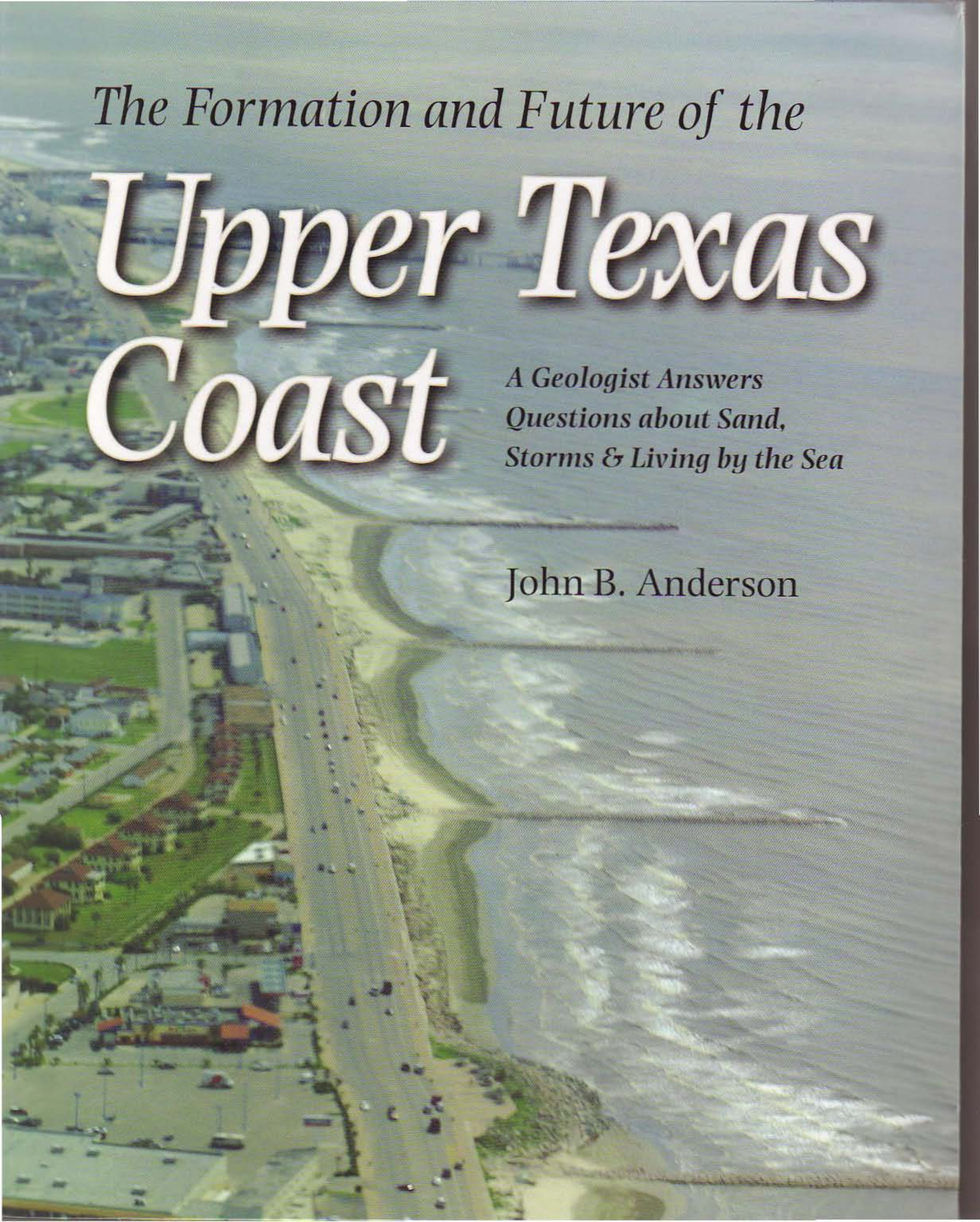

The Formation and Future of the Upper Texas Coast

A Geologist Answers Questions about Sand, Storms & Living by the Sea

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Coastal Processes

View of the beach during low tide.

What happens to the sand that erodes from our beaches?

Wave Motion and Sand Movement

As waves approach the shore, they begin to drag on the seafloor, which causes them to become steeper and break. A breaking wave is literally surface water that has overrun water near the bottom. The location where waves break is called the breaker zone. Its location varies as wave height varies. Landward of the breaker zone is the surf zone, where extreme turbulence from breaking waves lifts sand off the seabed. The area where waves swash back and forth onto the beach is called the swash zone (fig. 1.1).

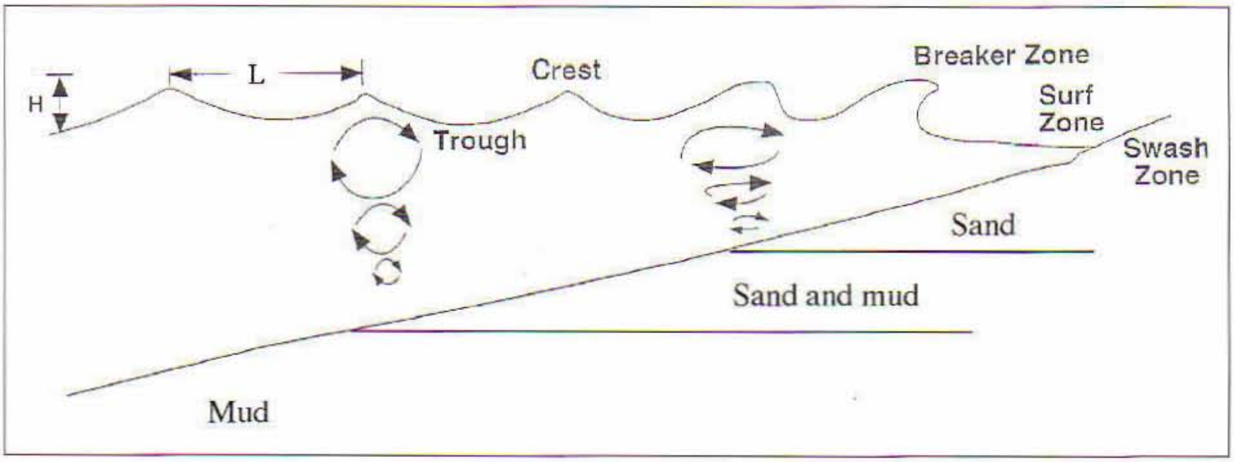


Figure 1.1. When waves approach the beach they become steeper as they drag on the bottom. Eventually the surface water overruns the bottom water, and the wave breaks. As the height of the wave (H) and the length of the wave (L) increases, the wave breaks farther from shore.

Landward of the swash zone is the main part of the beach. Coastal geologists refer to this as the storm beach because it becomes a swash zone during storms and extremely high tides. Sand that is moved landward by swash and wind piles up at the landward side of the beach to create a beach ridge, which includes dunes. This is the natural barrier that protects the coast from storm wash-over. As the beach retreats landward, the dune line moves with it. Unfortunately, construction on the beach has too often prevented this natural movement of the dune line, so it is becoming a rarity along our coast.

The motion of water within a wave is orbital, or circular, and the upward component of wave motion lifts sand grains off the seabed each time a wave passes. This is why waves are so efficient in transporting sand. The depth of wave orbital motion increases with wave height and length (the distance between wave crests), meaning that larger, longer waves, in essence, dig deeper, transporting sand from greater depths than do smaller waves. As waves approach the beach they lift sand grains off the bottom and toward shore. If you stand in the breaker zone you can feel this motion of sand from the breaking wave. The sand that is transported shoreward is deposited as a sandbar. As the bar grows, waves break over it, so the breaker zone becomes more confined. The location of the breaker zone depends upon the wave length and height on any given day. When onshore winds (those that move from water toward shore) are strong, large waves

The beaches around San Luis Pass are among the most rapidly changing Texas beaches because sand is constantly shifting from the beach into the offshore bars and vice versa. Here, houses at Treasure Island are literally sitting seaward of the surf zone, having been left behind by the ever-shifting ebb tidal delta.

West of San Luis Pass, along Follets Island and around Surfside Beach, the coast has a low profile; Surfside has an average elevation of 4 feet. The most significant loss of sand from the beach occurs during storms when sand is washed across the beach into the wetlands and back-barrier bays. Eventually, this sand will be reclaimed and moved back into the longshore transport system as the shoreline advances landward. Meanwhile, the sand helps to maintain wetlands by providing a framework on which marsh vegetation grows.

that the delta was a prominent lobe, marked by shallow depths, offshore of the river mouth. Within a few decades after the river was diverted, the lobe was gone, having been eroded by storm waves, and a new delta lobe was formed to the southwest, offshore of the new Brazos River mouth. This is one of several examples of the fact that sediment that occurs offshore in water depths of up to 30 feet is eventually exhumed as the shoreline advances. Much of the sand that is exhumed is delivered back into the longshore transport system. In this case, the delta was removed in about two decades. Another example is the erosion of the old Bolivar Roads ebb tidal delta that occurred after the construction of the ship channel and jetties, which blocked sand supply to the tidal delta (fig. 1.5). The lesson here is that it doesn't take long to see the impact of human tampering with the coastal system.

Now let's get back to the question of where the sand eroded from area beaches goes. Most of the sand that erodes from Bolivar Peninsula is trapped on the beach east of the North Jetty. The sand eroded from Galveston Island ends up in the San Luis Pass tidal delta. Sand eroded from Follets Island washes over this narrow barrier into wetlands and bays. A similar fate awaits sands removed from beaches between the Freeport jetties and the Brazos Delta. During major storms, sand can be removed from the beach and transported far offshore and deposited as storm beds. However, sediment cores taken offshore have rarely sampled storm beds, so this mechanism of sand removal from the coast does not appear to be significant.

As for what happens to the area immediately offshore of the beach as the shoreline moves landward, the answer is pretty well known. As the shoreline retreats landward, the shoreface retreats with it, leaving little remaining shoreface deposits on the inner continental shelf. Sand is confined to the area closest to shore, generally within a kilometer (0.6 miles) of shore and within the steepest, most dynamic portion of the shoreface. The rate of shoreface movement is more or less equal to changes that occur on the beach. If sand is taken from the shoreface for beach nourishment, an unstable offshore profile is created and sand will be delivered from the nourished beach back to the shoreface to reestablish the equilibrium profile.

Storm beach. During an extreme high tide, the wave swash extends to the base of the dunes.

View looking west on Galveston Island showing the dune line. Features like this are becoming more and more rare because humans have interfered with their natural landward migration.

Two sandbars, one near the beach and an outer bar where the waves are breaking.

break farther offshore to form sandbars farther offshore. Surf fishermen are well aware that there is more than one sandbar off the beach, each separated by depressions that run parallel to the coast. The depressions, or runnels, are where the fish tend to congregate.

Sandbars form far from shore during strong winds, when waves are larger. These offshore bars tend to endure, because when winds diminish, the waves are too small to have much influence on the bars. On any given day there may be as many as three sandbars and associated breaker zones. Over periods of weeks, as the weather and wave conditions vary, sandbars migrate landward and old bars are remolded into new ones. If you were to measure the seafloor depth from the beach to a few hundred yards offshore on a regular basis, you would observe constant change in

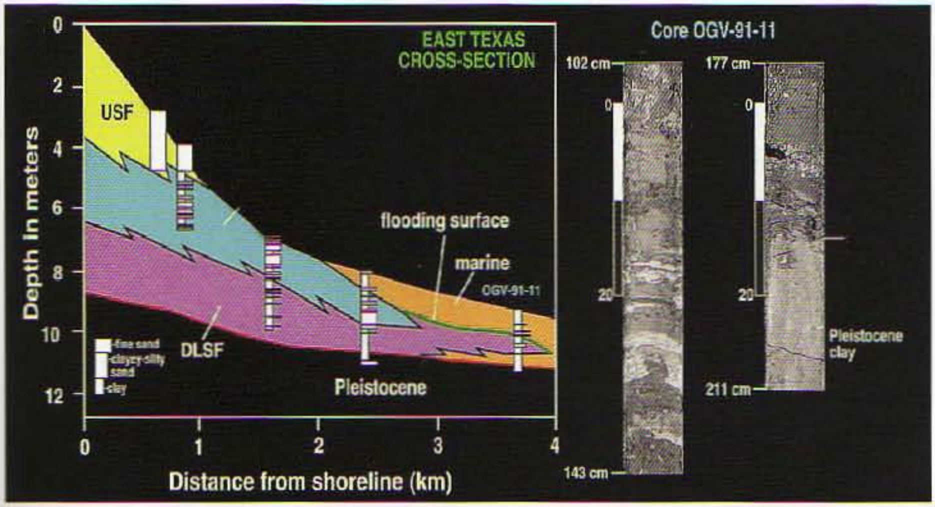


Figure 1.2. Sediment cores collected offshore of Galveston Island State Park show the change from sand to mud in an offshore direction. They also show that mud (in orange) now buries sand as a result of coastal retreat. The photographs on the right are examples of sediment cores used to construct this profile. The lighter units are sand, which is very fine grained and unsuitable for beach nourishment. The darker layers are mud, which further limits the quality of the sediment for beach nourishment. Modified from Rodriguez, Fassell, and Anderson 2001.

the location of runnels and bars. This highly dynamic near-shore zone is referred to as the upper shoreface. This part of the coast is under the constant influence of waves, and only sand is deposited here. It is also the steepest portion of the shoreface and, along the upper Texas coast, occurs between the shoreline and about 15 to 18 feet (5 to 6 meters) water depth.

Seaward of the wave-dominated upper shoreface is a zone that is influenced by waves only during storms. During storms, sand is delivered to this zone, the lower shoreface, from onshore. During fair weather conditions, the seafloor is more quiescent and mud is deposited. With time, sand mixes with mud. Along the upper Texas coast, the lower shoreface extends seaward of the upper shoreface to water depths of about 24 to 30 feet (8 to 10 meters) (fig. 1.2). The depths of these zones and their sediment types differ largely according to differences in the bottom profile along the coast. Seaward of the lower shoreface is the continental shelf.

For those of us concerned about coastal erosion and beach nourishment, it is important to know where within the coastal setting sand is being transported by waves and coastal currents. The term *closure depth* is commonly used to describe the maximum depth of sand transport. One way to estimate closure depth is to use such factors as wave length and height. However, in my opinion, the best way to determine the closure depth is to use the actual distribution of sand in the shoreface and to observe the migration of sandbars over time.

The coastal waters of the upper Texas coast tend to be muddy much of the time because larger waves resuspend mud that rests on the seafloor just offshore. This sediment is then moved alongshore by coastal currents.

Longshore Currents

The constant movement of waves toward the beach causes water to pile up at the coast, and that water ultimately has to move back offshore. But before it does, the water may flow parallel to the shore as a longshore current. This happens when waves approach the beach from an angle. Longshore currents can be quite strong if the winds are strong and the waves approach from a sharp angle. These longshore currents accelerate as more water is continuously added to the coastal current.

We all have experienced longshore currents. Recall the time you were drifting on your float and suddenly realized that you had drifted down the coast some distance from where you entered the water. You were taken there by longshore currents. The experience could have been much worse, because ultimately longshore currents veer offshore as waves move more water onshore. This offshore flow occurs either as discrete currents known as rip currents or as a more dispersed flow commonly referred to as undertow. These offshore-directed currents pose a danger to swim-

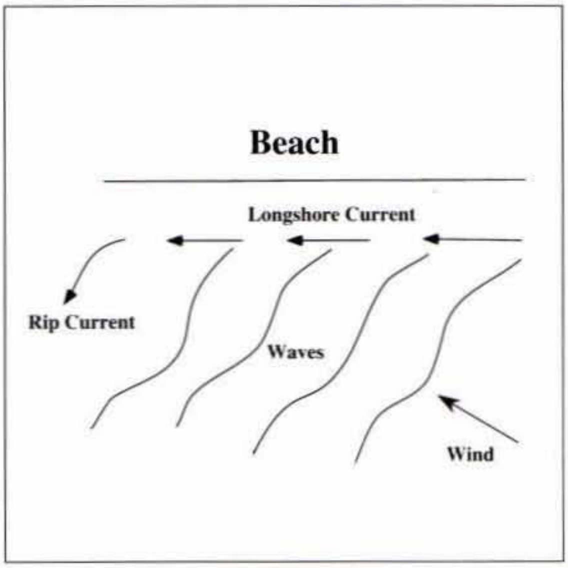


Figure 1.3. Waves that approach the coast from an angle force water onshore and alongshore to produce longshore currents.

mers, who often panic when they feel themselves being pulled offshore. The trick is to remain calm, because the current will dissipate when it flows a short distance offshore and its water is displaced.

Along the upper Texas coast, prevailing winds are from the southeast. This creates waves that approach the coast from the southeast and longshore currents that flow from east to west. These longshore currents transport sand, and the constant movement of sand along the coast is called longshore transport. The quantity of sand moved within the longshore transport system is evident wherever longshore currents are blocked by man-made structures. For example, at the west end of Bolivar Peninsula, sand transported to the west by prevailing longshore currents is trapped by the North Jetty, which extends 4.5 miles offshore. It is estimated that the jetty has trapped 28 million cubic yards of sand since it was constructed. Another way to visualize the volume of sand moving within the longshore transport system is to imagine dump trucks traveling west along Galveston Island filled with sand. A new load of sand would pass every twenty minutes.

From November through March, low-pressure weather systems (fronts) frequently move across the upper Texas coast. When they do, we experience strong offshore winds (those that blow from the shore out to the sea). These winds dampen waves, and longshore currents are weak.

Figure 1.4. Along Bolivar Peninsula, the longshore drift system delivers sand toward Bolivar Roads, the pass between Galveston Island and the peninsula. But before the sand reaches the inlet it is blocked by the North Jetty. If you drive to the area just east of the jetty, you can see the extensive beach that has formed from sand trapped on the "up-drift" side of the jetty. Note the location of the 1856 shoreline (dashed line) before the jetty was constructed. Note also the linear features that extend along the peninsula. These beach ridges, separated by depressions or swells, formed when the peninsula was growing naturally. Photo from the U.S. Geological Survey.

Shifting northerly and southeasterly winds enhance tides, and beaches expand and contract accordingly.

On Galveston Island, as fronts move across the coast and to the east, winds blow from the west, and longshore currents flow toward the east. Although this is not the prevailing longshore current direction, sand is trapped behind the jetties on the east end of the island, where it remains because the jetties prevent waves and longshore currents from removing this sand. This is why East Beach is so expansive.

The Bolivar jetties were constructed to protect ships entering the ship channel and to prevent sediment from filling the channel. Before the jetties were constructed, sand was transported through the Bolivar Roads inlet into Galveston Bay or offshore, where it accumulated as an extensive bar off the mouth of the inlet. The sand delivered into the bay accumulated in a sand body that is referred to as a flood tidal delta, because the

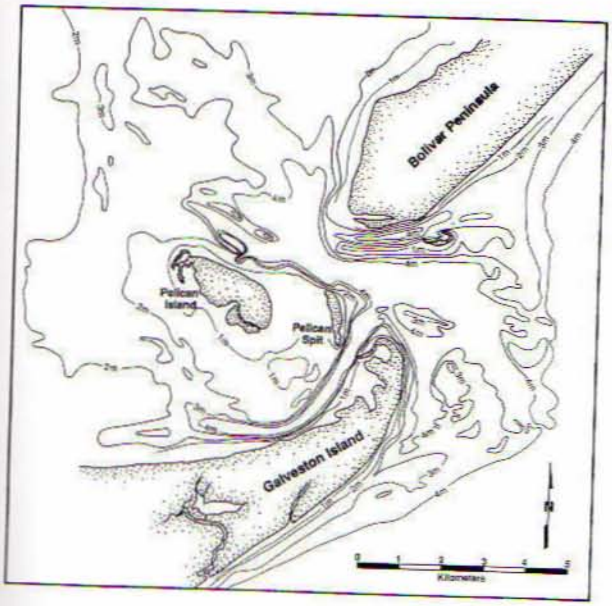
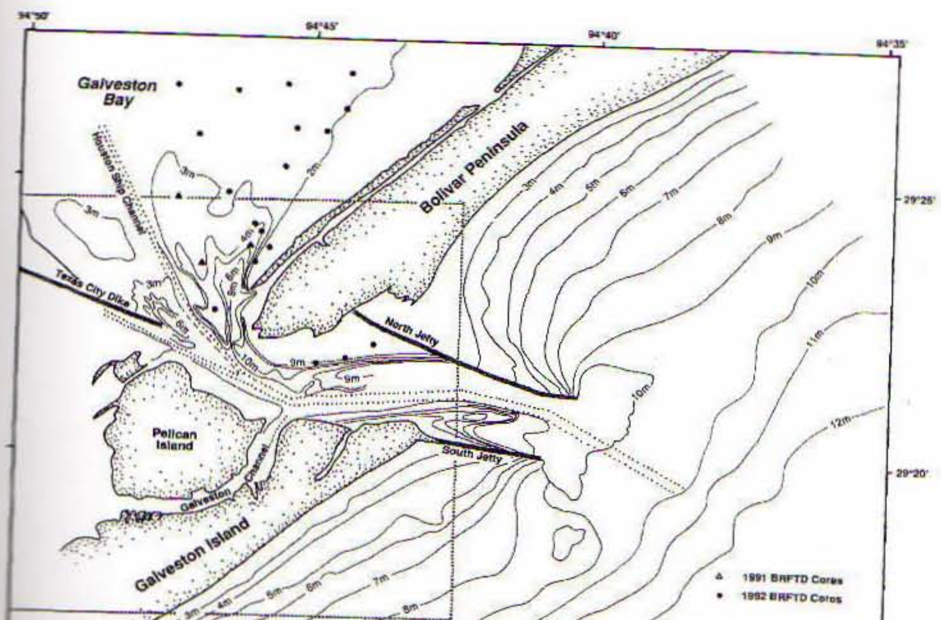
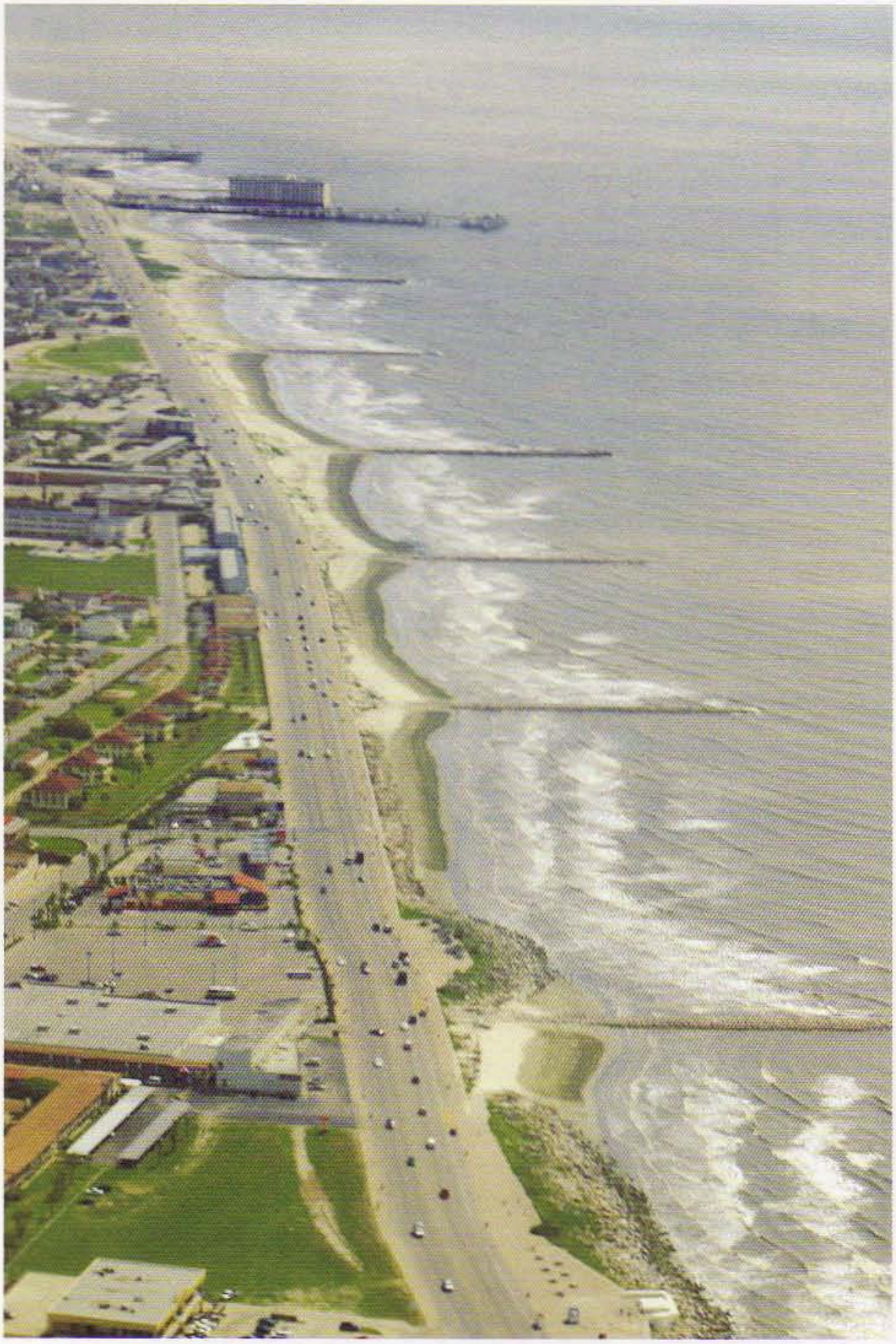


Figure 1.5. *After the turn of the twentieth century, jetties were constructed to provide protection for vessels entering the ship channel at Bolivar Roads. The chart at the top is from 1856, and the one at the bottom is current. Note the changes that have occurred in the ebb and flood tidal deltas since the jetties were constructed.*





Rock groins that extend offshore of the Galveston Seawall capture sand that moves within the longshore transport system.

Aerial view of the San Luis Pass tidal delta. Photo from GlobeXplorer.

sand is delivered there during the rising or flood tide. Pelican Island was originally part of the flood tidal delta. The offshore sand deposit is referred to as the ebb tidal delta because the offshore-directed or ebb tide delivers the sand to these areas. After the jetties were constructed, the ebb tidal delta was eroded, which is evident in the differences in offshore bathymetry (water depth) between the two charts in figure 1.5. The flood tidal delta was mostly buried in mud.

Along Galveston Island, sand is mostly transported to the west. But the longshore drift has been altered by rock groins that extend offshore of the

The beaches east of San Luis Pass have experienced significant growth and retreat in recent years. In the recent past they have eroded rapidly. This area is part of the tidal delta and, as such, is subject to constant change.

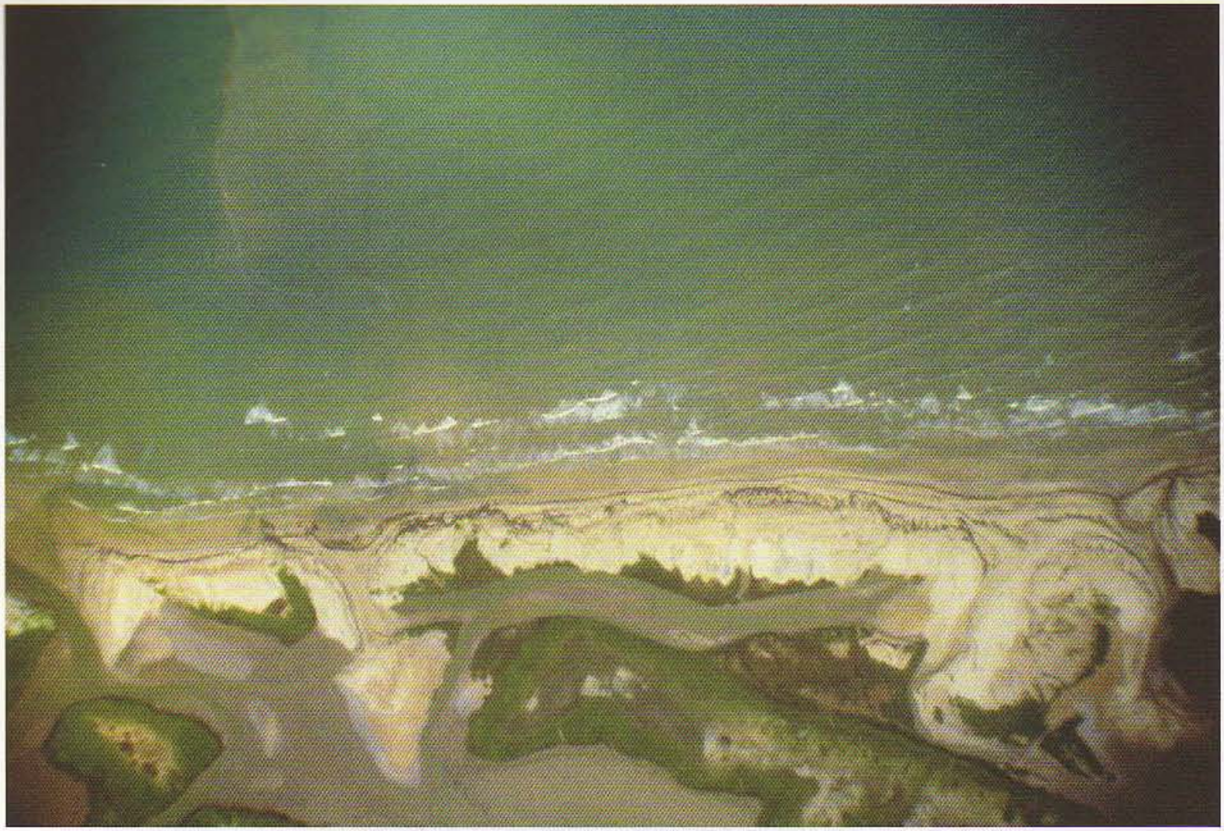
seawall. The groins were built to trap sand moving within the longshore drift system and to slow the rate of beach erosion. They have also slowed the rate of sand delivery to beaches west of the Galveston Seawall. Actually, so little sand is currently moving in the longshore transport system that removing the rock groins would have little effect on coastal erosion.

Most of the sand eroded from Galveston beaches is transported westward and ultimately ends up in the San Luis Pass tidal delta. You can see these sand accumulations from the bridge at San Luis Pass. Or, if you are a boater, you may have run aground on one of these bars. With time, the tidal inlet and delta migrate toward the west, the direction of longshore transport. Sediment cores collected to the east of the modern tidal delta within West Bay have sampled sand from the former delta that is now buried beneath bay mud.

San Luis Pass is one of the few remaining natural tidal inlets on the Texas coast. As such, it has a history of westward migration that occurs as more and more sand is delivered there by the westward longshore transport system. The beaches adjacent to the ebb tidal delta have a history of constant fluctuation as the tidal delta alternately shifts landward and seaward. As the deep tidal inlet migrates toward the west, it undermines houses.

The beaches around San Luis Pass are among the most rapidly changing Texas beaches because sand is constantly shifting from the beach into the offshore bars and vice versa. Here, houses at Treasure Island are literally sitting seaward of the surf zone, having been left behind by the ever-shifting ebb tidal delta.

West of San Luis Pass, along Follets Island and around Surfside Beach, the coast has a low profile; Surfside has an average elevation of 4 feet. The most significant loss of sand from the beach occurs during storms when sand is washed across the beach into the wetlands and back-barrier bays. Eventually, this sand will be reclaimed and moved back into the longshore transport system as the shoreline advances landward. Meanwhile, the sand helps to maintain wetlands by providing a framework on which marsh vegetation grows.



Aerial view west of the Brazos Delta after Tropical Storm Frances. Note how sand has been washed across the beach into the lagoons and wetlands.

What happens to the area immediately offshore of the beach as the shoreline moves landward?

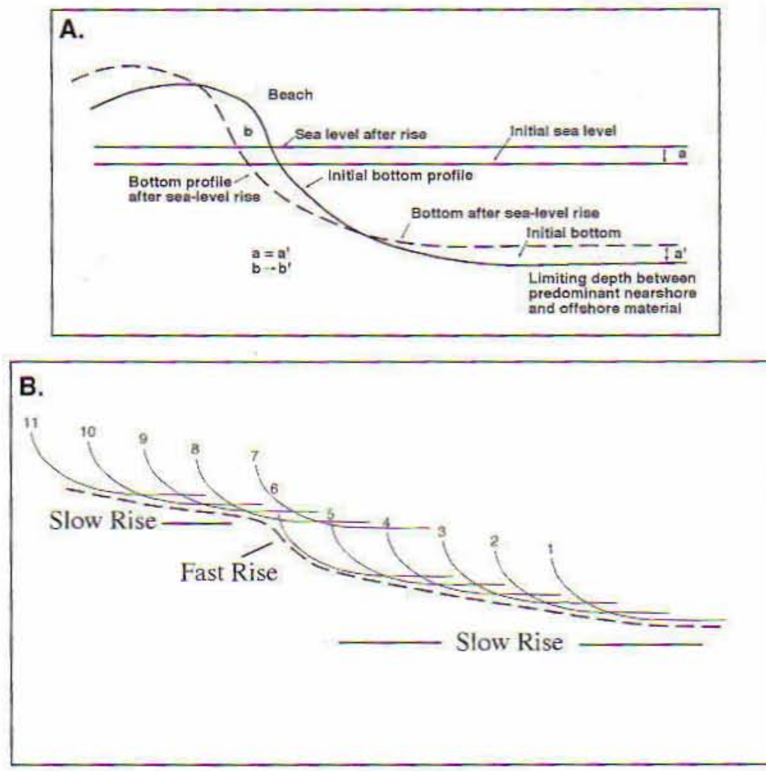
The fact is, the beach is not the only part of the coast that is retreating landward. The shoreface is also retreating, and at the same rate as the beach. This is because nature works to maintain a constant beach and shoreface profile as the coast retreats landward. Coastal geologists refer to this as the equilibrium profile.

Figure 1.6 shows two of the several geological models for how the shoreface and beach move landward. Note that a constant shoreface profile is maintained. The only exception occurs when the rate of sea level rise changes or when the amount of material being eroded by waves changes

In its natural state, the beach will maintain a constant profile as it retreats landward. However, if the beach is not allowed to migrate landward, it grows narrower and its profile grows steeper. That is the case here, where a bulkhead was constructed to stop coastal retreat. The result is a more unstable beach, and the houses on the beach are highly susceptible to storm undercutting. The stairs in this photograph have been undercut by erosion, leaving them suspended one foot above the beach.

This photograph illustrates the degree to which the beach profile is lowered with time. In this case, the metal bulkhead is approximately 4 feet high, so the beach profile has been lowered that much. With time, or during a major storm, the bulkhead will be destroyed, and the natural beach profile will be reestablished, undercutting the houses behind the bulkhead.

Figure 1.6 a and b. These two models attempt to capture how the shoreface and beach migrate landward in response to relative sea level rise. Note that in model A, a constant shoreface profile is maintained during retreat. Sand that is eroded from the shoreface is either moved landward or remains in the longshore transport system. Model B illustrates the manner by which the shoreface moves landward and cuts a new profile. The shape of this profile is controlled by the rate of sea level rise and by sediment supply. During a fast rise, or a significant reduction in sediment supply, steps are created in the profile as the shoreface shifts rapidly landward. Changes in the offshore profile also occur where waves encounter different substrates that are either easier or harder to erode. Modified from Brunn 1962 and Swift 1975, respectively.



significantly. Sand that is eroded from the beach and upper shoreface moves landward or remains in the longshore transport system. This is why it makes little sense to dredge sand from the shoreface to nourish a beach. Doing so increases the slope of the shoreface, creating an unstable profile that must be compensated for by the offshore movement of sediment until the stable profile is reestablished.

As the shoreface migrates landward, an erosion surface is left behind on the shelf. Compare the models in figure 1.6 with the actual profile shown in figure 1.2. Note that at a distance of 4 kilometers from the beach, the sandy sediments that composed the beach and inner shoreface have been entirely eroded, almost as though a huge bulldozer had plowed its way landward, removing anything above the base of the shoreface. That is exactly what storm waves do to the shoreface and beach. This process is called shoreface ravinement, and it produces a surface where marine mud rests directly on deposits that were laid down many thousands of

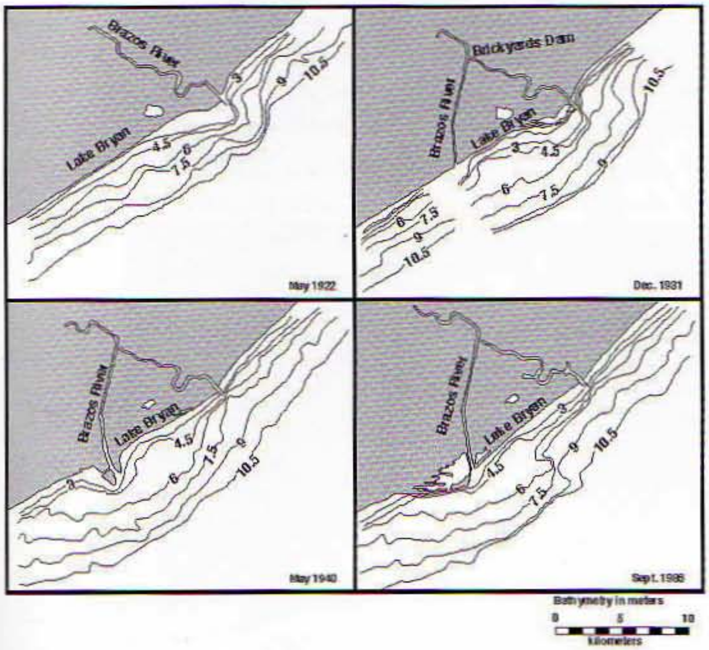


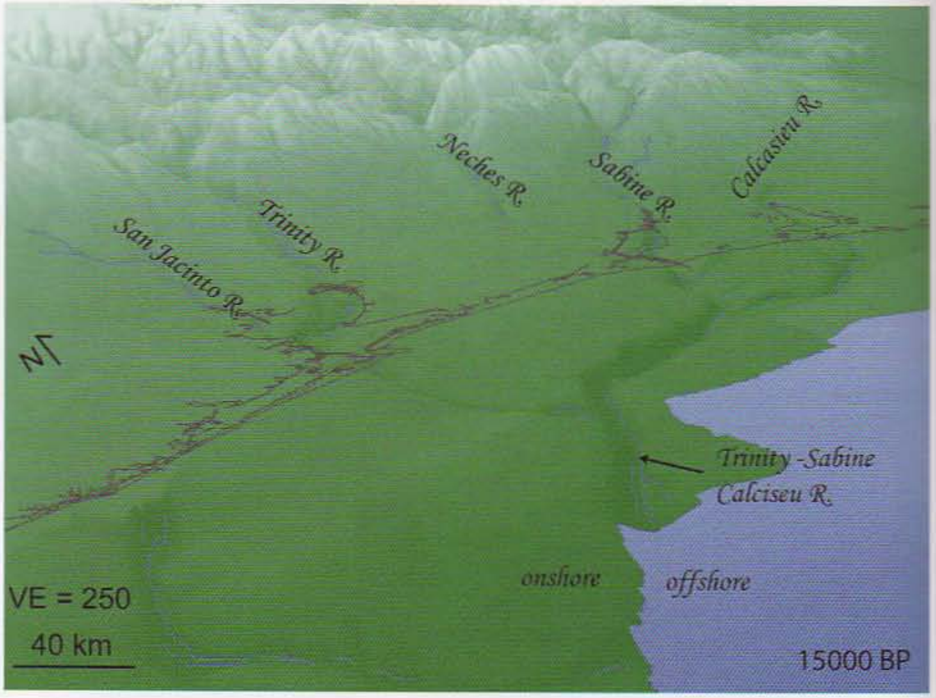
Figure 1.7. These charts show the Brazos Delta before and after the Brazos River was diverted in 1929. Note that a prominent delta (shallow area) existed offshore of the river before it was diverted. Note also the westward shift of the delta after the river diversion, which indicates that the sand that was eroded from the old delta was redeposited in the new delta.

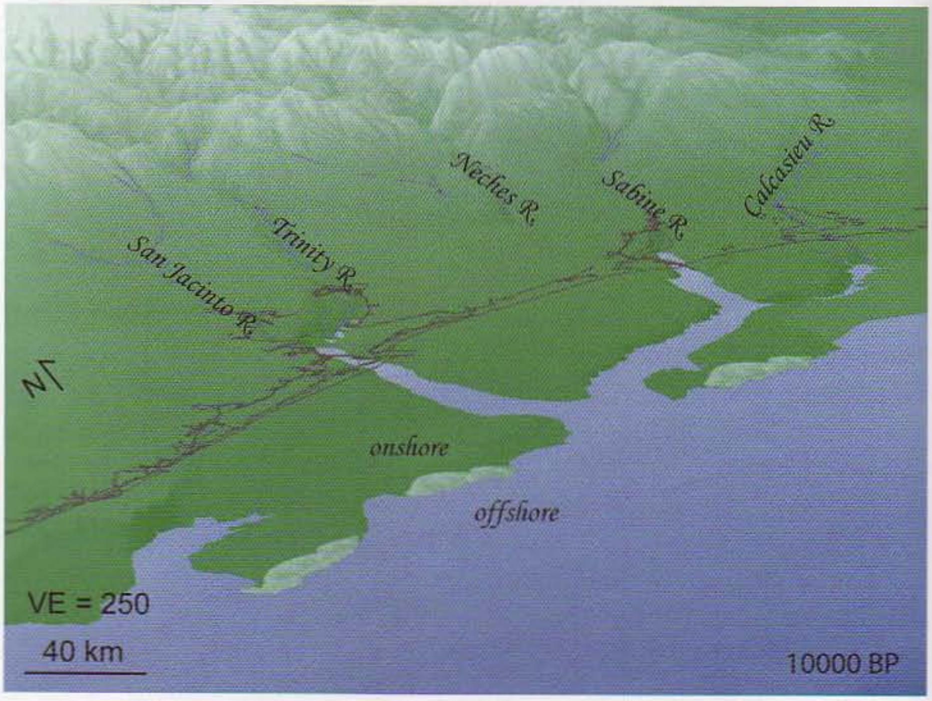
years ago in the Pleistocene. This surface is called the shoreface ravinement surface. Off the west Florida and Alabama coasts, sand is so plentiful that the shoreface profile does not erode below the level of these sands. That is why Floridians have been able to nourish their beaches with sand from the area directly offshore of the shoreface.

Based on the models shown in figure 1.6, any part of the coastline that is situated above the shoreface ravinement surface is destined to complete destruction as the shoreline advances landward. Sediment cores from offshore confirm these models (fig. 1.2). Most of Galveston Island and Bolivar Peninsula are resting above this surface and will be destroyed in coming centuries. This is also why there is little in the way of an offshore record of old barrier islands that existed on the shelf prior to 5,500 years ago. They were removed by shoreface ravinement. Sand banks are an exception: those are discussed in chapter 2.

One of the most impressive characteristics of the north Texas coast is the rapid rate at which shoreface ravinement occurs. For example, figure 1.7 shows old bathymetric maps for the area offshore of Surfside Beach, where the Brazos Delta was located before the river diversion of 1929. Note

Figure 2.16. This set of block diagrams summarizes the evolution of the upper Texas coast. Note that elevations are highly exaggerated. Courtesy of K. Milliken.






Neches R.
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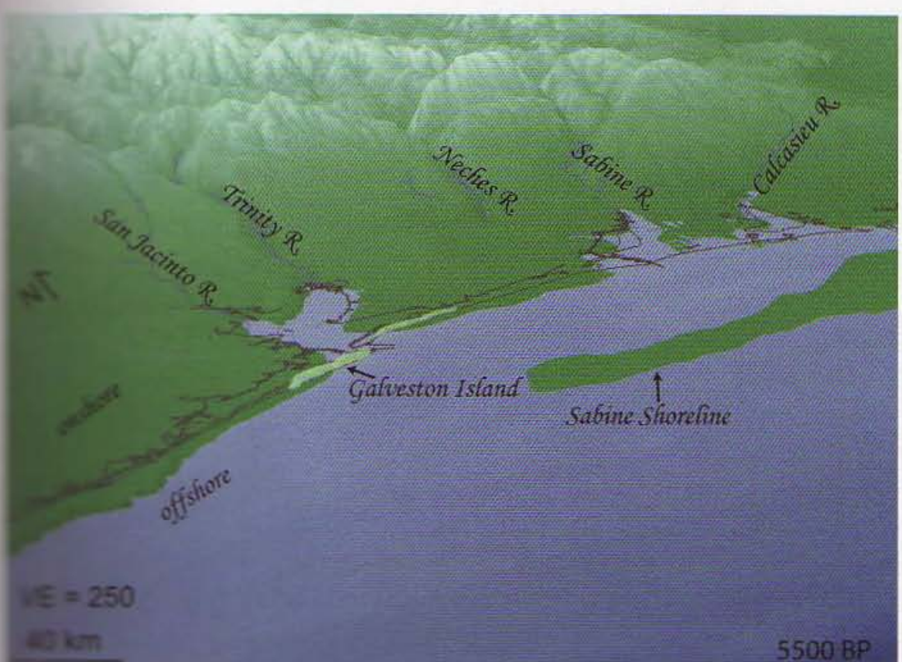
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