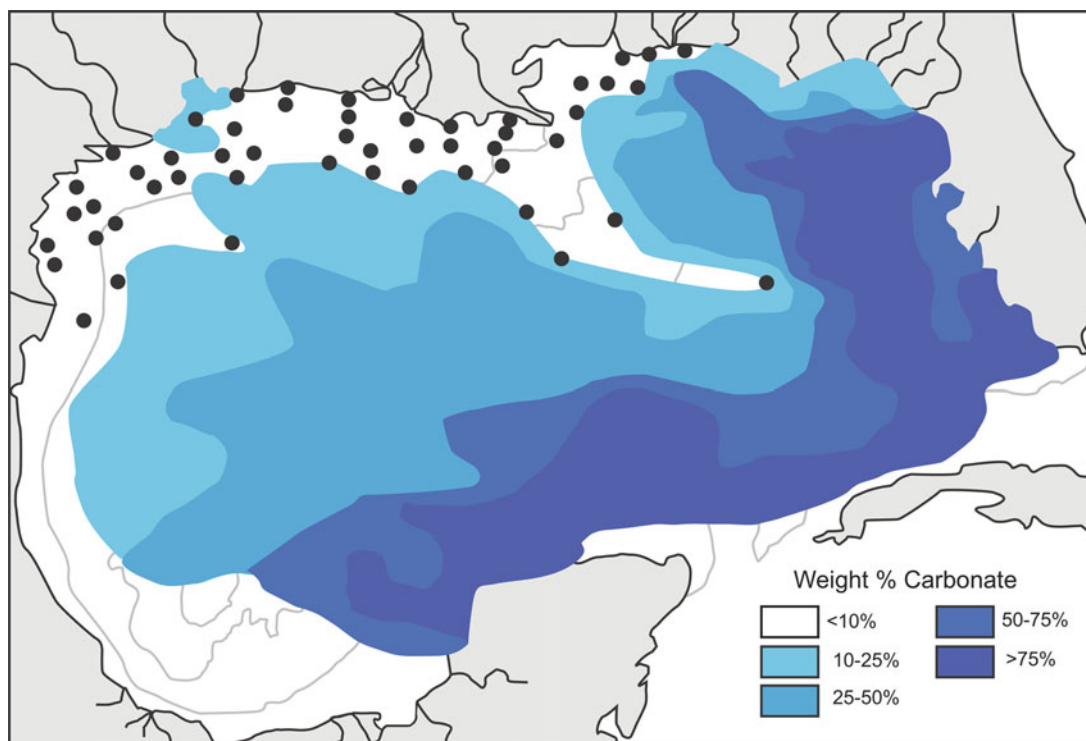


Figure 3.16. Map of the weight percent carbonate throughout the Gulf of Mexico (from Caso et al. 2004). Black dots are sample locations.

sediment ranges from 0 to 100 %. The particle size and the shape also range widely. As a consequence, the rate of transport of skeletal particles is hard to measure.

Calcium carbonate sediment is mostly found in shallow water, but there is also deepwater carbonate sediment (Figure 3.16). Calcium carbonate sediment comprises primarily planktonic foraminifera (single-celled animals) and submicroscopic algae called coccolithophores. These sediments, often called calcareous ooze sediments, are common on the abyssal plain of the Gulf. Such microscopic and submicroscopic skeletal particles can form limestones in the ancient record and become major petroleum producers.

3.3.2.2 Phosphate Skeletons

Fish skeletons tend to be phosphatic except for the otoliths (ear bones), which are calcium carbonate. Because fish skeletons are generally rather fragile and predators commonly consume the fish body, skeletal fragments of phosphatic composition are not common in sediments. Otoliths do tend to be preserved in sediments, but they are scarce in the overall volume of marine sediments.

3.3.2.3 Siliceous Skeletal Material

Three major categories of organisms have siliceous skeletal material: sponges, radiolarians, and diatoms. Sponges are soft benthic animals, but several of them have tiny siliceous spicules that help to support their soft structure. Radiolarians are planktonic, microscopic animals that are also siliceous. The other category is diatoms, which are photosynthetic, microscopic organisms. All of these siliceous organisms are quite small and are typically minor constituents of marine sediments in the Gulf of Mexico except for radiolarians.

3.3.3 Chemical Sediments

The direct precipitation of minerals from seawater is present in the Gulf but is not common or widespread. Evaporite minerals are limited to places where salinities reach more than 200 ppt. This would include local places in Laguna Madre and some sites on the Mexican coast. Gypsum and halite are the only evaporate minerals that are even somewhat common, and they are local and subject to dissolution.

Calcium carbonate is the other type of chemical sediment that is directly precipitated from seawater, in some cases with the aid of photosynthesis. Calcium carbonate can be very fine grained and is often referred to as lime mud. It is only common in Florida Bay. Ooids are sand-sized, spherical grains of calcium carbonate that are precipitated in thin layers over a nucleus. They are commonly limited to places where currents, typically tidally generated, are present. Ooids occur in tidal passes in the Florida Keys and off the east coast of the Yucatán Peninsula.

3.3.4 Sediment Grain Size

Sediment particles range widely in grain size. Because of this, the classification of grain size of sediment particles is based on $-\log_2$. This makes it possible to use a small number of categories to cover the entire range of sizes. Typically, sediments are categorized by both particle composition and size (e.g., quartz sand).

3.3.4.1 Gravel

Sediment particles larger than 2 millimeters (mm) (0.08 inches [in.]) are called gravel. They can range up to very large particles including boulders (greater than 25.6 centimeters [cm] [10 in.] in diameter). In fact, not much gravel is carried into the Gulf of Mexico because by the time eroded material makes its way down a long river, the size is reduced considerably. Some beaches have gravel composed of shells, and in some places, such as on the northwest coast of Cuba and parts of Mexico, gravel particles are eroded from rocks close to the beach and are still large. Gravel may also be produced as storms erode reefs. Gravel-sized particles in deep water are essentially all shell material.

3.3.4.2 Sand

Much of the terrigenous sediment present on the continental shelf of the Gulf is sand. Although commonly misinterpreted, sand is only a size term; it has nothing to do with the composition of the sediment. All sediment particles between 2.0 mm and 0.0625 (1/16) mm (0.08 and 0.0025 in.) regardless of origin or composition are called sand. The confusion between the two designations is that the sediment on most beaches, in many streams, and in sand boxes is within this grain size range and is mostly quartz. In many natural environments, sand is mixed with other particles, some larger and some smaller.

3.3.4.3 Silt

Silt is the grain size that is between very fine sand at 0.0625 (1/16) mm (0.0025 in.) and clay (4 μm [0.00016 in.]). Particles of this grain size are a minor component of most Gulf environments except for river deltas. Silt is mostly quartz with minor percentages of other nonlayered silicates.

3.3.4.4 Clay

Clay is another confusing term used in conjunction with sediments; it can mean clay minerals, as described above, or it can mean a grain size. Clay size actually means any sediment particle with a diameter smaller than 4 μm (0.00016 in.). Most of the clay-sized particles are also clay minerals, but some are not. These very small grains are easily transported by rivers and currents in the Gulf. As a consequence, they are very common throughout most of the various environments except where waves and currents are strong, such as in tidal inlets and along the beach/surf zone. These sediment particles are most abundant in estuaries, deltas, and the deep basin.

3.3.4.5 Mud

Although a commonly used term in colloquial English, *mud* is really an appropriate term in scientific literature. Mud—the mixture of silt and clay—is widely distributed in Gulf sediments. Because both silt and clay involve very small sediment particles that are commonly not separated in analysis, this combination term, *mud*, is used. This term will be used in the following discussions.

3.4 GENERAL SEDIMENT DISTRIBUTION

Because of the scale of the geography of the Gulf of Mexico, there have been few studies of the basin-wide distribution of sediment types. A recent effort in this direction by Balsam and

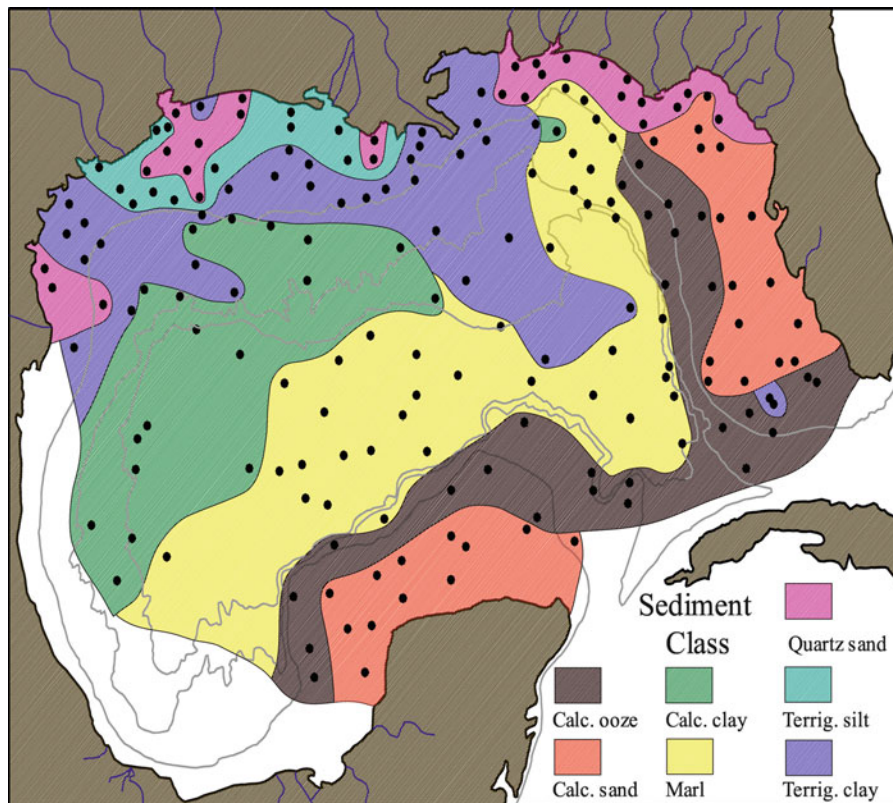


Figure 3.17. Map showing Gulf of Mexico sediment distribution along with sample sites (from Balsam and Beeson 2003: reprinted from Deep Sea Research Part I: Oceanographic Research Papers, Vol 50, Seafloor sediment distribution in the Gulf of Mexico, Figure 4, Copyright 2003, with permission from Elsevier). Contrast this map with that in Figure 3.10.

Beeson (2003) has synthesized sediment samples from the top of 186 cores that cover the entire Gulf (Figure 3.17).

From these samples, the authors have been able to produce relatively simple maps of various sediment characteristics. One of the least complicated maps to interpret is a map showing carbonate content (Figure 3.16). This map shows the influence of the Florida carbonate platform, the Mississippi Delta area, and the expected pattern of decreasing carbonate moving from the deep basin up onto the continental shelf.

3.4.1 Abyssal Plain

Sediments on the abyssal plain tend to be rather homogenous. They are a combination of calcareous ooze (formed by an accumulation of planktonic foraminifera) and thick turbidite sequences. Much of this turbidite material was transported through the Mississippi Canyon and across the Mississippi Fan (Bryant et al. 1991). There is also some clay mineral sediment, most of which had its origin at the mouth of the Mississippi River. Thin turbidite layers are interbedded with the calcareous ooze on the top of these salt dome knolls. The heavy mineral suite is typical of that from the Mississippi River with hornblende and epidote being dominant (Davies and Moore 1970; Davies 1972).

The deep-sea mud that is dominated by clay minerals shows that the most abundant species of clay mineral is smectite. Illite is the next most abundant (Sionneau et al. 2008). Chlorite and kaolinite are the minor clay mineral species.

3.4.2 Mississippi Fan

Most of the sediments on the Mississippi Fan (Figure 3.4) have their origin in the Mississippi River. Because of the slope of its surface, mass wasting is a major process for the delivery of these sediments (Coleman and Roberts 1991). Debris flows and turbidity currents are the primary methods for sediment delivery (Twichell 2011). These sequences contain wood fragments and shells of shallow-water organisms testifying to their shallow-water origin.

The upper sediments of the fan include fine sand, silt, and clay (mud). Layers of this material are covered by foraminiferal muds that are 20–50 cm (8–20 in.) thick with rates of accumulation being calculated at about 30 cm (1 ft) per 1,000 years (Huang and Goodell 1970).

Sediments of this huge accumulation are varied; some are turbidite units and some are thin layers. The thin layers of only a millimeter (0.04 in.) or so in thickness may be annual, almost like rings on a tree. On the other hand, a thick single layer might represent as long as a century (Bryant and Liu 2000). The turbidite units are the thickest of the sediment units, commonly greater than 5 cm (2 in.). This type of individual deposit can be up to 100 cm (40 in.) thick. The graded bedding in the turbidites contains medium to fine sand but is dominated by mud. The debris flow deposits may also include clay clasts. They typically show an erosional base, graded bedding, and the C, D, and E units of a Bouma sequence.

3.4.3 Continental Slope

The continental slope on the west edge of the Florida Platform and the Yucatán Platform margin is steep and is currently accumulating little sediment. The fans and sandy shelf-edge deltas accumulated during sea-level lows during the pre-Holocene era. The rough and irregular topography on the slope (Figure 3.6) causes much ponding of the sediment. Sediments from the Rio Grande source contain the highest percentage of quartz, and sediments from the Veracruz area contain the lowest percentage of quartz. The Mississippi River, which produces the most sediment (Figure 3.5), has an intermediate percentage of quartz in comparison with the other two source areas (Davies and Moore 1970). On both the Texas and Mexico slope in the western Gulf, the sediments are dominated by bluish to brownish fossiliferous mud (Morelock 1969). More specifically, the northwestern Gulf sediments are highly bioturbated hemipelagic muds, with some foraminifera interbedded with laminated silt and muds that are barren (Bryant et al. 2000).

At the shelf-slope break (Figure 3.18), there is not only a break in bathymetry but also a change in the attitude of the sediments. At this break, sediments dip seaward on the slope due to folding and faulting associated with salt diapirs (Morelock 1969). The upper Texas slope is covered with thick mud that is an extension of the sediment on the outer shelf. This mud is the reworked product of the fluvial-deltaic accumulations during lowstands of sea level (Pequegnat 1976). Freshwater shells have been found in these sediments at and near the shelf-slope break indicating that paleoshorelines were in the vicinity (Parker 1960). At the present time, essentially no sediment is being delivered to this environment.

Overall, the thickness of sediment on the slope is quite thin except for local slope fans (Figure 3.19). In the northwestern area of the Gulf, only about 70 cm (28 in.) of mud is present. This represents an average rate of accumulation of only 4.6 cm (2 in.) per 1,000 years (Bryant and Liu 2000); this rate of accumulation conflicts with a rate of about 20 cm (8 in.) per 1,000 years determined by H.H. Roberts of Louisiana State University. The slope sediment fans are

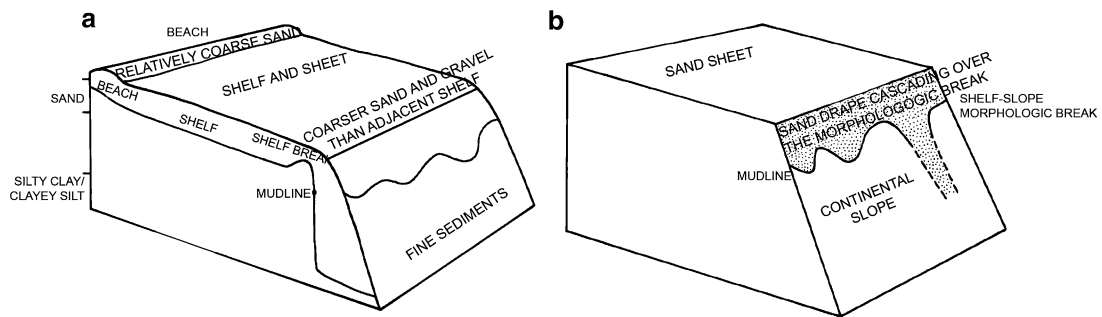


Figure 3.18. General diagram of the outer continental margin showing (a) the main sediment provinces and (b) the shelf-slope break (from Blake and Doyle 1983: reprinted with permission from the Society for Sedimentary Geology).

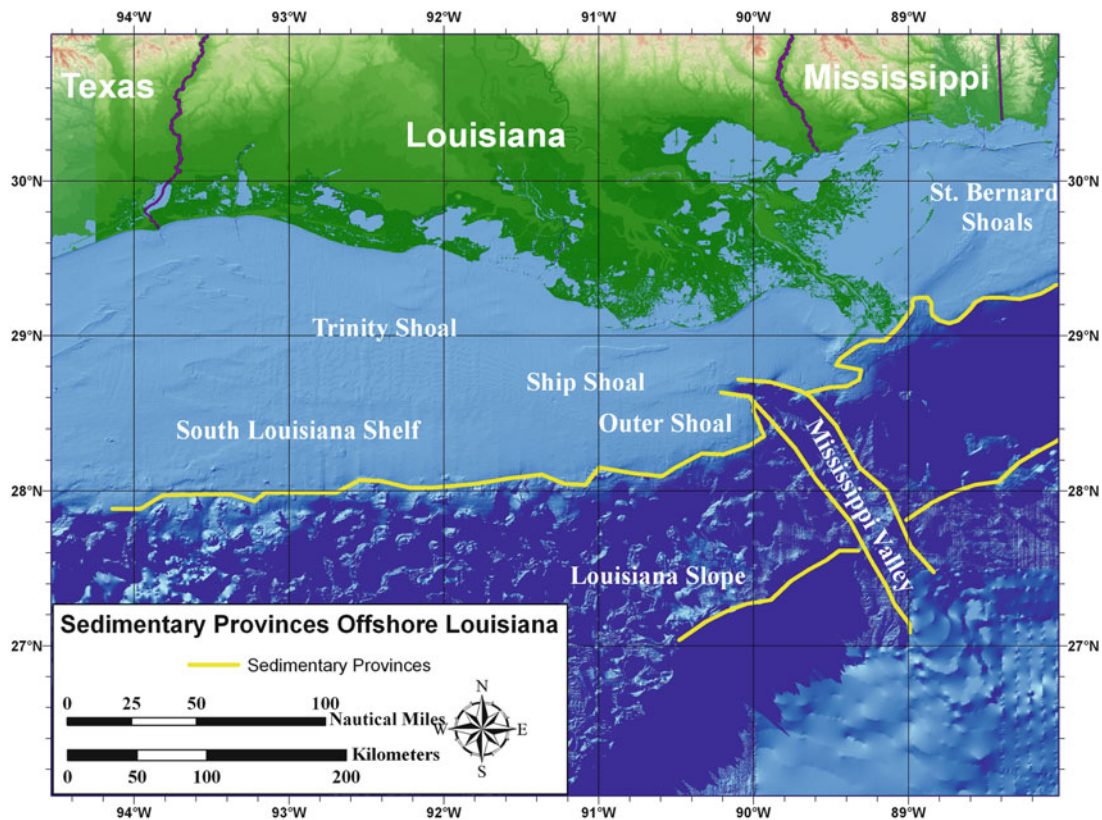


Figure 3.19. Generalized map showing the continental slope cut by the Mississippi Valley off the Louisiana coast with adjacent continental shelf and deep basin area (from Williams et al. 2011).

associated with Quaternary lowstands of sea level. Examples are on the Texas coast where such fans are tied to ancestral courses of the Brazos River and Colorado River (Abdullah et al. 2004). These fans begin at about the 200-m (656-ft) isobaths, essentially at the shelf-slope break, and descend down the slope. Sediments in these fans can be unexpectedly coarse and include some gravel.

3.4.4 Continental Shelf

Shelf surface sediments of the Gulf of Mexico tend to reflect a combination of runoff from the land and the nature of the geological underpinning of the particular region. The Florida Peninsula and the Yucatán Peninsula have similarities because both rest on a carbonate platform. The remainder of the shelf sediments in the Gulf is primarily the result of fluvial input, with the Mississippi River discharge dominating the northwestern Gulf. Much of the sediment on the shelf is directly or indirectly the result of the multiple cycles of sea-level change that took place during the Quaternary Period.

It is possible to designate six sediment provinces of the continental shelf of the U.S. Gulf of Mexico using detailed analysis of the silt fraction of bottom samples. The six sediment provinces are: (1) Apalachicola, (2) Mobile, (3) Mississippi, (4) Brazos–Colorado, (5) Guadalupe, and (6) Rio Grande (Mazullo and Peterson 1989). These provinces are based on the past and present locations of rivers that contributed these sediment grains primarily during low stages of sea level during the Quaternary and they have been reworked during subsequent sea-level rise. A study of 350 grab samples focused on grain roundness and shape (Mazullo and Peterson 1989). As expected, the sediment grains from the Mississippi River dominate the entire northern Gulf shelf but are most abundant in the west of the delta.

3.4.4.1 West Florida Peninsular Gulf

Sediments on the continental shelf off the Florida Peninsula are scarce beyond a depth of about 6 m (20 ft). Out to this depth they are shelly, quartz sand that has been reworked from Quaternary cycles of sea-level change. This is a zone of transition between the quartz-dominated sediment on land and the carbonate-dominated sediment of the mid- and outer shelf (Brooks et al. 2003a). The most common minor constituent is phosphorite that is reworked from the Miocene deposits of the Florida Platform. The carbonate sediment is being produced biogenically within the shelf itself. The highest content of organic carbon is 5–6 % in the muddy sand and mud facies of the inner shelf (Brooks et al. 2003b).

Farther out on the shelf, it is possible to delineate bands of surface sediment facies that parallel the bathymetric contours (Reading 1978; Hine et al. 2003a). The inner shelf is dominated by quartz sand as described above, and the middle shelf is carbonate skeletal material (Figure 3.20). There is a belt of calcareous coralline (red) algae on the outer shelf. Just beyond that is a narrow belt of ooids (Figure 3.21), which must be relict deposits that formed during the recent lowstand of sea level. At the present time, this shelf is sediment starved because the estuaries remain void of sediment and virtually no sediment is being delivered to the shelf itself. The total modern sand sheet is about 8 m (26 ft) thick and composed of 90 % quartz and 10 % carbonate.

There are grain size trends that relate to the composition of the shelf sediment. The content of sand is 90 % or more most of the way across the shelf. Near the outer region, sand content decreases rather rapidly. The percent carbonate in the sediments gradually increases from the transition from quartz in the shoreface (where it is only 25 %) to near the edge (where it increases to nearly 100 %) (Doyle and Sparks 1980). As for the clay minerals, smectite content increases offshore and kaolinite decreases offshore. The heavy mineral suite associated with the quartz-rich area is characterized by zircon, tourmaline, garnet, and staurolite (Fairbanks 1962).

3.4.4.2 Florida Panhandle

The Florida panhandle shelf is quite different than that on most of the Florida Platform because it includes a relatively thick sequence of sediment that is the result of the dominance by

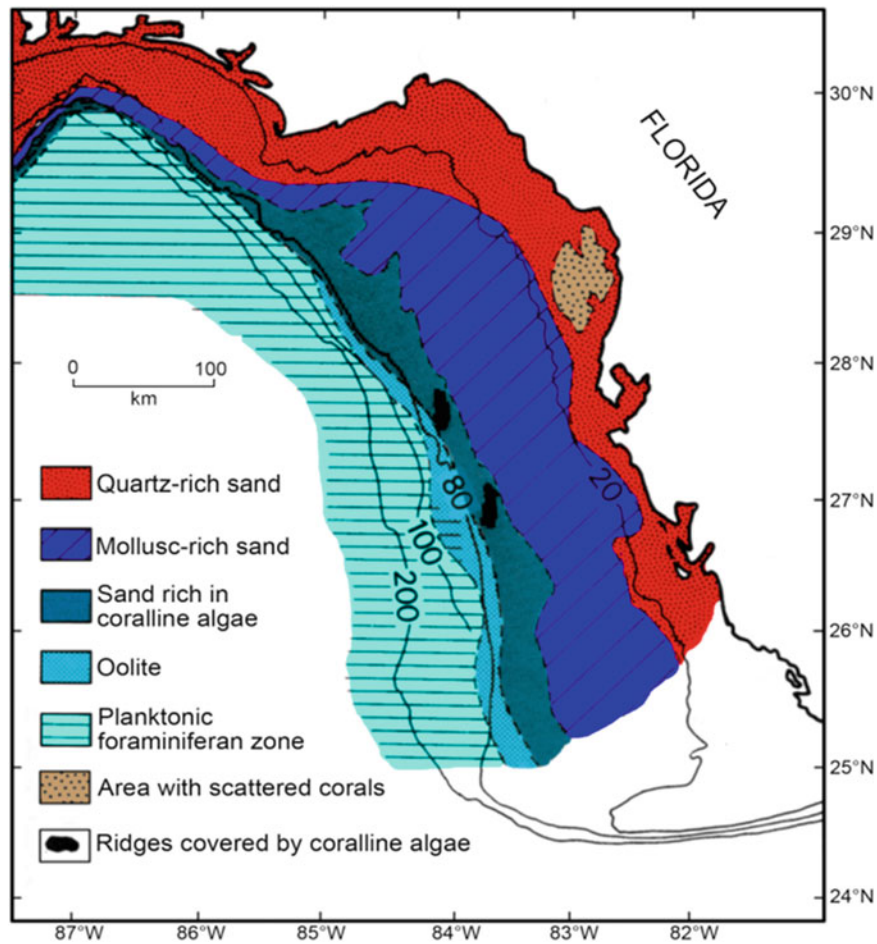


Figure 3.20. General map of the surface sediment facies on the west Florida shelf (from Reading 1978).

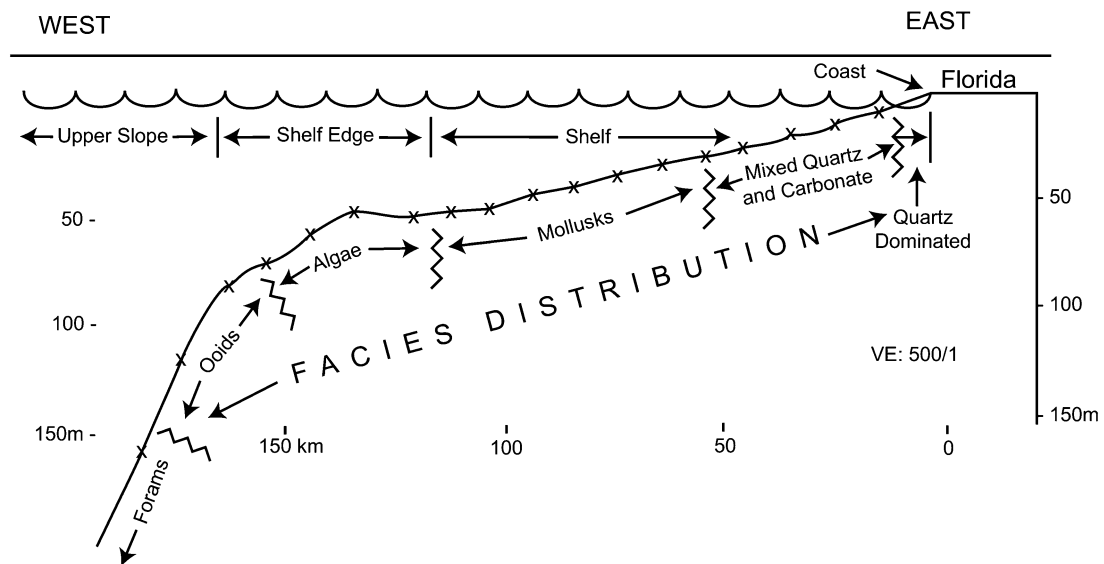


Figure 3.21. Profile diagram across the west Florida shelf showing sediment facies (Hine et al. 2003a, b). Reprinted from Marine Geology, Vol 200, Hine AC et al., The west-central Florida inner shelf and coastal system: A geologic conceptual overview and introduction to the special issue, Figure 5, Copyright 2003, with permission from Elsevier.

rivers and river deltas (Hine and Locker 2011). The origin of the sediment is the Apalachicola River and delta and other streams to the west that feed the Florida panhandle and the Alabama shelf (McKeown et al. 2004). The ancestral Apalachicola Delta is still visible in the bathymetry of this shelf and is a major contributor to the sediment on the present shelf as the Holocene sea-level rise has moved over it. This sediment has been reworked into numerous shoals and ridges as sea level advanced after the glacial maximum (Donoghue 1993). This area has been relatively sediment starved since the beginning of the Holocene. The sediment is dominated by terrigenous sand and contains minor amounts of shell.

The surface sediments here comprise fine and medium sand and are moderate to well sorted (McBride et al. 2004). Combined with the adjacent Alabama/Mississippi shelf, there is a trend in sediment texture from coarser- to finer-grained and from less sorted to more sorted. The outer edge of the shelf is dominated by carbonate sediment of a reefal origin with mixtures of terrigenous sand-silt-clay of inter-reef origin.

There are shelf-edge carbonate hardgrounds and bioherms that have up to 15 m (49 ft) of relief and are located at depths of 90–120 m (295–395 ft). These features probably reflect shoreline regions that existed during the last major sea-level lowstand (Bart and Anderson 2004). Overall carbonate content of this shelf area is typically less than 25 %.

3.4.4.3 Alabama–Mississippi

The Alabama–Mississippi continental shelf is a continuation of that off the Florida panhandle, and the sediments reflect that trend. The sediment is quartz-dominated, fine sand (Kopaska-Merkel and Rindsberg 2005). Sand-size sediment comprises more than 90 % of surface sediments (Bowles 1997). Looking more specifically at the shelf environments, the outer areas have a lime mud surface with relict reefs/carbonate buildups at two depth zones: 654–680 m (2, 145–2,230 ft) and 97–110 m (318–361 ft) (Roberts and Aharon 1994). Ludwick (1964), one of the original detailed studies on this shelf, showed distinct bands of sediments that parallel the shore (Figure 3.22). Ludwick also noted the presence of reefal materials at the outer portion of the shelf. Further work in 2001–2002 by the U.S. Geological Survey (USGS) revealed extensive hardgrounds in this area and some sandstones.

Shoreward of this carbonate region is a transition of terrigenous sand and mud. Further in on the shelf, there is topography that suggests relict barriers and shorelines. A detailed study by the Geological Survey of Alabama (Kopaska-Merkel and Rindsberg 2005) found that the inner shelf comprised five lithofacies with terrigenous sand, mud, and biogenic debris being the main constituents: (1) graded shelly sand, (2) clean sand, (3) dirty sand, (4) biogenic sediment, and (5) muddy sand (Figure 3.23). The sand is medium grained (mean of 0.43 mm [0.017 in.]). Shell content of the inner shelf sediment is higher than on the present beaches of Alabama.

A systematic study of the total organic carbon across the shelf found that the values range from a trace amount to a high of 2.9 % (Kennicutt et al. 1995). Most of the samples contained less than 1 % total organic carbon by weight. The high values were at or near the shelf edge in the head of De Soto Canyon. This study included five samplings over 26 months. A major finding of this study is the variability of the sediment content in as little as 6 months.

3.4.4.4 Louisiana

The Mississippi Delta has a major impact on the sediments of the continental shelf adjacent to the Louisiana coast. The active lobe of the delta extends across the entire shelf with the river discharging directly onto the continental slope (Figure 3.5). The shelf here ranges from only about 15 km (9.3 mi) wide off the Mississippi Delta to more than 150 km (93.2 ft) wide adjacent

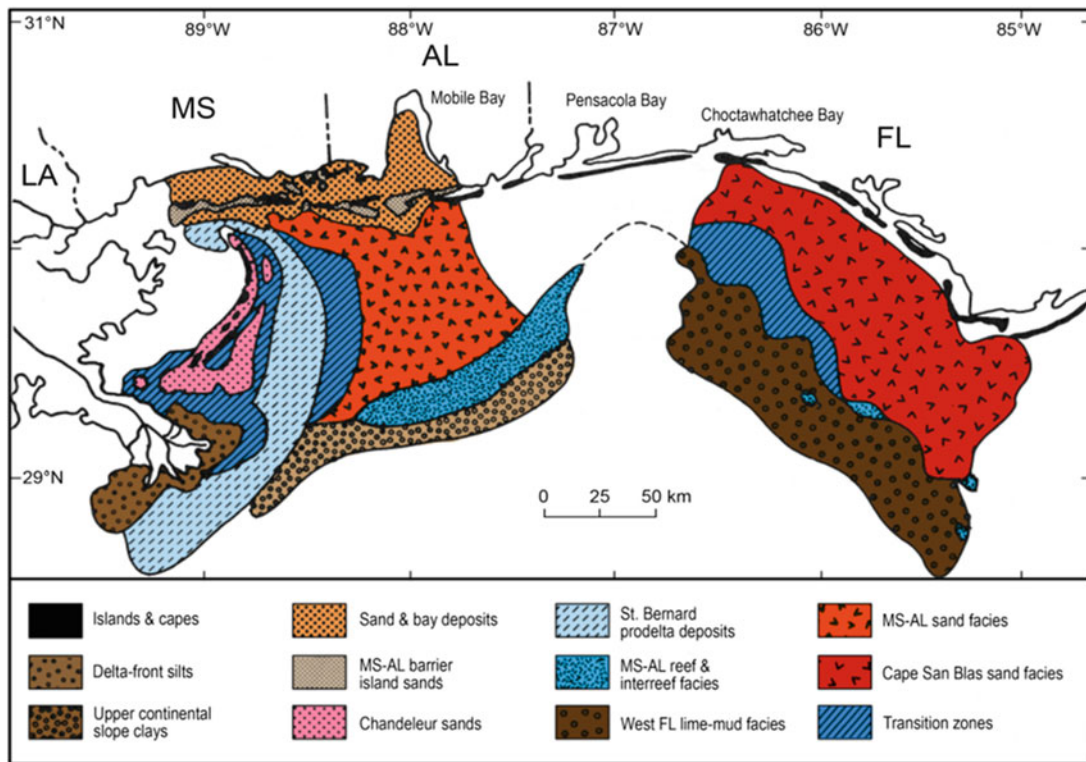


Figure 3.22. Surface sediment facies on the northeastern Gulf continental shelf (modified from Ludwick 1964).

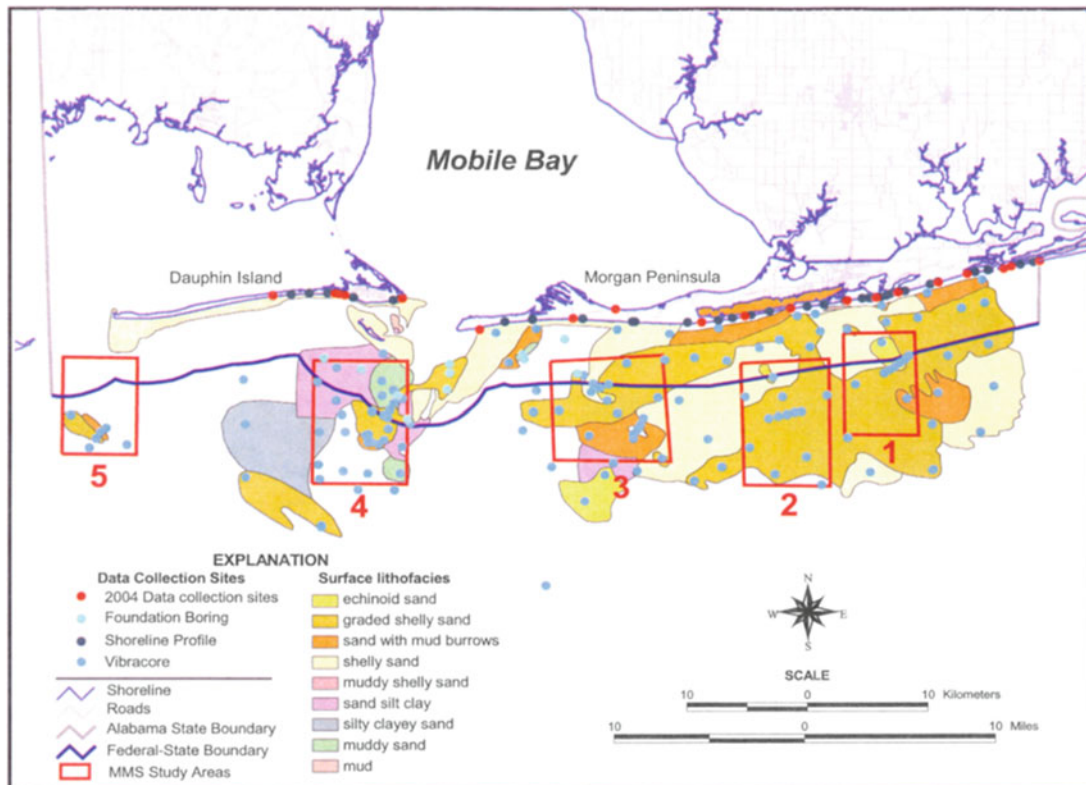


Figure 3.23. Map of shelf sediments produced by the Alabama Geological Survey in the search for beach nourishment sand (from Kopaska-Merkel and Rindsberg 2005).

to the Chenier Plain in western Louisiana. As expected, the modern lobe of the delta experiences the highest rate of sediment accumulation in the Gulf, about 1 m (3.3 ft) per year. Slump structures and gullies are common here.

A major element of this shelf is the presence of four large, elongate sand bodies (Williams et al. 2011). These sand bodies are the products of the reworking of abandoned lobes of the delta as it prograded across the continental shelf. The sand shoals represent old shoreline accumulations that were reworked during the Holocene transgression.

The sediment in these shoals is well-sorted terrigenous sand. These four shoals contain many millions of cubic meters of beach quality sand that has great potential for nourishment projects on the present, eroding barrier islands. Ship Shoal, the largest of these, is 50 km (31 mi) long and 7–12 km (4–7 mi) wide with a relief of up to 7 m (23 ft). The mean grain size on this shelf ranges from medium to fine sand. The nearshore area in the western portion of this shelf is fine, as is the sand from Trinity and Ship Shoal (Figure 3.12). The bottom sediments farther offshore in the west are medium sand.

The wide shelf to the west is essentially covered with a blanket of mud that has been provided by the Mississippi River. This mud is rather thin, less than 8 m (26 ft) thick throughout and is underlain by fluvial and deltaic sediments from sea-level lowstands during the Quaternary. Some of the sediment sequences, as revealed by cores, show a complex of facies including carbonate debris.

3.4.4.5 Texas

The inner shelf off the Texas coast will extend to depths of about 15 m (50 ft). The sediments here have various origins but two are major contributors—the Mississippi River and reworking of older sediments as the sea level rose over the past 8,000 years or so. Shells and shell debris are another significant component. The influence of the river diminishes from northeast to southwest along the Gulf. In the most eastern portion of the Texas shelf, mud is dominant or about equal with sand in the surface sediment. Local areas have linear sandy areas representing old shoreline accumulations left behind as relict sediments when the sea level rose.

Moving westward along this region, mud is still very abundant with patches of sandy mud dominating. Holocene sediment is quite thin only a few kilometers from the shoreline (White et al. 1985). The relatively high concentrations of muds tend to be related to the locations of lowstand deltas where mud was dominant, such as the paleo-Trinity delta. A similar situation is associated with the Brazos River. In general, sand dominates out to maximum depths of 5–8 m (16–26 ft) (White et al. 1988). This pattern of sediment distribution continues to near the middle of the Texas inner shelf.

Across the inner zone of the Texas shelf, the percentage of sand increases noticeably. This zone in the southern part of the Texas shelf includes numerous sandy ridges that are shoreline remnants from previous high stands of sea level.

Geographically, the Texas shelf is considered to be subdivided into three provinces: (1) the Colorado–Brazos delta complex, (2) the south Texas intra-deltaic ramp, and (3) the Rio Grande delta complex (Holmes 2011). Sediment that reaches this shelf region may come from three drainage systems—the Mississippi River and the two fluviodeltaic complexes mentioned above. There are numerous shore-parallel structures along the Texas continental shelf. Some are biogenic banks and reefs, and others are terrigenous sediments (Holmes 2011). The modern sediment blanket is rather thin in most places and rests on the fluvial-deltaic deposits of the Quaternary lowstands of sea level. Mud dominates the shelf surface except over the ancestral Rio Grande and Sabine deltas, where sand is the most abundant grain size (Berryhill 1975). The modern surface off the Texas coast tends to be a mud blanket (Eckles et al. 2004).

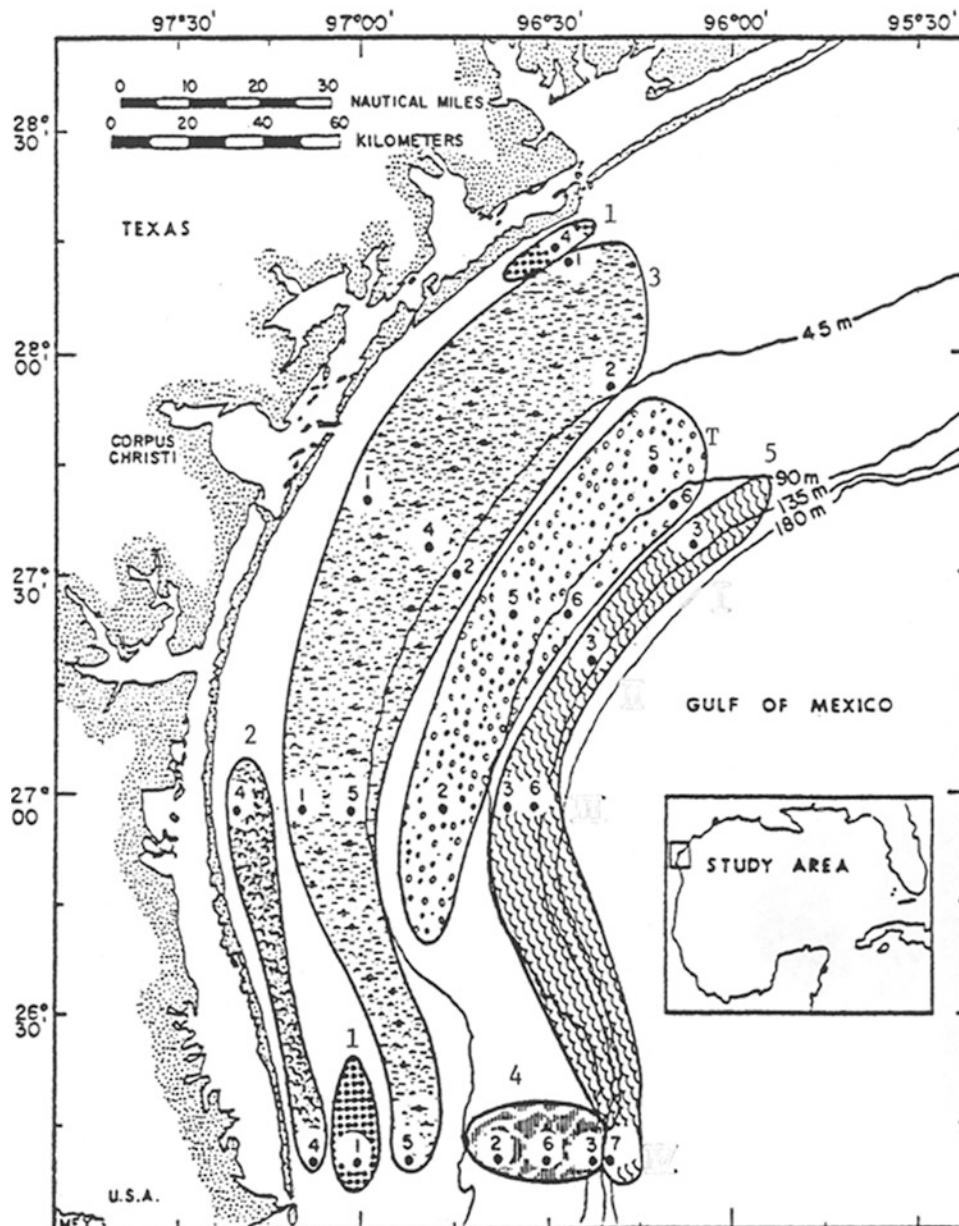


Figure 3.24. Bands of sediment on the continental shelf of south Texas show that most sediment textures and compositions on this shelf are coast-parallel (Behrens et al. 1981). From *Environmental Studies of a Marine Ecosystem: South Texas Outer Continental Shelf* edited by R. Warren Flint and Nancy N. Rabalais, Copyright 1981. Courtesy of the University of Texas Press. Details of sediment characteristics are shown in Table 3.9 of Behrens et al. (1981).

The inner shelf sediments are generally organized with parallel sediment types (Figure 3.24). The surf and nearshore zone tends to be sand dominated due to the high energy in this area. Moving farther offshore, this pattern is lost and more local variations are present. For example, the easternmost part of the Texas inner shelf is quite muddy with less than 10–12 % sand (White et al. 1987). Moving toward the west, sand dominates the shelf out to a depth of about 15 m

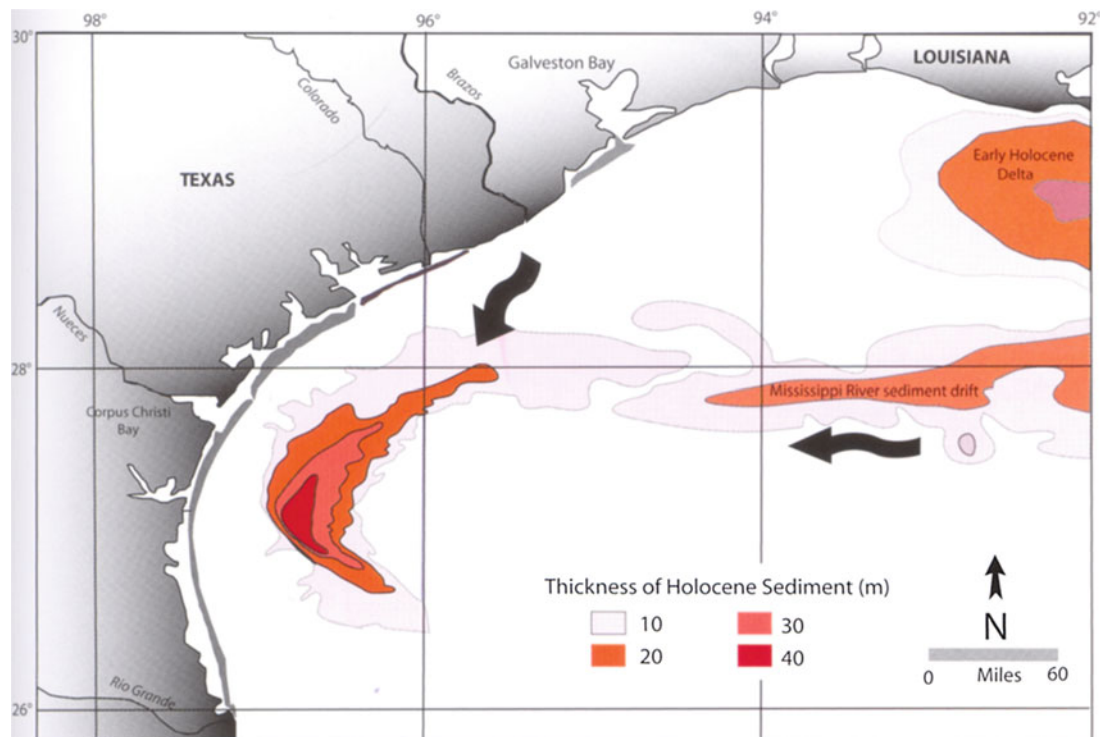


Figure 3.25. Map showing the distribution and thickness of Holocene sediment on the northwest Gulf of Mexico. The greatest thickness is on the south Texas shelf (from Holmes 2011).

(50 ft), then muddy sand and sandy mud dominate out to the mid-shelf. General mean grain size ranges from about 3.0Φ to 7.0Φ (Φ is $-\log_2$ in mm). There is a thick mud layer offshore in the central part of the Texas shelf (Figure 3.25).

Muddy sand and sandy mud with mean grain sizes mostly around 5.0Φ are found west of the ship channel into Houston (White et al. 1985). Down the coast, the inner shelf is quite muddy and is 6.0 – 7.0Φ . The sand content increases approaching and crossing the mouth of the Colorado River (White et al. 1988). Moving toward the Port Lavaca area, the sand percentage increases with mean grain size of very fine sand in the surf zone grading out to coarse silt. Continuing to the south, the pattern of grain size becomes relatively organized; the values are essentially parallel to the coast (Figure 3.24), from 3.5 to 6.5Φ (from White et al. 1983). In the mid-south coast of Texas, near Kingsville, the inner shelf sediments are dominated by sand with increasing mud offshore. All major categories of sediment texture are present on the inner shelf. The gravel is shells and shell debris. The sand fraction is 87% quartz, 6% feldspar, and 4% rock fragments; accessory minerals make up the remaining 3%. The heavy mineral content is about half black opaques (magnetite, etc.) along with tourmaline, hornblende, zircon and pyroxenes, and rutile. These heavies are similar to those described along the entire coast by Bullard (1942). The mud content increases when approaching the Rio Grande delta area (White et al. 1986).

The region in the central portion of the Texas shelf that shows what seems to be unusual bathymetry (Figure 3.10) also has an unusual sediment accumulation. This area of about 300 km^3 (72 mi^3) represents the second largest sediment depocenter on the Gulf of Mexico shelf (Figure 3.25) next to the Mississippi Delta (Holmes 2011). The thickness of this mud blanket is tens of meters, more than half of which was deposited during the past 3,000 years. It is interpreted that the origin of this late Holocene sediment is the production of mud from the Brazos, Colorado, and Mississippi Rivers.

The outer shelf sediments have a high abundance of calcium carbonate. This comes from the relict reefs and banks that developed during Quaternary lowstands of sea level. They have been partially reworked by the post-glacial rise in sea level and the debris incorporated into the outer shelf sediments (Rezak et al. 1985).

3.4.4.6 Mexico and Cuba

Sediments on the continental shelf of Mexico either reflect the nearby sources of terrigenous material or, as in the case of the Yucatán Peninsula, they are autochthonous carbonate sediments. Terrigenous sand and mud dominate the northern portion of the shelf.

Toward the south, volcanic rocks provide the source for shelf sediments and the composition reflects this. In the central Mexico coast near Veracruz, the shelf narrows in the area of volcanoes, and volcanic glass is a prominent component of the shelf sediment. Shelf sediment on the coast near Isla del Carmen falls below 50 % carbonate (Carranza-Edwards 2011). Moving into Campeche Bay, the sediments transition from terrigenous to carbonate. Sediments and bathymetry across the Campeche Bank of the Yucatán Peninsula are comparable to that of the west Florida shelf (Figure 3.26).

3.4.5 Mississippi Delta

The sediments of the Mississippi Delta have been well documented in the literature. There are essentially three primary geomorphic/physiographic provinces: the delta plain, the delta front, and the prodelta from land to the Gulf. The delta plain is the upper surface, much of which is supratidal or intertidal (Figure 3.27). This province is dominated by mud, with sand bodies representing modern and relict point bars on the numerous channels. The tremendous influence by human activities, primarily the petroleum industry, has had a major impact on this province. The rapid rise of relative sea level is causing the destruction of much of the wetlands portion of it. Sediments are subjected to widespread pollution from both river discharge and human activities. The delta front portion of this complex is dominated by sorted sand and occupies the outer edge of the delta where wave action dominates. These sands are worked by waves and currents into shore-parallel sediment bodies (Coleman and Roberts 1991).

The vast majority of the sediment volume in this delta is mud and comprises the prodelta province (Figure 3.27). These sediments accumulate rapidly and are generally saturated with water causing major instability problems. Failure and gravity slumping is widespread. Some diapirs—not only of salt but also mud—are present.

3.4.6 Beach Sediments

The nature and composition of beach sediment show a fair amount of commonality throughout the Gulf of Mexico. There are two main categories of beach sediment composition—terrigenous and carbonate—but some places show subequal mixtures. Sediment texture is typically well sorted and well rounded, except where the composition is bimodal with shells being a significant part of the composition. Carbonate-dominated sediments are in the Florida Keys, around the Yucatán Peninsula, and east of Havana on the Cuban coast.

In a few places, minor constituents show some concentrations due to the underlying geology. One is on the west-central coast of the Florida peninsula, where phosphorite is anomalously high due to the abundance of this mineral in the underlying Miocene strata. The thin dark layers on storm beach surfaces reflect the presence of this material.

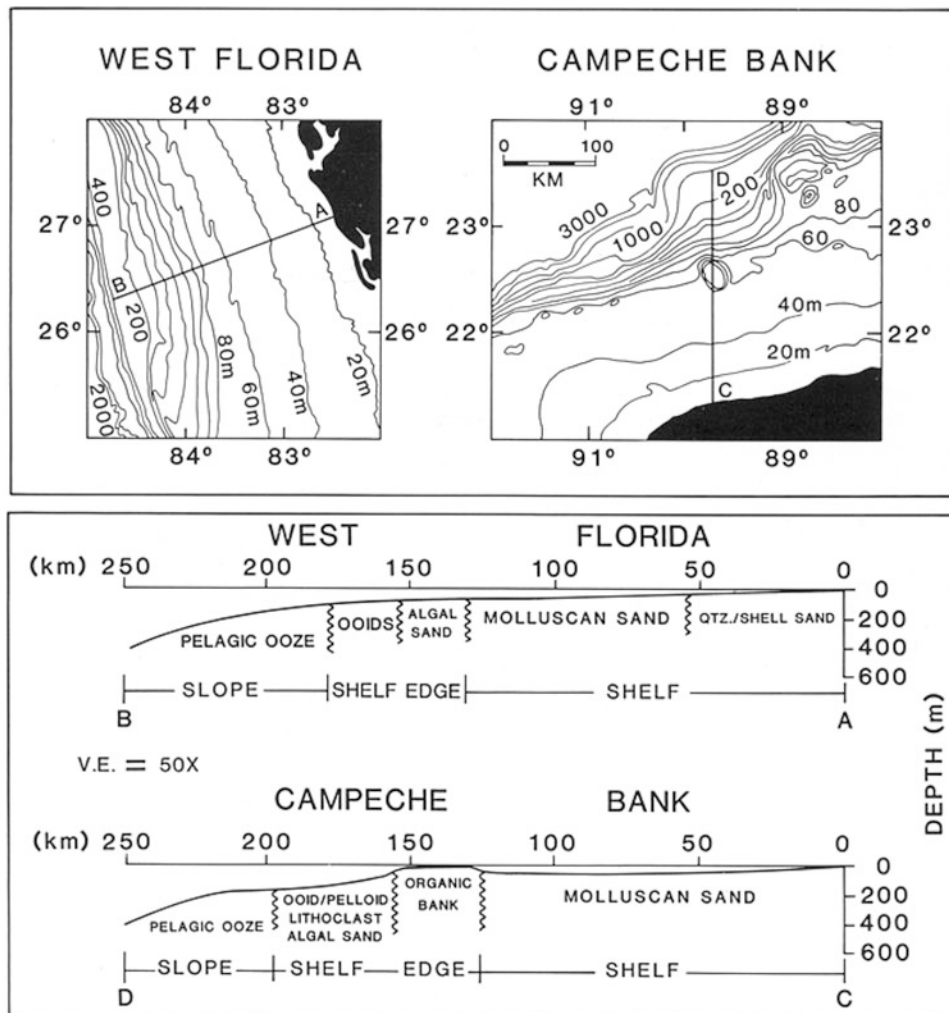


Figure 3.26. Similarities between the shelf and shelf-slope break on the west Florida Shelf and the Yucatán Shelf in Mexico (from Hine and Mullins 1983: reprinted with permission from the Society for Sedimentary Geology).

The concentration of shells in some local places provides what is an anomalous carbonate beach in an otherwise terrigenous-dominated beach environment. Examples include the southern portion of Sanibel Island, Florida and near the middle of Padre Island, Texas, not far north of the Mansfield Pass jetties.

Another anomaly in beach composition is the presence in some locations of what are commonly called *tar balls* which are small, pebble size clumps of oil-bound sand (Figure 3.28). The oil is from seeps on the floor of the Gulf. Tar balls are most common off the Texas coast and the coast of Mexico west of the Yucatán Peninsula.

3.4.7 Estuaries and Lagoons

Numerous estuaries line the Gulf Coast. They are generally somewhat similar in their origin in that they are drowned river systems. Most are muddy, shallow, and brackish. Tidal flux varies widely, but the tidal range is microtidal throughout the Gulf. The following discussion will address the nature of the sediment in each of the major estuaries.

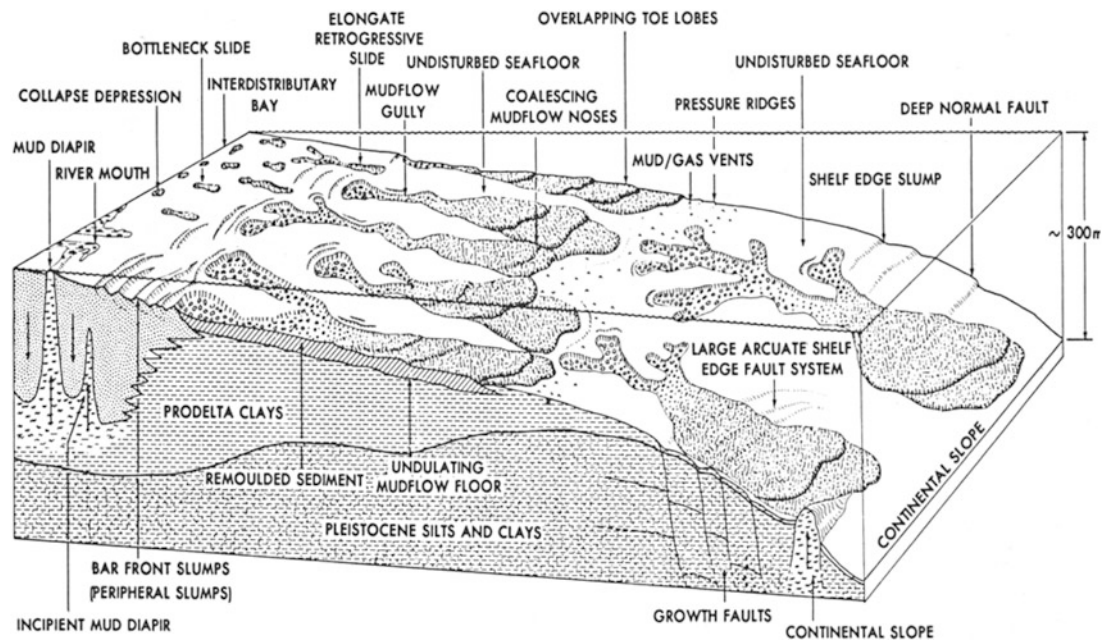


Figure 3.27. Block diagram of the various sedimentary facies on the Mississippi Delta (Coleman 1988). Republished with permission of the Geological Society of America from *Dynamic Changes and Processes in the Mississippi River Delta*, J.M. Coleman, Vol 100, pp 999–1015, 1988; permission conveyed through Copyright Clearance Center, Inc.



Figure 3.28. Small tar ball on the beach. This size of a ball will cover most of a person's heel when stepped on (photo courtesy of NOAA). These tar balls are from natural seeps and are common along the northern Gulf Coast especially in Texas.

3.4.7.1 Florida Bay

Florida Bay lies between the Florida Keys and the south Florida mainland. It is a triangle-shaped, shallow bay with scattered small mangrove islands. It is open to the Gulf on its west side (Figure 3.29) and receives its freshwater supply from the sheet flow that moves across the Everglades. This bay covers 1,393 km² (538 mi²) and has an average depth below 2 m (6.6 ft). Sediments in this shallow bay are calcium carbonate and a combination of lime mud and



Figure 3.29. Satellite image of the Florida Keys and Florida Bay (courtesy of NASA).

skeletal material. These soft sediments are only a few meters thick and rest on the limestone surface of the Miami Oolite and the Key Largo formations (Enos and Perkins 1977) that form the basis of the Florida Keys.

3.4.7.2 Charlotte Harbor

Charlotte Harbor is one of the two large estuaries on the Gulf Coast of the Florida Peninsula. It has an area of 700 km² (270 mi²). Rapid growth from the 1950s to the present has increased the population to more than one million. It is served by the Myakka, Peace, and Caloosahatchee Rivers (Figure 3.30), which are presently carrying freshwater but little sediment. The sediment in this estuary has been studied in detail by Evans et al. (1989) and Brooks (2011). Modern (Holocene) sediments may be up to 3 m (10 ft) thick and are mostly fine quartz sand. Sandy shell is the dominant sediment in the tidal channels and passes. Phosphate minerals are up to 9 % by weight (Folger 1972) and are delivered by the Pease River from the central Florida phosphate-mining district. Mud is a minor constituent but is widespread. Mud is a combination of clay minerals, clay size quartz and calcite, and particulate organic matter (Huang and Goodell 1967).

3.4.7.3 Tampa Bay

Tampa Bay is an estuary surrounded by intensive and extensive development with a total of about three million residents. It is also a major tourist destination. The bay is supplied with runoff by the Manatee, Alafaya, and Hillsborough Rivers (Figure 3.31), but little sediment is being discharged by any of them (Brooks 2011). The USGS (2006) study of the bay includes detailed surface sediment analyses. Maps produced from this study show variation in the bay, but overall, the sediment is rather similar throughout. Grain size in most of the bay is fine and medium sand with muddy sediments concentrated in the northern portion of the two arms of the estuary. Mud is less than 10 % throughout the bay except for the upper part of the eastern bay where it reaches more than 50 % at some locations. The mud is a combination of clay minerals, fine quartz, and particulate organic matter. Carbonate composition provided by biogenic shells and debris is low except in the lower bay where it may exceed 50 % (USGS 2006).

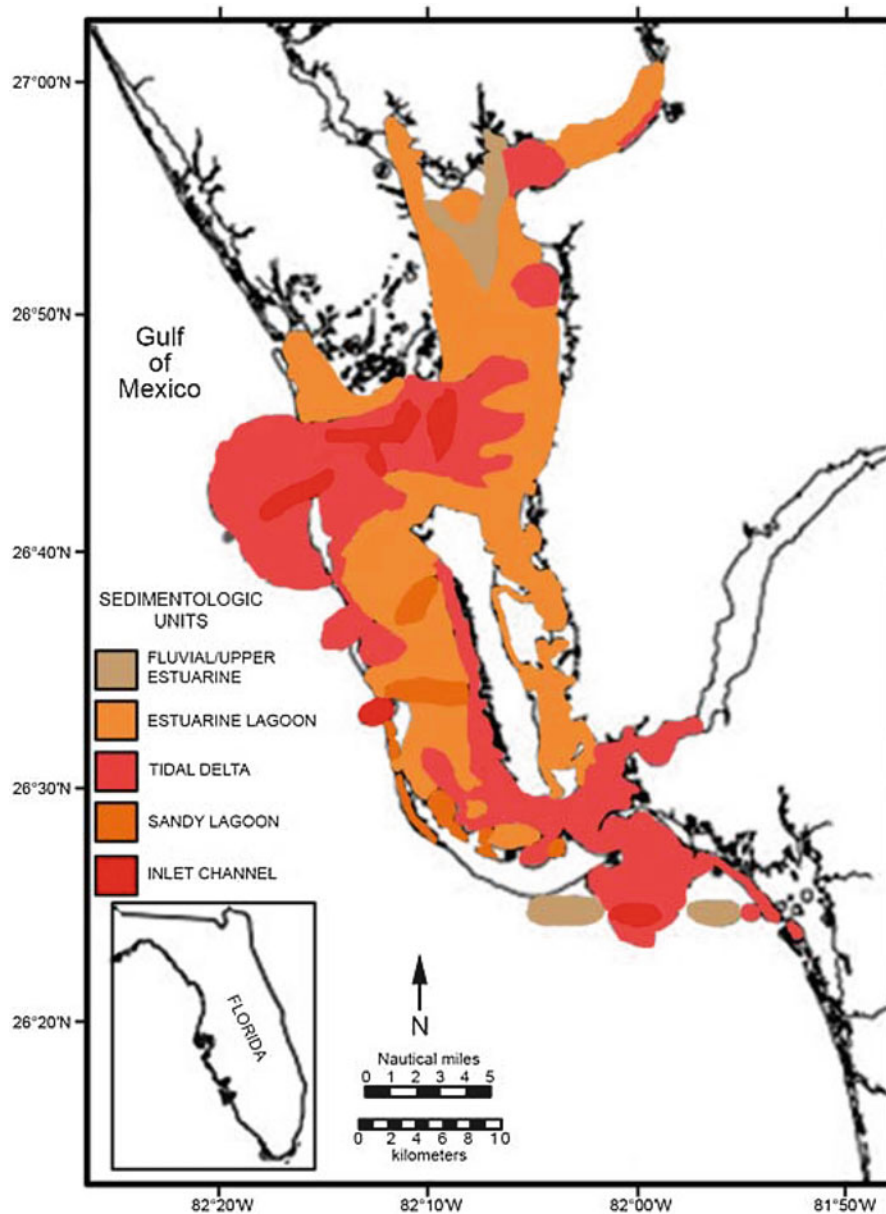


Figure 3.30. Map of sediment facies for Charlotte Harbor area. These facies can be related to sediment grain size (Evans et al. 1989). Reprinted from *Marine Geology*, Vol 88, Evans et al., Quaternary stratigraphy of the Charlotte Harbor estuarine lagoon system, southwest Florida: Implications of the carbonate-siliciclastic transition, Figure 7, Copyright 1989, with permission from Elsevier.

3.4.7.4 Apalachicola Bay

The sediment of Apalachicola Bay is dominated by mud with several areas of large and productive oyster beds (Figure 3.32). Much of the mud is actually deposited as oyster fecal pellets. The oyster reefs range in length from about 1 to 1.7 km (0.62–1.06 mi) and are oriented northwest–southeast. Quartz sand is a minor but widespread constituent.

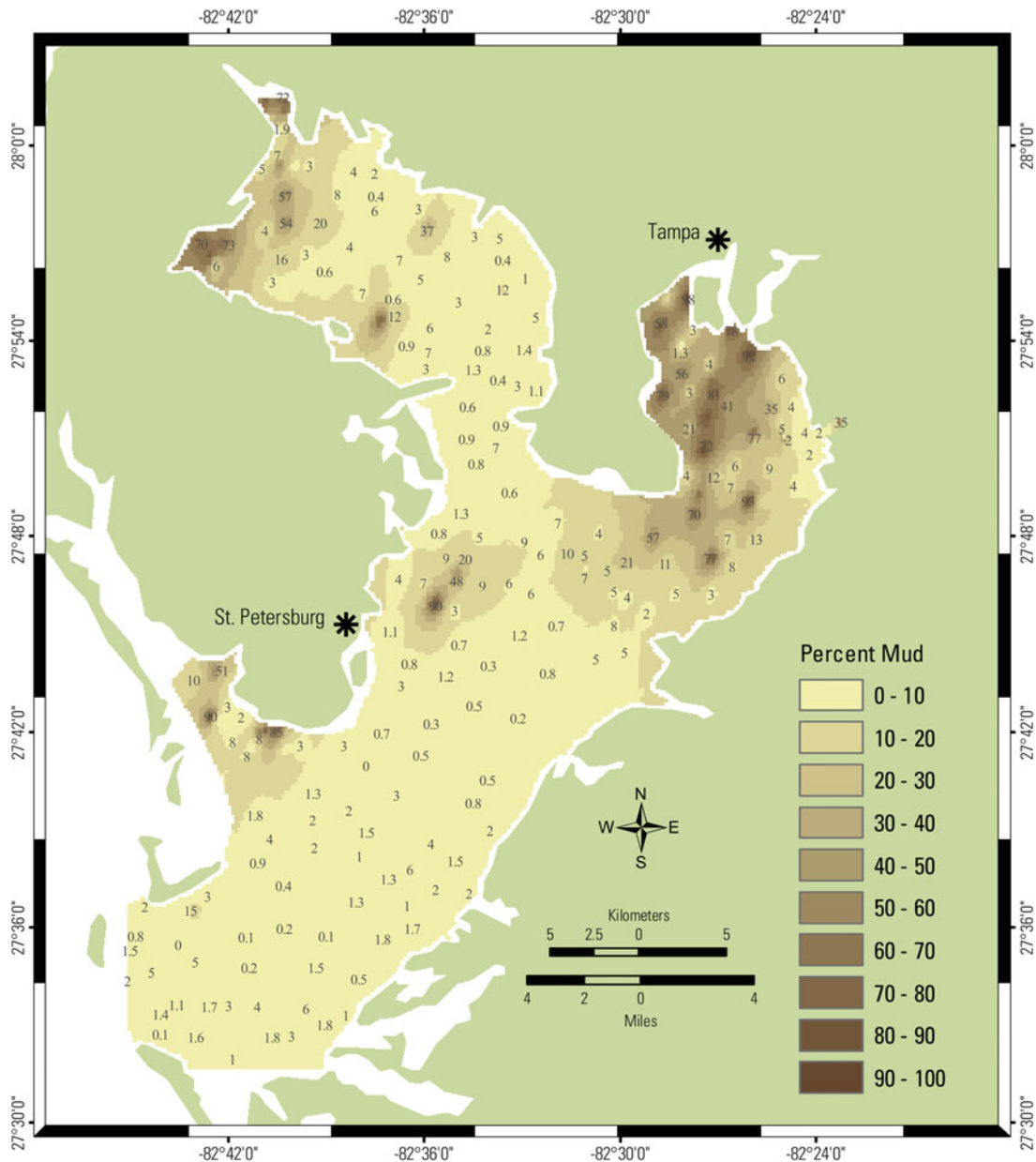


Figure 3.31. Image of Tampa Bay showing the percent of mud. The reciprocal can be considered as the sand percent because the gravel shell component is small (courtesy of the USGS).

3.4.7.5 Pensacola, East, and Escambia Bays

The Pensacola, East, and Escambia Bays have an unusual shape and are dominated by muddy sand (Figure 3.33). Like most coastal plain estuaries, sediments in this system are derived primarily from the rivers that empty into the estuaries. Both mud and sand are spotty in their distribution. Some sand is blown and washed over the adjacent barriers, but washover is infrequent because dunes along this part of the northern Gulf Coast are large. Washover occurs only where dunes are cut and washover channels develop.

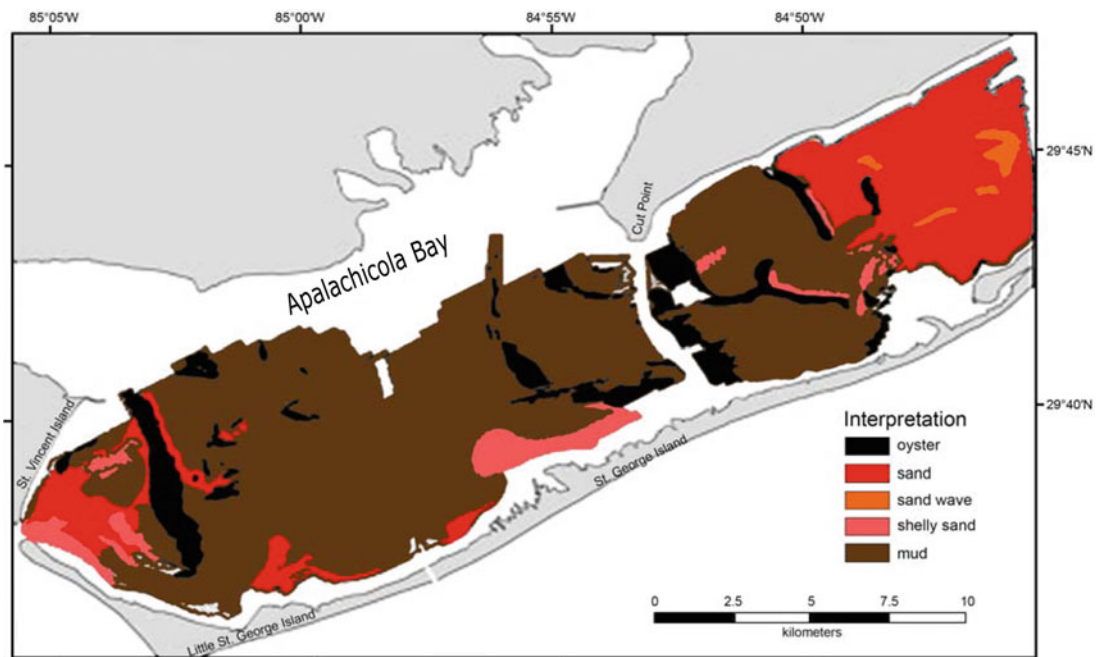


Figure 3.32. Map of Apalachicola Bay, Florida showing oyster reefs and sediment types (Twichell et al. 2010). Reprinted from *Estuarine, Coastal and Shelf Science*, Vol 88, Twichell et al., Geologic controls on the recent evolution of oyster reefs in Apalachicola Bay and St. George Sound, Florida, Figure 3, Copyright 2010, with permission from Elsevier.

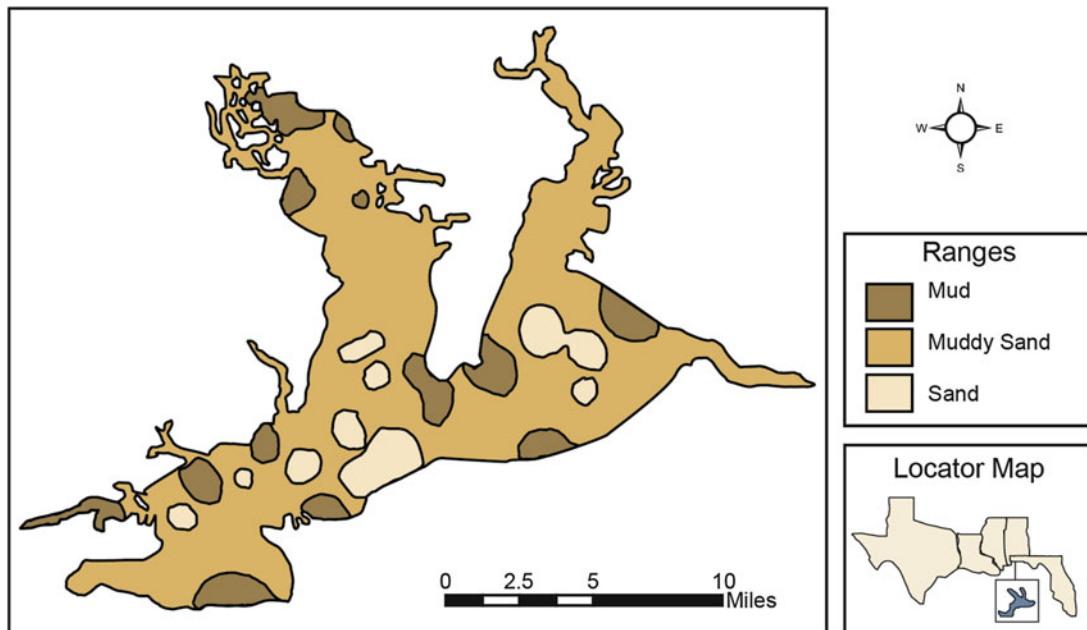


Figure 3.33. Map of Pensacola, East and Escambia Bays, Florida showing the grain size of the sediments (from Macauley et al. 2005).

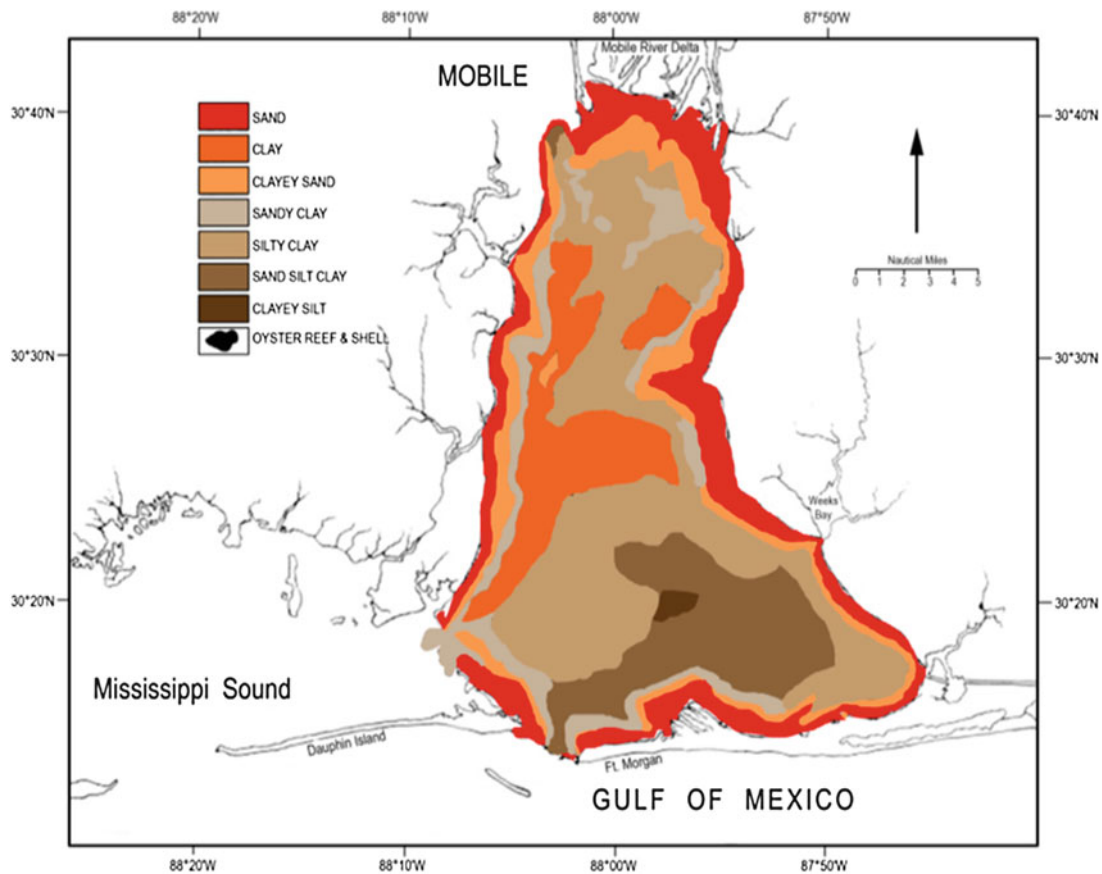


Figure 3.34. Surface sediment distribution map of Mobile Bay, Alabama, and the adjacent area (modified from Ryan 1969).

3.4.7.6 Mobile Bay

Large amounts of sediment—nearly five million metric tons—are carried into Mobile Bay every year. About 33 % of it remains in the delta at the mouth of the Mobile River, 50 % of it settles in Mobile Bay, and the remaining 15 % makes its way into the Gulf. The sediments of Mobile Bay (Figure 3.34) are rather uniform. Mud virtually dominates the estuary except for a thin margin where some sand is present. Clay minerals are the primary grain type with montmorillonite being dominant. There is also a decrease in montmorillonite abundance from the head of the bay down toward the open Gulf. The other clays present are kaolinite and illite (Isphording 1985). The total organic carbon content is high throughout; some areas have concentrations well above 2 % by weight.

3.4.7.7 Galveston Bay

Texas has five primary sources of sediments:

- Active streams: Most bays have active streams that carry terrigenous sediment in a combination of bed load and suspended load emptying into them.

- Erosion of shorelines: Some sediments are derived from the erosion of the shorelines of the bays, and most of these sediments come from bays that have small bluffs of Quaternary sediment, such as Lavaca Bay and Copano Bay.
- Tidal inlets: Tidal inlets enter and influence some of the bays; these inlets may transport marine sediment into the bay, generally accumulating in the form of a flood-tidal delta.
- Eolian and washover processes: Eolian and washover processes carry sand across the barrier islands and into the Gulfward margins of the bays.
- Biogenic shell material: The only nonterrigenous sediment that is common in the bays; biogenic shell material is found as both whole shells and as sand and gravel-sized debris. The bulk of this shell sediment is from oysters.

There is a general pattern to the sediments in the Gulf estuaries. They are all relatively low energy environments with low to modest energy caused by tidal flux. Waves are small with short periods. As a consequence, the standard pattern is somewhat target shaped with high sand content along the margins and mud in the center. Mud dominates and commonly covers about two-thirds to three-quarters of the area of the bay. Many of the estuaries have oyster reefs that cause local variations in the coarse fraction of the sediments. Shell debris in both gravel- and sand-sized particles is common in association with these reefs. The oysters are major factors in the sedimentation of the estuaries because of their huge capacity for filtering suspended sediment out of the water column and producing coarse silt and fine sand-sized pellets of mud.

The sediment distribution maps of the Texas estuaries are all taken from the sequence of publications of the University of Texas Bureau of Economic Geology by William A. White et al. (1983, 1985, 1986, 1987, 1988, 1989a, b). Sediment abundance is shown by the same symbols throughout (Figure 3.35).

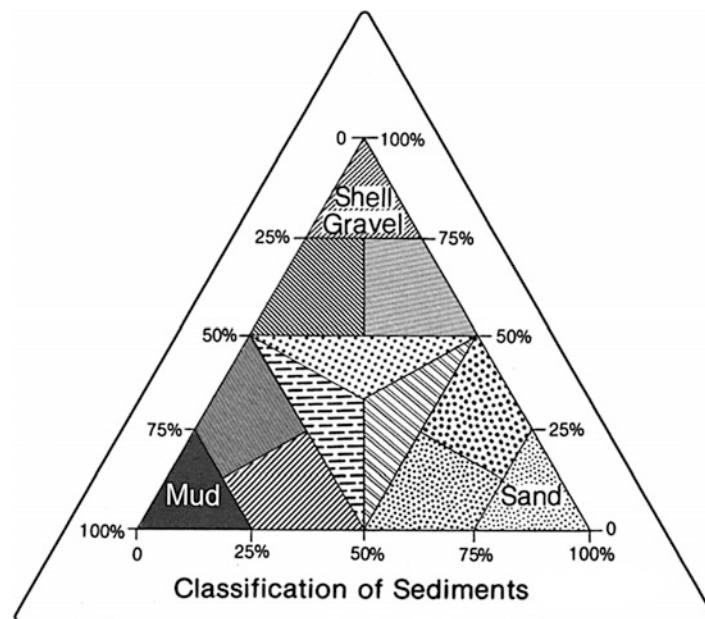


Figure 3.35. Triangular classification of surface sediments in the Texas estuaries with gravel, sand, and mud as the major categories. Figures 3.35, 3.36, 3.37, 3.38, 3.39, and 3.40 are all based on this classification (from White et al. 1983).

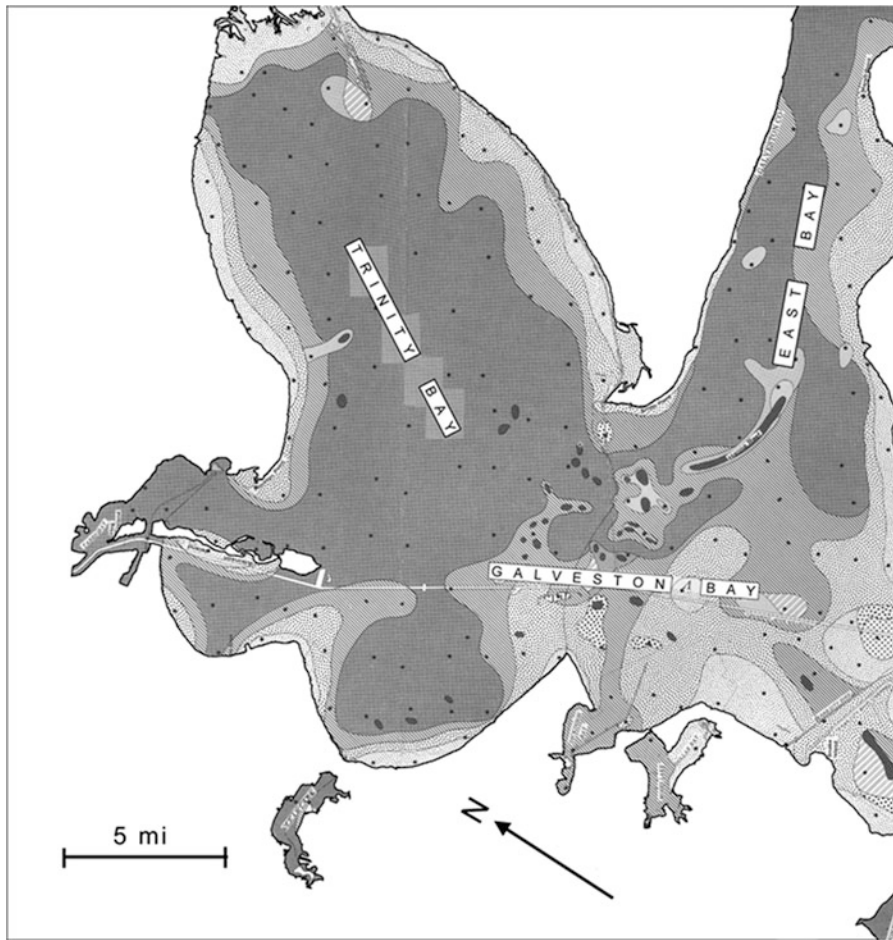


Figure 3.36. Surface sediment distribution map of the Galveston Bay complex. Black dots represent sample locations (from White et al. 1985). Black is oyster reefs.

Galveston Bay (Figure 3.36) is shallow throughout, averaging only about 2 m (6.6 ft) deep, but it has multiple deep shipping channels. Sediment sources are mainly from the barriers, especially the Bolivar Peninsula and the Gulf. Little sediment is provided by the Trinity River (Phillips 2005).

The topography of the bay is like a shallow bowl with relief caused by oyster reefs. This bay produces 80 % of the oyster meat in Texas. The oyster reefs also contribute significantly to bay sediments; both shells and pellets of mud are produced by these extremely active filter feeders.

Most of the sediment in Galveston Bay is mud, sandy mud, and muddy sand. The central part of the bay is mud (Figure 3.36). Sand is concentrated in the bay margin and associated with the flood-tidal delta near Bolivar roads and the Trinity River delta. Oyster reefs are widespread, and shell gravels are associated with them. Some of the sand in the bay is also derived from oyster shells. Human influence on sediment distribution is in the form of spoil mounds from dredging of the Houston Ship Channel (USEPA 1980).

The percent sand shows a general trend from high (60–100 %) at the shoreline, decreasing to about 20 % near the bay center (White et al. 1985). In general, the sand abundance, and therefore the grain size, decreases in a similar trend. Overall sand abundance is related to energy levels of both tidal currents and waves.

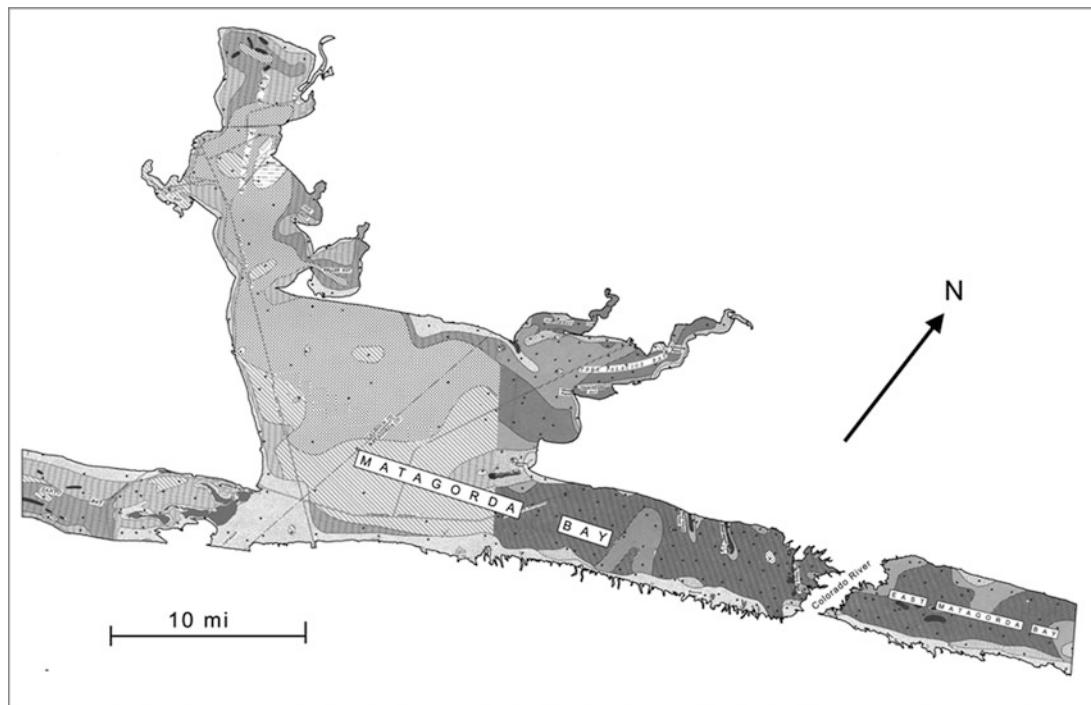


Figure 3.37. Surface sediment distribution map of Matagorda Bay area (from White et al. 1988, 1989a). Black is oyster reefs.

3.4.7.8 Matagorda Bay

Matagorda Bay is a rather narrow bay that separates the mainland from Matagorda Island. The Colorado River Delta has prograded across the bay over the past century, and the river now empties directly into the bay. This bay has a relatively complicated geography and includes both a typical estuarine morphology and a backbarrier portion that is bisected by the Colorado River delta (Figure 3.37). The Colorado River delta has prograded across the bay with the major channel emptying directly into the Gulf (Kanes 1970). This progradation has been extremely rapid and took place over a few decades during the twentieth century.

Unlike most of the Texas estuaries, Matagorda Bay does not have significant oyster reef development; oyster reefs are restricted to a few just west of the river delta that are oriented shore-normal and a few in East Matagorda Bay that are shore-parallel. The surface sediment pattern is similar to that of most bays of this coast. Mud dominates the area with increasing sand toward the shorelines. The relative abundance of sand reflects the location relative to wind direction and waves. The more protected areas show mud closer to the shoreline. The landward side of the Matagorda barrier has extensive sand due to washover and blowover.

There is little tidal flux in this system, and as a result, no sandy sediment accumulations are related to tidal flux except in the southwest corner of the bay. Both the constructed ship channel and Pass Cavallo are located here. The ship channel has small spoil banks, which are relatively high in sand, and the tidal inlet has a large flood-tidal delta that is sand dominated (Figure 3.37).

3.4.7.9 San Antonio Bay

San Antonio Bay is located at the mouth of the combined San Antonio and Guadalupe Rivers where a large bayhead delta—the Guadalupe Delta—has formed (Figure 3.38). The

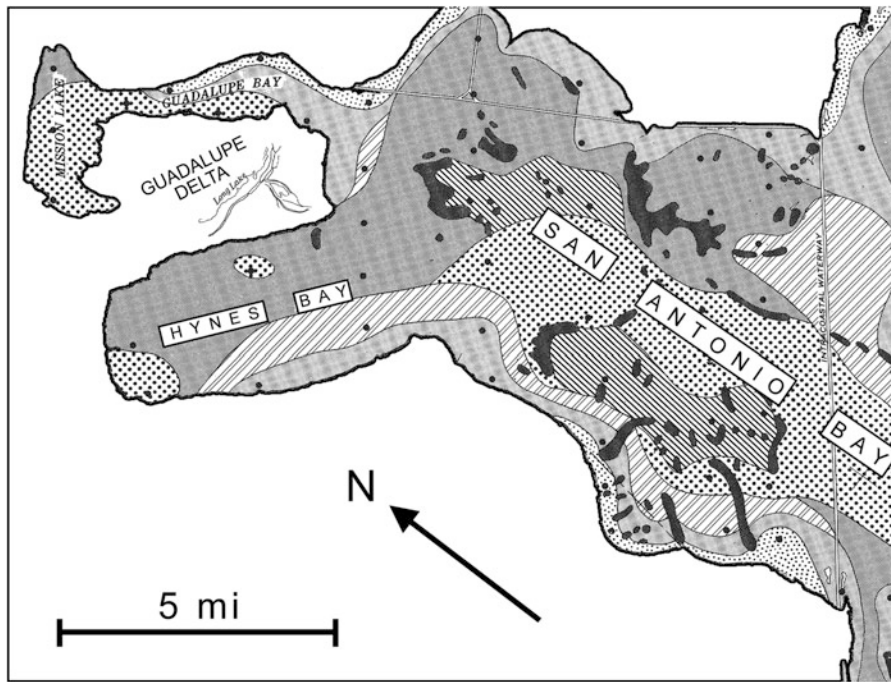


Figure 3.38. Surface sediment distribution map of San Antonio Bay, Texas (from White et al. 1988, 1989a, b). Black is oyster reefs.

Guadalupe River delta dominates the northwest part of San Antonio Bay and has shown significant progradation over the past century, but has somewhat stabilized during the past few decades. The delta sediments are more than 60 % plant remains (Donaldson et al. 1970); the bay sediments, as a whole, are only about 4 % plant remains.

This bay is the second most productive oyster region on the Texas coast. The reefs are scattered throughout the bay. This bay has no locations where tidal flux is a factor in sediment texture or accumulation. The bay is less than 2 m (6.6 ft) deep on average and is brackish. There are some low bluffs along the shoreline that produce sand when eroded.

An important aspect of San Antonio Bay is related to how the widespread oyster reefs influence sediment texture. The majority of the bay is regularly dredged by oystermen with their trawlers. This disturbance of bottom sediment tends to produce slightly coarser grain size because the dredging suspends fine sediment allowing it to travel to other parts of the bay (White et al. 1989a).

The entire bay is dominated by mud composed primarily of clay minerals. Morton (1972) studied 80 samples from throughout the bay for their clay mineralogy and found that smectite, illite, and kaolinite were the dominant species with smectite being the overwhelming majority.

3.4.7.10 Aransas and Copano Bays

Copano and Aransas Bays are similar to San Antonio Bay in their sediment composition and distribution. These bays are also important to the oyster industry in that reefs are extensive in both. They have the typical pattern of sediment texture distribution with fines in the middle and becoming coarser near the shoreline. Copano Bay has some low bluffs that are exposed to the prevailing wind and therefore are subject to some erosion. Extensive oyster dredging also influences the sediment texture here. Another factor is the petroleum industry's considerable

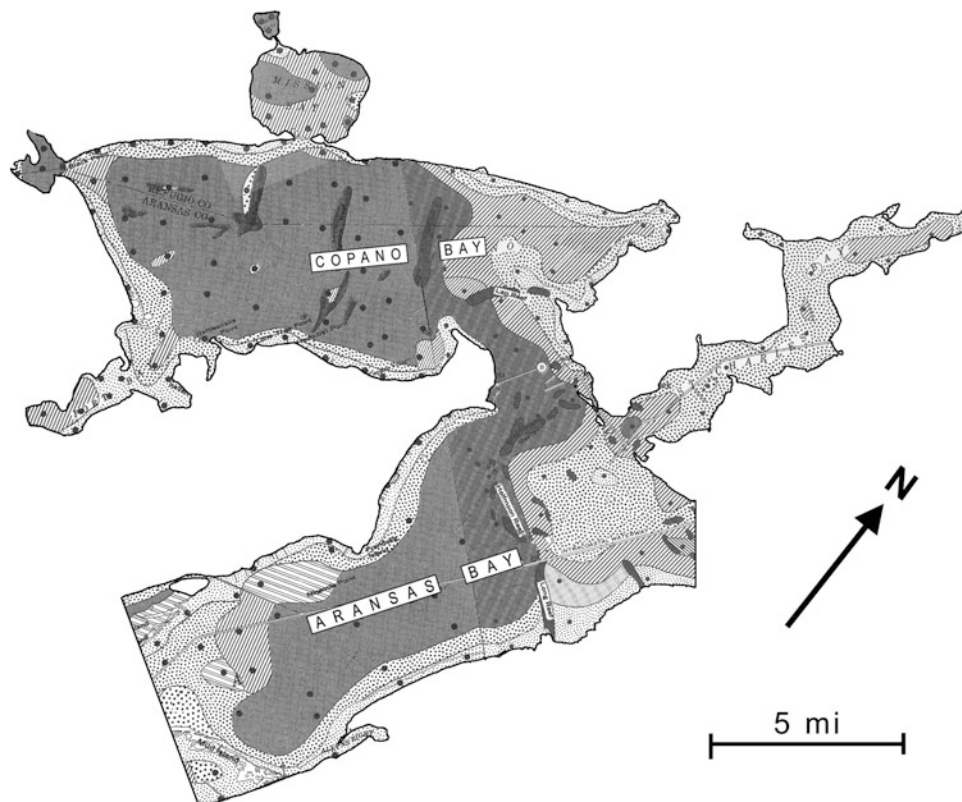


Figure 3.39. Satellite image of Aransas (*lower*) and Copano (*upper*) Bays (from White et al. 1983, 1989a). Black is oyster reefs.

drilling and related activity that has taken place in both bays. Drilling activity, construction, maintenance, post drilling activity, and the presence of the permanent structures in the bay all have an influence on the bays' surface sediments.

St. Charles Bay, which is a branch of Aransas Bay, is sand dominated as compared to other bays along this coast (Figure 3.39). Sand also dominates the northeast part of Aransas Bay adjacent to St. Charles Bay. The corresponding end of Copano Bay also shows a high percentage of sand. Both of these locations are on the downwind portion of the respective bays relative to the strong prevailing wind along this coast.

Both of these bays are major oyster areas. These animals are tremendous filter feeders and pass many liters of turbid water through their system every hour. As a consequence, the fine silt and clay-sized particles are aggregated into fecal pellets that are typically sand sized. Oyster shells are a common constituent and contribute most of the gravel fraction to the sediment. The sediment is mostly mud and is patchy because of the abundance of oyster reefs. There is some sand around the bay margins.

3.4.7.11 Corpus Christi Bay and Nueces Bay

The Nueces River is the primary source of freshwater and sediment to both the Corpus Christi Bay and Nueces Bay. The present sediment contribution of this river is minimal because of impoundments along its course. In the past, however, considerable terrigenous sediment was carried to these two bays by this river. Although the pattern of surface sediment on Corpus

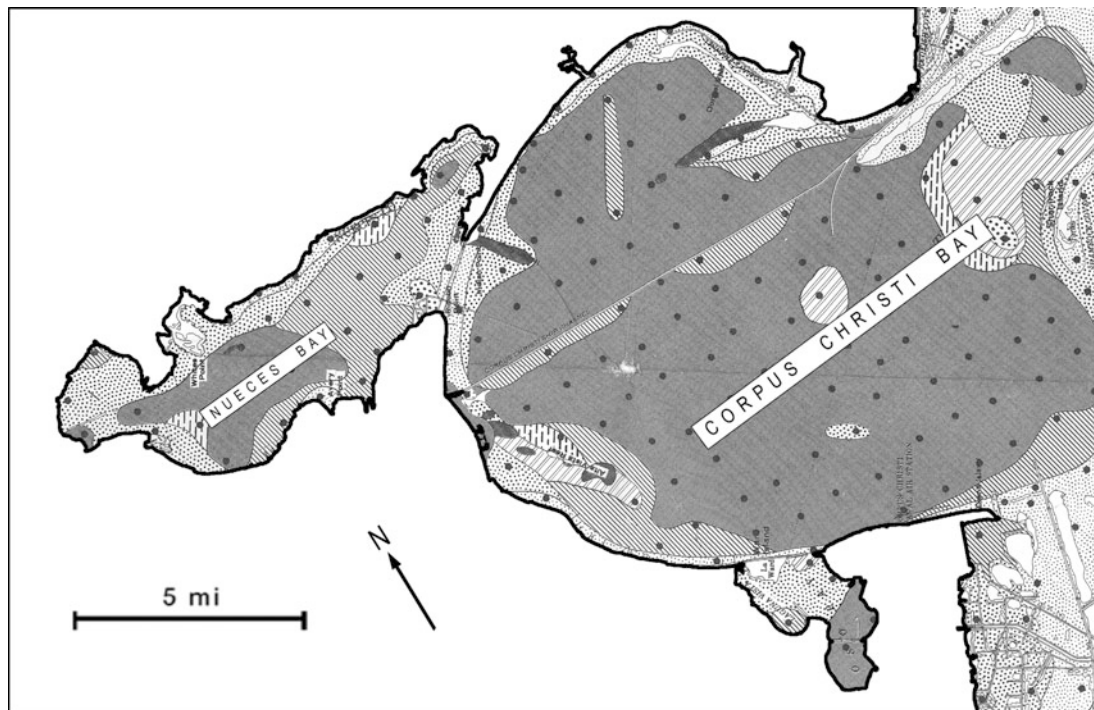


Figure 3.40. Surface sediment distribution map of Nueces and Corpus Christi Bays (from White et al. 1983).

Christi Bay is typical of this coast with a huge portion being mud dominated and a trend to more sand to the shoreline, Nueces Bay is different (Figure 3.40).

Mud comprises a fairly small portion of the surface sediment in Nueces Bay. Much of the bay is covered by sandy mud. The delta area is also high sand. Some of this can be attributed to the extensive dredging for oyster shell that has taken place in this bay (White et al. 1983). Oyster shell and oyster debris are fairly common in Nueces Bay but not in Corpus Christi Bay.

The constricted area between the two bays is also the site of the causeway across them. The combined effects of the constriction and the causeway structure have caused a relative coarsening of surface sediment. This has resulted from tidal flux through the constriction/structure and its location on the downwind end of the bay where the fetch is maximum (Figure 3.40).

Corpus Christi Bay is much larger than Nueces Bay and is dominated by mud in its surface sediment, mostly with a mean grain size of greater than 7.0ϕ (White et al. 1983). Sand increases to the shorelines. The only variations in this pattern are associated with a large oyster reef in the northeast part of the bay, the coarsening associated with dredge spoil along the ship channel, and the area near the population center associated with Corpus Christi. An oyster reef is also present in the northeast area.

3.4.7.12 Baffin Bay

Baffin Bay is unique among the coastal bays of the United States in that it receives little freshwater and virtually no terrigenous sediment at the present time. Its geography is an obvious drowned fluvial system, which is much more evident for Baffin Bay than for other

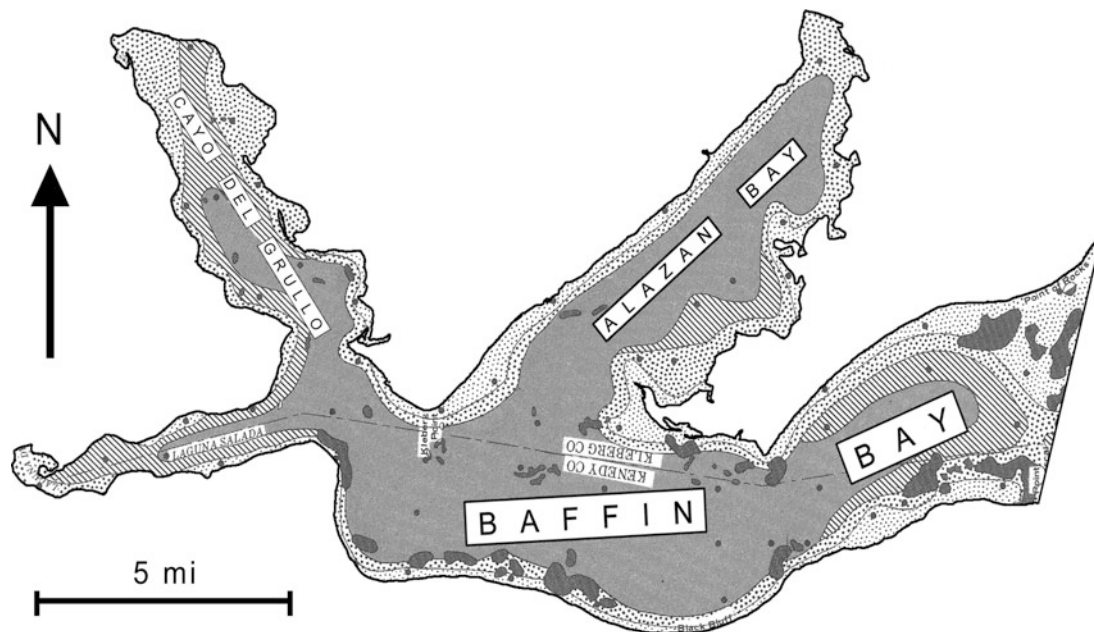


Figure 3.41. Surface sediment distribution map of Baffin Bay and part of adjacent Laguna Madre, Texas. It is apparent from the geography of the bay that it is a drowned fluvial system (from White et al. 1989b). Black is serpulid worm reefs.

bays along this coast. Because of its location in a semi-arid portion of the western Gulf, Baffin Bay is hypersaline.

Other reefs in this bay, called worm reefs, are constructed by the polychaete worm, *Sabellaria alveolata* (Andrews 1964). These worms do not secrete the tubes that they live in; they construct the tubes out of sand and shell grains. The worms are abundant in Baffin Bay (Figure 3.41). Their distribution is primarily along the shoreline and near the entrance.

The nonreefal portions of Baffin Bay are dominated by mud with sand percentage increasing toward the shore. Because the streams that feed Baffin Bay are intermittent, almost no terrigenous sediment is presently being contributed to the bay. The combination of environmental conditions does permit precipitation of carbonate sediment, including dolomite (Behrens and Land 1972). Ooid sand is also produced and is concentrated along the northern margins of the bay (White et al. 1989b). Exposed Pleistocene beach rock also contributes gravel-sized particles along the margin where this material is exposed.

The grain size of Baffin Bay sediments is primarily a relict condition from earlier times when the climate was wetter and the streams that fed the bay were regularly discharging water and sediment. The bay floor is mud, dominated by silt-sized grains. This sediment grades shoreward through sandy mud and then muddy sand.

The margins of the bay have scattered beach rock reflecting the nature of the climate and very low wave energy. Other indicators of such a climate and absence of terrigenous input is the presence of ooids scattered along relatively high-energy parts of the bay (Rusnak 1960; Behrens 1964).

Baffin Bay is very shallow with essentially no fluvial or marine input of runoff or sediment. Sand dominates along the bay margins, and mud is less than 20 % (White et al. 1989b). This bay originated as a fluvial system, as is shown by its outline. It is hypersaline, and as a consequence, sabellaria reefs have replaced the oyster reefs of other Texas estuaries. In addition, there are local populations of carbonate sediment and evaporate minerals.

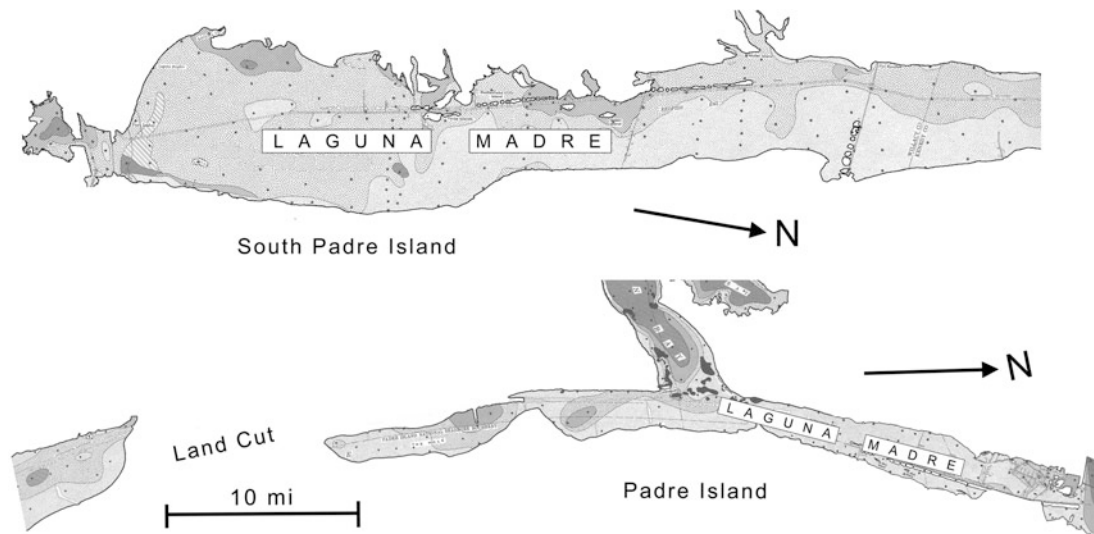


Figure 3.42. Surface sediment distribution map of Laguna Madre, Texas. Black is serpulid worm reefs. Top map is north and bottom is south (from White et al. 1986).

3.4.7.13 Laguna Madre

Most of the surface sediments in this lagoon are sand, which reflects the frequent and widespread washover/blowover from adjacent Padre Island (Figure 3.42). The land cut area is essentially pure sand and is the product of these processes. Grain size in Laguna Madre ranges from medium to fine sand with low amounts of mud. Laguna Madre also has muddy central areas with sand-dominant margins (White et al. 1986, 1989b). In places carbonate sediments, primarily ooids, are formed (Land et al. 1979). Locally there may be evaporate minerals that result from the high salinity. These are most common in the form of gypsum sand crystals that are present on the surface and at depths of greater than 4 m (13 ft) (McBride et al. 1992). This area has been arid and semi-arid for millennia resulting in little or no vegetation on either the barrier island or the mainland. The result has been considerable sand carried to the lagoon via eolian sediment transport.

3.4.7.14 Lagoons of Mexico and Cuba

The bays of the coast of Mexico are numerous and varied. They are essentially all lagoons in that salinity tends to be either high or shizohaline. The amount of runoff ranges widely; thus, a wide range in salinity and the sediment may be either terrigenous, carbonate, or a mixture of both. Coastal lagoons in Cuba are essentially absent.

Laguna Madre in Mexico is somewhat similar to that of the United States. It is shallow, hypersaline, and has some carbonate and evaporite precipitation in a terrigenous-dominated system. The fine, well-sorted sand is largely from washover and blowover of the barrier island on the Gulfside of the lagoon.

The Alvarado lagoon system in the Veracruz area is a good example of a Mexican Gulf Coast lagoon environment. It is a complex of four water bodies fed by a like number of lagoons providing terrigenous sediments with a small number of carbonates produced mostly by washover from storms. These lagoons are quite polluted. Like many of the coastal lagoons

of Mexico, a substantial amount of pollution is the result of extensive mosquito spraying. The sediments have a fairly bimodal grain size with most of the open water locations being in the mud range with mean grain sizes in the $4.0\text{--}7.0\Phi$ range and the coarse sediments in the $-1.0\text{--}2.0\Phi$ range. The coarse sediments are in places where currents are fast due to constrictions at inlets or channels between adjacent inlets (Rosales-Hoz et al. 1985).

The Celestun lagoon is an elongate water body separated from Campeche Bay by a long carbonate barrier. The sediment in the lagoon is nearly equally distributed between sand, silt, and clay-sized particles (Gonneea et al. 2004; Pech et al. 2007). This means that mud dominates.

Nichupte Lagoon is essentially at the boundary of the Gulf of Mexico and the Caribbean Sea. It is in the vicinity of Cancun on the Yucatán Peninsula. This coastal water body is probably the most polluted because of the high level of development in the vicinity. The sediments are all carbonate and are dominated by sand (65–75 %); mud is the remainder. Organic carbon is relatively high with values that range from 1.6 to 5.6 % with a mean of about 3.5 % by weight (Valdez-Lozano et al. 2006).

The coast of Cuba that is in the Gulf of Mexico is limited to the northwest portion of the country, essentially from the western tip of the country to the eastern tip of Varadero Beach, west of the small city of Matanzas. This coast includes five coastal bays about which there is virtually no information on their sediments. The following comments are based on the geomorphology of the area and their demographics. The five bays from west to east are Bahia Honda, Bahia de Cabanas, Bahia del Mariel, Havana, and Bahia de Matanzas.

Bahia Honda has no significant fluvial discharge and therefore not much sediment is being delivered. It has a bedrock shoreline and a modest amount of relief on its shoreline. Because the community on its border is industrial and there was a U.S. military base, it is assumed that the sediments are somewhat polluted. Bahia de Cabanas is quite similar to Bahia Honda in its general setting and geomorphology but is apparently more pristine in character. It has been designated as an excellent site for mariculture development (Texas A&M University—Corpus Christi, Harte Research Institute). Bahia del Mariel has an industrial port, and although it is smaller than the two previously addressed bays, it is similar in other respects and probably has somewhat polluted sediments. The most developed coastal bay is the harbor in Havana, which is very polluted. Bahia de Matanzas is a funnel-shaped bay that is served by three rivers. The combination of the rivers and the potential of tidal sediment delivery in a funnel-shaped estuary have probably led to a fair amount of sediment delivery.

3.5 SUMMARY

The Gulf of Mexico is essentially a small ocean basin. It contains all of the physiographic and geologic elements of a true ocean basin. The continental margin mimics that of an ocean basin with a continental shelf, continental slope/rise, and an abyssal plain. The slope/rise province is dissected by submarine canyons. Large deep-sea fans are also present. The deep basin is an abyssal plain environment with little relief.

The coastal zone of the Gulf includes a range of environments including estuaries, lagoons, fluvial deltas, barrier islands, and tidal inlets, which reflect the tectonic stability of the basin and the generally extensive coastal plain.

Nearly all sediments are either terrigenous or carbonate. Locally there may be evaporate accumulations. The terrigenous sediments are dominantly derived from fluvial discharge and then dispersed via various current systems along the coast or into deep water. A few locations in Mexico and Cuba have some terrigenous sediment, which eroded from bedrock exposures along the coast. The Florida coast and its carbonate sediments may be of biogenic origin or from direct precipitation.

Sediment textures range widely depending in part on the environment in which they accumulate. Terrigenous sand is rather limited to coastal, high-energy environments such as beaches and tidal inlets. Mud is typical of deltas, the outer shelf, and the deep sea. The coarsest sediments tend to be carbonate skeletal dominated beaches in Florida and Mexico.

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