Figure IV-2-6. Drowned glacial erosion coast: Maine (Potts Point, South Harpswell, near Brunswick, July 1994). Rock headlands and ridges run southwest into the Gulf of Maine

as recreational areas, as habitat for various species of birds, as shore protection, and as temporary sources and sinks of sand in the coastal environment. Although dunes are found along many sandy coasts, they are finite resources and need to be protected and preserved. The seminal work on dunes is Brigadier R.A. Bagnold's *The Physics of Blown Sand and Desert Dunes* (Bagnold 1941). More than 50 years after its publication, this book continues to be cited because of its sound basis on the laws of physics and its readability. Part III-4 of the *Coastal Engineering Manual* reviews the physics of wind-blown sediment transport and presents methods that can be used to estimate transport volumes.

b. Origin of dunes. Many large dune fields are believed to have originated when sea level was lower and sediment supply was greater (Carter 1988). Many are on prograding shorelines, although shoreline advance does not seem to be a requirement for dune formation. In northwest Europe, most of the dunes formed from shelf debris that moved onshore during the late Pleistocene and early Holocene by rising sea level. Dune-building phases have been interrupted by periods of relative stability, marked by the formation of soils. The dunes at Plum Island, Massachusetts, may have formed after 1600 (Goldsmith 1985).

c. Sediment sources. The normally dry backshore of sandy beaches may be the most common source of dune sands. A flat or low-relief area inland of the coastline is needed to accommodate the dunes, and there must be predominant onshore or alongshore winds for at least part of the year. To move sand from the beach to the dunes, wind speed must exceed a threshold velocity for the particular size of sand available. If the sand is damp or if the grains must move up a slope, the velocities required for sediment transport are greatly increased. The foreshore of the beach can also be a source of sand if it dries between tidal cycles. This is especially true in areas where there is only one high tide per day (diurnal), allowing a greater amount of time

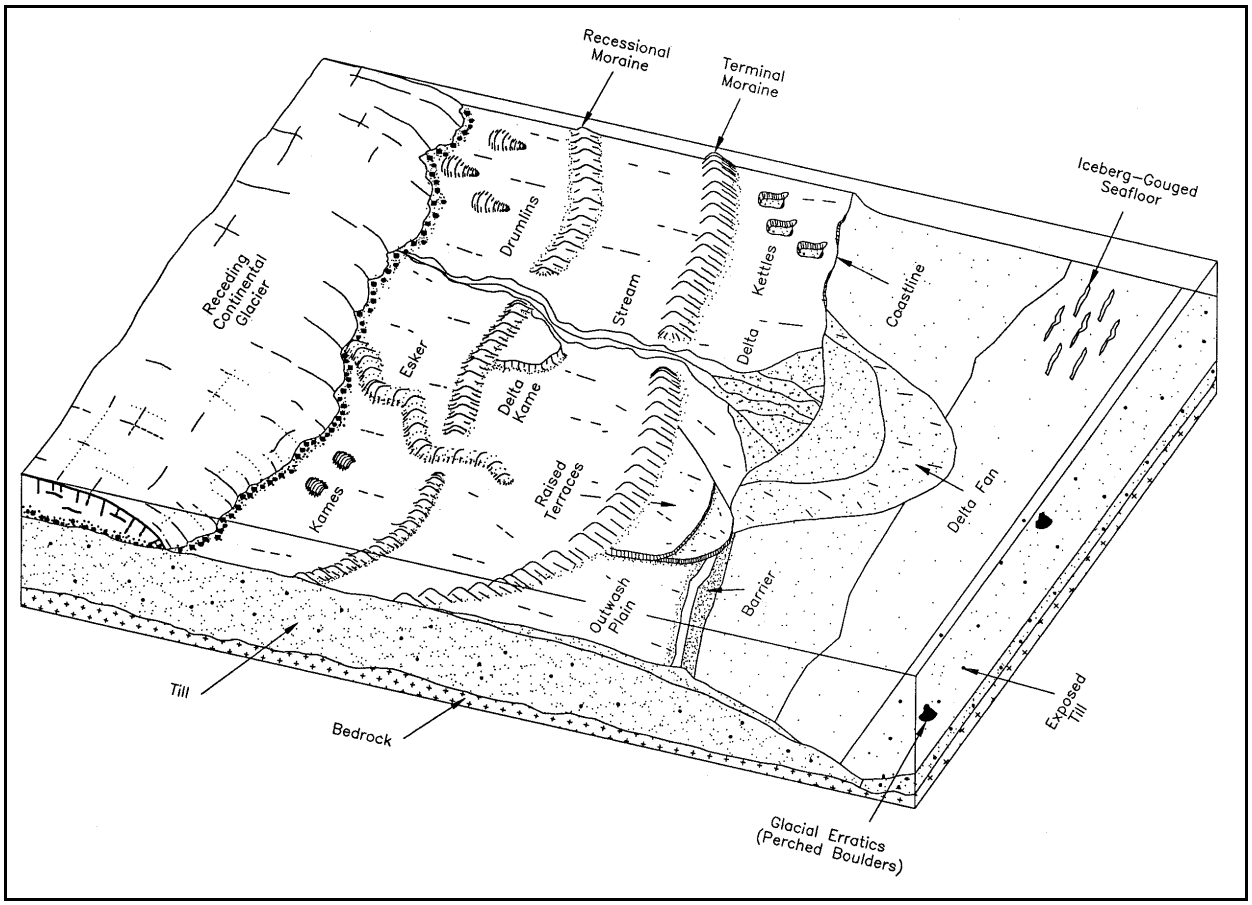

Figure IV-2-7. Typical glacial depositional structures

for the foreshore to dry between inundations. Sand storage in dunes must be estimated as one component of sediment budget calculations (EM 1110-2-1502).

d. Modification and stability. Most dunes show evidence of post-depositional modifications. These include:

(1) Physical changes - slumping, compaction. Sand grains become rounded, frosted, and better sorted.

(2) Chemical alterations - oxidation, leaching, calcification. (The latter can solidify a dune, making it much more resistant to erosion.)

(3) Biological effects - reactivation, humification, soil formation.

The stability of dunes varies greatly, usually depending on vegetation cover. Dunes in arid climates are often not vegetated and are mobile. However, coastal dunes are normally vegetated by plant species adapted to the harsh coastal environment (Figure IV-2-10). Many dune grasses have long roots, rhizomes, and runners that help hold sand in place. In addition, dense vegetation displaces the aerodynamic boundary of the wind velocity profile upwards. This process produces a net downward momentum flux, promoting sediment trapping (Carter 1988).

Figure IV-2-8. Islands in Boston Harbor, Massachusetts (August 1988 - view looking south). These are glacial drumlins that have been extensively reworked by contemporary marine processes. The town of Winthrop (with a tall water tower) is on the drumlin in the center. Deer Island, in the harbor, is attached to Winthrop with a causeway

Figure IV-2-9. Glacial till bluffs just west of Montauk Point, Long Island, New York, facing the Atlantic Ocean (March 1998). As the bluffs erode, the fine material is carried away by waves, leaving a lag of boulders and cobble on the shoreface. In this area, the seafloor offshore is also covered with gravel, cobble, and coarse sand. Sand from the Montauk bluffs is carried by littoral currents to the west, where it nourishes the barrier beaches of Long Island's south shore