(5) In summary, several models have been advanced to explain how barrier islands respond to rising sea level. However, because the interactions in the coastal zone are so complex, trying to reduce barrier evolution to a series of simple scenarios is unrealistic. Much more research is needed to define the many factors that contribute to barrier evolution.

IV-2-10. Marine Deposition Coasts - Beaches

a. Introduction. Marine and lacustrine beaches comprise one of the most widely distributed coastal geomorphic forms around the world. Their importance as a buffer zone between land and sea and as a recreational and economic resource has stimulated studies by earth scientists for well over a century. Although much has been learned about how beaches form and how they are modified, the coastal environment is incredibly complex, and each location responds to unique geologic conditions and physical processes. Some of these variable factors include:

(1) Seasonal cycles.

(2) Long-term trends.

(3) Changes in relative sea level.

(4) Variations in sediment supply.

(5) Meteorological cycles.

As a result, it is difficult to characterize beaches and predict future developments without the benefit of long-term studies and observations. The following sections describe the morphology and sediments of beaches and define terms (also see Table IV-1-1). For additional information and extensive bibliographies, the reader is referred to Carter (1988), Davis (1985), Komar (1976, 1983), and Schwartz (1973, 1982).

b. General definition. ***Beach*** is defined as a gently sloping accumulation of unconsolidated sediment at the edge of a sea or other large body of water (including lakes and rivers). The landward limit may be marked by an abrupt change in slope where the beach meets another geomorphic feature such as a cliff or dune. Although this landward boundary has been consistently accepted in the literature, the seaward limit has been more broadly interpreted. Some authors have included the surf zone and the bar and trough topography in their definition because the processes that occur in the surf zone directly affect the exposed portion of the beach. The length of beaches varies greatly. Some stretch for hundreds of kilometers, such as those on the Carolina Outer Banks. Others, called pocket beaches, are restricted by headlands and may be only a few tens of meters long.

c. Major subdivisions. Beaches are part of the littoral zone, the dynamic interface between the ocean and the land. The littoral zone is bounded on one side by the landward limit of the beach and extends tens or hundreds of meters seaward to beyond the zone of wave breaking (EM 1110-2-1502). Beaches can be divided into two major zones: the foreshore and the backshore.

(1) Foreshore.

(a) The foreshore extends from the low-water line to the limit of wave uprush at high water (Figure IV-1-2). The upper portion of the foreshore is a steep slope where the high water uprush occurs. The seaward, lower, portion of the foreshore is sometimes called the *low-water or low-tide terrace.* This terrace often features low, broad ridges separated by shallow troughs, known as ridges and runnels (Figure IV-2-31).

Figure IV-2-31. Ridge and runnel system, low water terrace, Charlestown Beach, Rhode Island. Sea grass debris in the foreground marks the height of the wave runup during the previous high tide. Where should the "shoreline" be defined on this beach?

Because the foreshore is frequently subject to wave swash, it usually has a smoother surface than the backshore. There may be a minor step near the low-water mark, called the *plunge step.* Often, shell or gravel is concentrated at the base of this step, while the sediments to either side are much finer.

(b) The foreshore is sometimes called the *beachface.* However, beachface is also used in a more restricted sense to designate the steepened portion of the upper foreshore where the high-water wave uprush occurs. Therefore, it is recommended that foreshore and beachface not be used synonymously and that beachface be restricted to its upper foreshore definition.

(2) Backshore.

(a) The backshore extends from the limit of high water uprush to the normal landward limit of storm wave effects, usually marked by a foredune, cliff, structure, or seaward extent of permanent vegetation. The backshore is not affected by waves regularly, but only during storms, when high waves and storm surges allow reworking of backshore sediments. Between inundations, the backshore develops a rough surface because of vehicle or animal traffic and the development of wind-blown bed forms. On eroding beaches, the backshore may be missing, and the normal high-water uprush may impinge directly on cliffs or structures.

(b) Alternate terms for backshore are backbeach and berm. "Berm" is a common term because backshore areas are sometimes horizontal and resemble man-made berms. However, many beaches have a sloping backshore that does not resemble a berm, and some have more than one berm, representing the effects of several storms. Thus, berm is not synonymous with backshore, but may be a suitable description for selected areas. The term is sometimes used in beachfill and beach erosion control design.

(3) Coastline (or shoreline). The boundary between the foreshore and backshore, the high water line (hwl), is often defined to be the coastline. This is a practical definition because this land-water interface can be easily recognized in the field and can be approximated on aerial photographs by a change in color or shade of the beach sand (Crowell, Leatherman, and Buckley 1991). In addition, the coastline marked on the topographic sheets ("T-sheets") typically represents this same hwl, allowing a direct comparison between historic maps and aerial photographs. Some researchers have equated the coastline with the low-water line, but this boundary is not always marked by any evident feature or change in sand color. In various studies, one can find shoreline defined by almost any level datum. These inconsistencies make it difficult to compare shoreline maps prepared by different surveyors or agencies. Definition of "shoreline" often is controversial because it affects the legal definition of setback lines and other constraints placed on development in the coastal zone. A more detailed discussion of hwl identification is presented in Anders and Byrnes (1991); Crowell, Leatherman, and Buckley (1991); and Gorman, Morang, and Larson (1998).

d. Beach material.

(1) Sand beaches. On most of the coasts of the United States, the predominant beach material is sand (between 0.0625 and 2.0 mm, as defined by the Wentworth classification). Most sand beaches are composed mostly of quartz, with lesser percentages of feldspars, other minerals, and lithic (rock) fragments. Table IV-2-4 lists beach sediment types and common locations.

Table IV-2-4
Types of Beach Sediment

Type	Typical Locations
Quartz sand	East Coast of U.S. between Rhode Island and North Florida, Gulf Coast between West Florida and Mexico, portions of West Coast of U.S. and Great Lakes
Calcite shell debris	South Florida, Hawaii
Volcanic sand	Hawaii, Aleutians, Iceland
Coral sand	South Florida, Bahamas, Virgin Islands, Pacific Trust Territory
Rock fragments	Maine, Washington, Oregon, California, Great Lakes
Clay balls	Great Lakes, Louisiana

(2) Coarse beaches. Coarse beaches contain large amounts of granule-, pebble-, cobble-, and boulder-sized material (larger than 2.0 in the Wentworth classification). These beaches, found in the northeast, in the Great Lakes, and in mountainous reaches of the Pacific coast, occur under conditions where:

(a) Local streams flow with enough velocity to carry large particles to the shore.

(b) Coarse material underlies the beach (often found in areas influenced by glaciation or on metamorphic coasts).

(c) Coarse material is exposed in cliffs behind the beach (Figure IV-2-9).

The constituent material may be primarily angular rock fragments, especially if the source area, such as a cliff, is nearby (Figure IV-2-32). If the source area is far away, the most common rock types are likely to be quartzite or igneous rock fragments because these hard materials have a relatively long life in the turbulent beach environment. Softer rocks, such as limestone or shale, are reduced more readily to sand-sized particles

Figure IV-2-32. Shale beach and bluffs, southeast shore of Lake Erie, near Evans, New York. Bedding planes in the shale are lubricated by groundwater, and freeze-thaw cycles split the rock along the planes. The rubble on the beach breaks down quickly, leaving a grey sand with plate-shaped grains

by abrasion and breakage during their movement to the coast and by subsequent beach processes. Coarse beaches usually have a steeper foreshore than sand beaches.

(3) Biogenic beaches. In tropical areas, organically produced (biogenic) calcium carbonate in the form of skeletal parts of marine plants and animals can be an important or dominant constituent. The more common particles are derived from mollusks, barnacles, calcareous algae, Bryozoa, echinoids, coral, Foraminifera, and ostacods. The percentage of biogenic material in a beach varies with the rate of organic production and the amount of terrigenous material being contributed to the shore.

IV-2-11. Salt Marshes

Coastal salt marshes are low-lying meadows of herbaceous plants subject to periodic inundations. During the constructional phase of a coastline, a marsh develops when sediment deposition exceeds sediment removal by waves. Three critical conditions are required for marsh formation: abundant sediment supply, low wave energy, and a low surface gradient. Once sediment accumulation reaches a critical height, the mud flats are colonized by halophytic plants that aid in trapping sediment when flooding occurs and add organic material to the substrate.

a. Distribution of salt marshes. Marshes occur in low-energy coastal locations, and the bay side of most barriers is fringed by tidal marsh or tidal flats. Likewise, mainland shorelines adjacent to bays are also typically fringed by marsh. Along the mainland of the United States, three regional marsh types have been recognized: (1) New England marsh; (2) Atlantic and Gulf Coastal Plain marsh; and (3) Pacific coast marsh

(Frey and Basan 1985). As much as 80 to 90 percent of the Atlantic and Gulf coasts have been bordering marsh around lagoons, estuaries, and deltaic environments (Inman and Nordstrom 1971). However, along the West Coast, less than 20 percent of the coastline has marsh because Pacific marshes are usually restricted to protected locations in river mouth lagoons or tectonically controlled bays. Morphologically and sedimentologically, Pacific marshes are similar to Atlantic and Gulf coast types, although they do differ in flora species and in the unequal semidiurnal range of tides.

New England marshes are adapted to high tide ranges, high wave energy, and cold winters. Atlantic Coastal Plain marshes are abundant and almost continuous from New York to northern Florida. The warm weather, low tide range, and low wave energy coastline of both the Atlantic and Gulf coastal areas of southern Florida gives rise to mangrove marshes. The deltaic plain of Louisiana supports a unique type of marsh called “flotant,” which is marsh flora sitting atop organic rich ooze. The ooze is a soft substrate that may be several meters thick over harder substrates. The rest of the Gulf Coast has fringing marsh behind its barriers.

b. Classification of salt marshes.

(1) Regional conditions such as temperature, sediment distribution, pH, Eh, and salinity contribute to the zonation of a marsh area. Plant successions, sediment accumulation, and marsh expansion vary but most marshes can be divided into two fundamental zones: low and high. Low marshes are younger, lower topographically, and usually subjected to the adjacent estuarine and marine processes. High marshes are older, occupy a higher topographic position, are more influenced by upland conditions, and are subjected to substantially fewer tidal submersions per year. The boundaries for these zones and their relationship to a given datum may differ from one coast to another. Differences in marsh boundaries might be related to tidal regularity and substrate composition. On the Atlantic coast, the tides are generally regular and near equal in semidiurnal range, whereas those on the Pacific coast are markedly unequal in semidiurnal range. Gulf Coast marshes are subjected to irregular and small-amplitude tides. Consequently, the demarcation of high and low marshes is not well-defined.

(2) Plant structures and animals are significant contributors to sediment accumulation in salt marshes (Howard and Frey 1977). Grasses dampen wind-generated waves. Stems and levees impede current flow, which helps trap suspended sediment (Deery and Howard 1977). The most obvious mechanism of sediment entrapment is the plant root system. Plant roots may extend more than a meter in depth along Georgia stream-side marshes and up to 50 cm in some adjacent habitats (Edwards and Frey 1977).

c. Sediment characteristics.

(1) Introduction.

(a) Salt marshes generally contain finer, better-sorted sediment than other intertidal environments. However, marsh substrates reflect the local and regional sediment sources. Along the Atlantic coast and shelf of the United States, Hathaway (1972) recognized two distinct clay mineral facies. The northern clay-mineral facies, extending from Maine to Chesapeake Bay, is primarily composed of illite, chlorite, and traces of feldspar and hornblende. The southern clay-mineral facies, which extends from Chesapeake to the South, is composed of chiefly kaolinite and montmorillonite.

(b) In New England and along many northern coasts overseas, peat is an important soil component of marsh substrate. Peat forms from the degradation of roots, stems, or leaves of marsh plants, particularly *Spartina* (Kerwin and Pedigo 1971). In contrast, peat is not a significant component of the southern coastal marshes except in Louisiana and Florida (Kolb and van Lopik 1966). The southern marsh substrate generally consists of silt- and clay-size sediment with a large percentage of carbon material. The major sources of organic carbon in most coastal marshes are in-situ plants and animal remains.

(c) Southern marshes can have up to 60 percent silt and up to 55 percent clay. Rapid biological decay and constant flushing prevent the accumulation of thick organic deposits. The exception to this is the "flotant" marshes, which may have over 50 percent organics. In the Unified Soil Classification, the substrate would be considered a fine-grained soil, and the field engineer could anticipate silt, clay, or organic-dominant material with low to high plasticity. Much of the organics present in marshes are incompletely oxidized, which if released into the lagoon/bay by excavation, can profoundly affect the water chemistry.

(2) Marsh plants.

(a) Marsh plants are typically tall, salt-tolerant grasses. About 20 genera of salt marsh plants are found worldwide, with the most important in North America being *Spartina*, *Juncus*, and *Salicornia* (Chapman 1974). Salt marshes are the temperate (and arctic) counterparts of tropical mangrove forests. They generally develop in shallow, low-energy environments where fine-grained sediments are deposited over sandy or till substrates (Figure IV-2-33). As the fine sediments build upward, the marsh plants can take root and become established. The established vegetation increases sediment trapping and leads to more rapid upward and outward building of marsh hummocks, which form the foundation of the marsh. The vegetation also creates lower energy conditions by absorbing wave energy and reducing current velocities, thus allowing accelerated sediment deposition.

(b) Like mangrove forests, many species of invertebrates, fish, birds, and mammals inhabit salt marshes and the adjacent tidal creeks during all or part of their life cycles. Thus, marshes are important to commercial and sport fishermen and hunters. In addition, several marsh species are considered endangered.

(c) Also like mangrove forests, man's main detrimental impact on these marshes has been dredge-and-fill operations for land reclamation and mosquito control. Air and water pollution are also serious problems. Although extensive areas of salt marsh remain on the east and Gulf coasts of North America, significant areas have been lost to development. The situation is much worse on the west coast, where most of the coastal marsh lands have been filled and perhaps permanently destroyed. Efforts to restore degraded coastal marshes have not generally been successful.

(3) Sediment transport and processes.

(a) Typically, most marshes have very slow rates of sediment accumulation, amounting to only a few millimeters per year (Pethick 1984). Natural and man-induced changes can have deleterious effects on marsh growth. For example, building levees or altering the drainage pattern can result in erosion and permanent marsh loss. Not only is suspended sediment important to vertical growth of the marsh, but biologic components, particularly organic detritus suspended in the water column, are critical to marsh health. The exchange of sediment and nutrients is dependent on the exchange between the local bodies of water.

(b) A marsh sediment budget usually includes consideration of the following factors (Davis 1985):

- Riverine sources.

- Offshore or longshore transport.