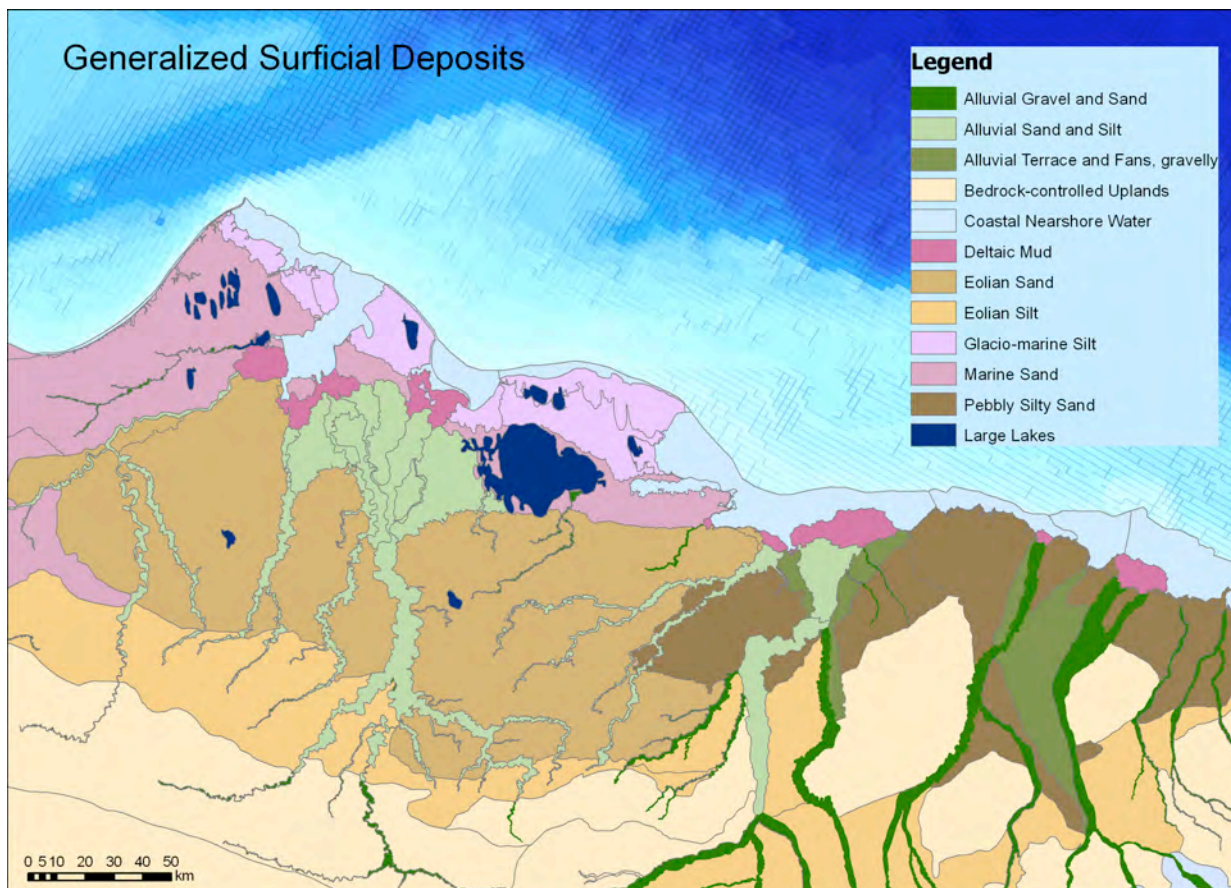


# Permafrost-influenced Geomorphic Processes

Geomorphic processes vary greatly among ecoregions in northern Alaska, extending from the Beaufort Sea coast to the Brooks Range (Figure 4.1). Regional differences in the distribution of surficial deposits, all of late Pleistocene origin, are a reflection of various past processes. The coastal areas are characterized by glaciomarine pebbly silt, glacial deposition of slightly pebbly silty sand from a northern ice sheet, and deposition of marine sand by marine transgression. The western portion of the Arctic Coastal Plain is covered by an eolian sand. The lower portion of the Arctic Foothills is blanketed by thick loess (silt). The upper foothills are underlain by bedrock near the surface; ridges typically have rocky residual soils, slopes are mantled with organic-rich colluvium (accumulations of sediment transported downslope by gravity), and basins are filled with organic-rich fine-grained colluvium. Floodplains dissect these deposits and tend to be gravelly in the foothills and the eastern portion of the Arctic Coastal Plain and sandy on the Arctic Coastal Plain in the western portion of northern Alaska.

Figure 4.1. Surficial deposits of the central portion of northern Alaska.

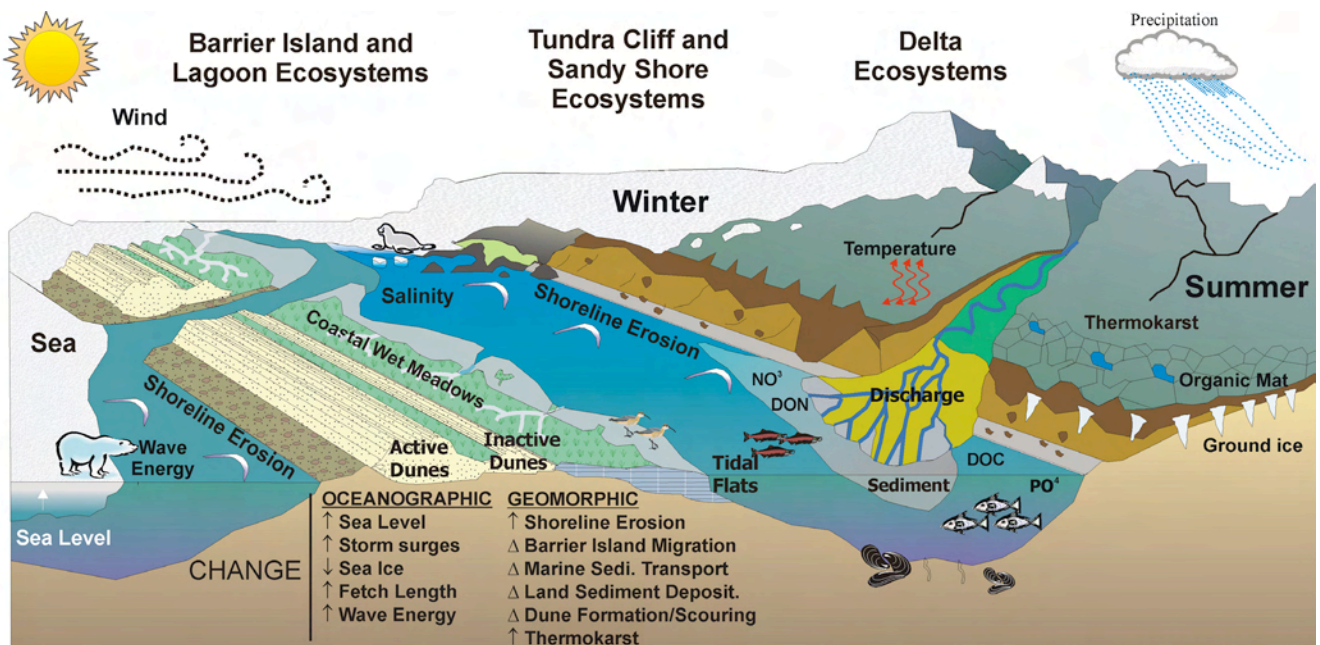


## Beaufort Coast

The Beaufort Sea coast is dominated by lagoons with sandy barrier islands, exposed coast with high-eroding bluffs, deltas, and low-lying drained-lake basins that are occasionally flooded by storm surges (Figure 4.2). These are dynamic environments that are greatly affected by sea ice, wind-driven waves and storm surges, coastal erosion, sedimentation by rivers and eroding coastal bluffs, and long-shore currents.

The most prominent changes associated with global warming will be the decrease in sea ice, increase in wave energy, and increase in storm surges related to increased fetch across the open Arctic Ocean. Sea level is currently rising at 3 mm/yr and projected to rise 0.5–1.0 m by the end of the century. Due to recent sea ice retreat, there has already been a substantial increase in erosion rates at Cape Halkett and Barter Island. Erosion rates along most of the Beaufort Sea coast are 1–2 m/yr, but recent observation reveal that erosion can be as high as 15 m/yr along some extremely ice-rich coastlines. A noticeable change in bank profiles from banks mantled with slumping soil material to steep undercut banks with collapsing blocks has also been observed. The increase in storm heights, accompanied by the projected sea-level rise, will cause additional flooding and salinization of low-lying terrain. This will likely increase the distribution of coastal barrens and meadows. Coastal ecosystems on deltas probably will remain in equilibrium with sea-level rise due to frequent sedimentation, which will maintain the ground surface near sea level. Changes in precipitation will likely have only minor effects, primarily on the inputs of sediment and organic carbon into lagoons and nearshore water.

Figure 4.2. A geomorphic and ecological conceptual model of the coastal ecoregion of northern Alaska illustrating the relationships among climatic, geomorphic processes, and biotic distributions.



Produced for ARCN-NPS by M. T. Jorgenson and D. M. Sanzone

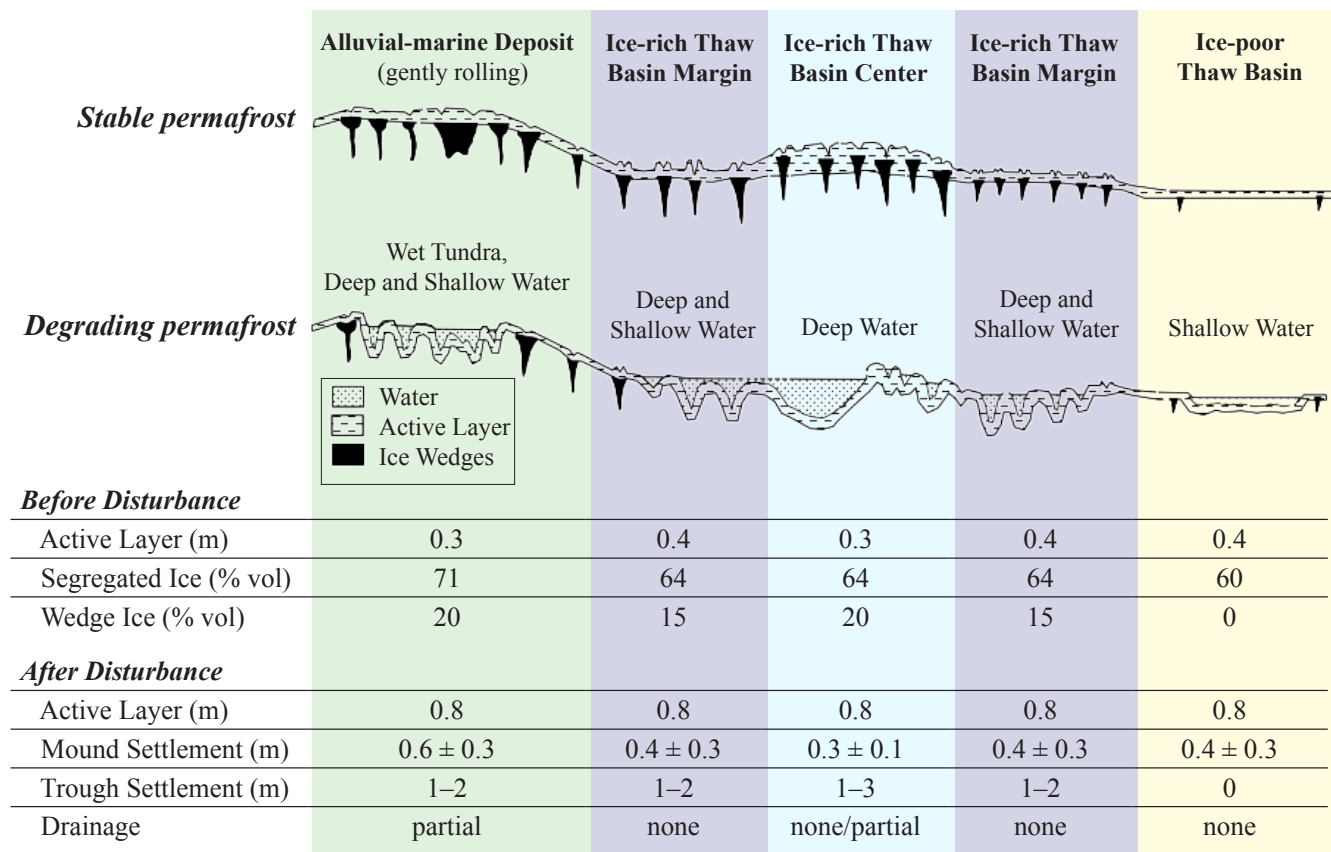
## Coastal Plain

The coastal plain has numerous surficial deposits related to initial coastal plain formation and subsequent lake development and drainage (Figure 4.1). Ice-rich deposits, such as delta and glacio-marine deposits have abundant thaw lakes and drained basins. In deposits where the ground-ice volume is not sufficient to allow development of thaw lakes, such as eolian sand and slightly pebbly sand till, the lakes formed in low-lying swales during the early Holocene and expanded through erosion of fine-grained sediments. The development and expansion of a drainage network during the Holocene has contributed to drainage of some of the large lakes. Once lakes are tapped and drained the exposed sediments are subject to permafrost aggradation. The sandy margins tend to aggrade little ice, while ice segregation and ice wedge development in the organic-rich silty centers is prevalent. This differential ice accumulation typically causes the drained centers to dome up and shift water to

the lower-lying sandy margins. Small ponds created by this hydrologic shift are abundant around the margins. The small ponds typically fill in with limnic sediments in the center and sedge peat around the margins.

The response of coastal plain deposits to warming (5 °C increase) and wetting (25% precipitation increase) will have a dramatic effect on the stability of ice wedges and will result in a redistribution of water. The redistribution of water, however, will depend on landscape position: whether the site is a water-shedding slope or a water-gathering basin. Because ice wedges are formed just below the active layer and are in close equilibrium with the existing climate, an abrupt warming will cause nearly all ice wedges to degrade. The degradation will cause impounding of water in thermokarst troughs and pits, draining of the adjacent polygon centers, and an increase in the water storage capacity of the tundra (Figure 4.3). At later stages of degradation, the thermokarst troughs will form drainage networks to further lower the water table. Thawing of ice wedges in ice-rich deposits may induce development of thermokarst ponds. Eventual integration of the thermokarst troughs and pits into drainage networks should further lower the water table and cause increased drying on the centers of the high-centered polygons created by the thawing ice wedges. In the low-lying basins, the water of deep lakes and shallow ponds will be fully recharged by spring snow melt with excess water running off. Under a warming scenario where precipitation is unchanged, increased evaporation during mid-summer should cause deeper draw downs of lakes and ponds in mid-summer, but water levels should increase again with fall rains and subsequent spring snow melt. Thermokarst of ice wedges in basins will create more capacity for water storage but should have little effect on water levels. Lake shoreline erosion by wind-driven waves and lake expansion from thermokarst is expected to continue and may increase with a longer ice-free season and warmer water. Lake expansion may affect ~1–3% of the landscape. Most drained-lake basins formed during a period of extensive drainage during the mid-Holocene, and contemporary lake drainage is uncommon. With expected warming, however, degradation of ice-wedges, which can integrate into drainage channels with a lower base elevation, may increase the drainage of lakes.

Figure 4.3. A cross-sectional profile of the coastal plain in northern Alaska illustrating the role of permafrost degradation in the redistribution of water.



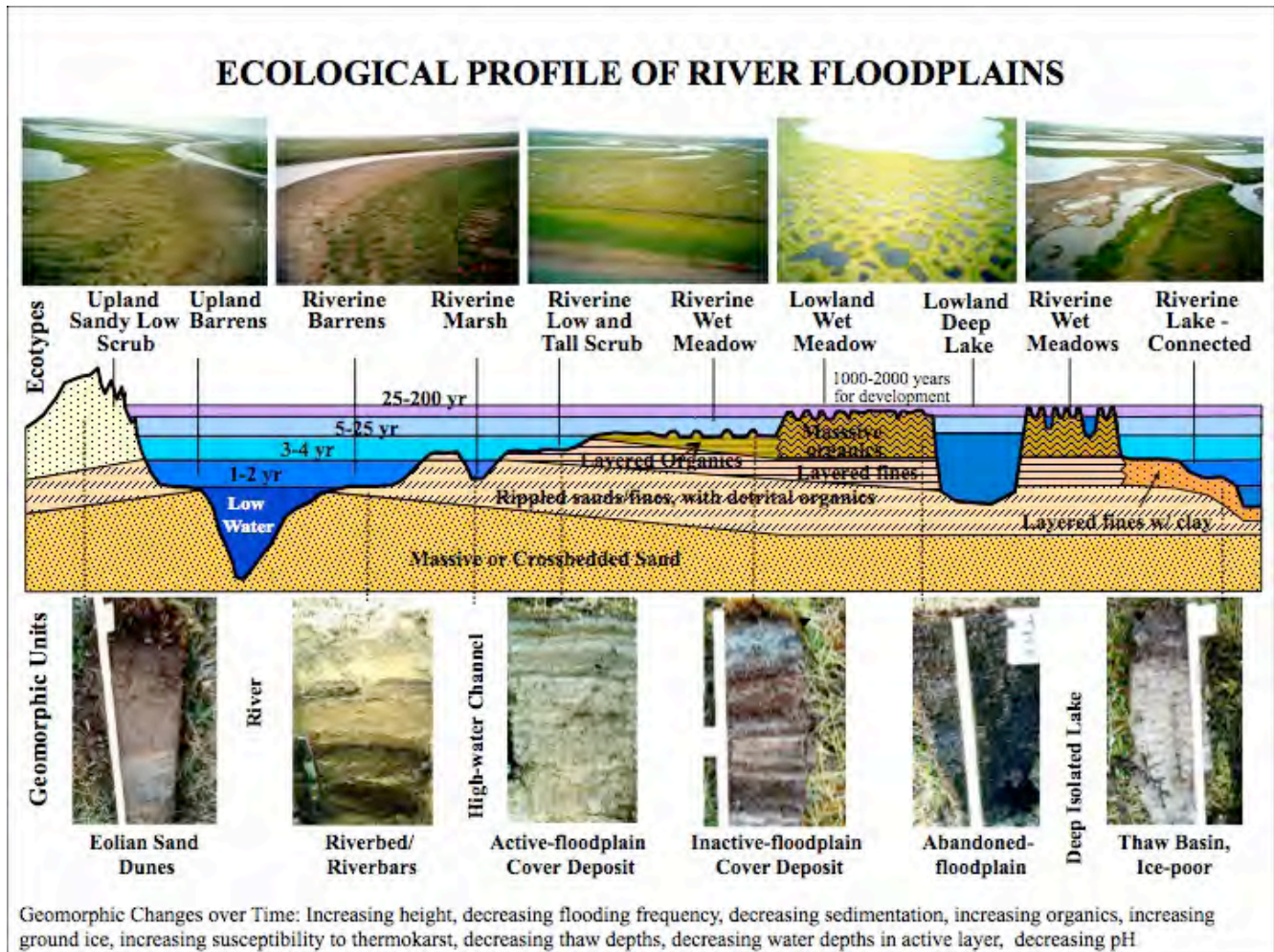


## **Floodplains**

Floodplains are active geomorphic environments because of sedimentation caused by flooding, erosion caused by channel migration, and deposition of sand blown off of barren riverbars (Figure 4.4). The varying flooding regime creates a sequence of deposits that include massive or crossbedded sand in the active channel, rippled interbedded sands and fines with distinctive detrital organics that are the remains of peat banks eroded upstream, layered fines caused by vertical accretion of silts during overbank flooding, layered organics and silts created by the accumulation of organic matter in between infrequent flooding events, and massive organics that accumulate on higher floodplains that are rarely flooded. During floodplain evolution, the deposits are modified by the aggradation of segregated and wedge ice, which deforms the surface, affects water runoff, and increases the susceptibility of older terrain to thermokarst. These deposits support a successional sequence of ecotypes from river to riverine barrens, tall shrub, low shrub, dwarf shrub, and wet sedge meadows. Although riverine ecosystems are not abundant (~8% of the Arctic Coastal Plain and ~4% of the Arctic Foothills), they are highly productive ecosystems, conduits of water, sediments, and nutrients, and used by a wide range of fish, bird, and mammal species.

Riverine ecosystems will respond to climate change in a variety of ways depending on the amount of warming and whether precipitation will increase or remain about the same. The response will be affected by reduced or increased sedimentation, delayed permafrost aggradation during early floodplain development, and degradation of permafrost in ice-rich late floodplain stages. In response to warming, permafrost aggradation will be slightly delayed in the barren portion of active floodplains, and degradation will be accelerated on the inactive and abandoned floodplains. Ice wedges formed in the later stages of floodplain development will degrade. This degradation will help lower the water table and will help form drainage networks that will accelerate drainage of riverine lakes. Assessing the consequences of altered precipitation (magnitude, seasonality, frequency, extreme events), discharge, flooding, sedimentation, and erosion is more uncertain. Many of the processes are more affected by extreme events rather than average conditions. Under higher precipitation, flooding, sedimentation, and erosion should increase favoring more productive, early successional ecosystems. In contrast, decreased runoff associated with drying during mid-summer may lead to increased channel stability and increased shrub growth on the stabilized active floodplain.

Figure 4.4. An ecological profile of sandy floodplains in northern Alaska illustrating the relationships among hydrology, geomorphology, soils, and vegetation.



## Foothills

The upland ecosystems of the Arctic Foothills have four distinctive geomorphic environments (Figure 4.5):

- rocky residual soils on ridges;
- gentle slopes mantled with ice- and organic-rich colluvium over bedrock;
- Pleistocene loess on the lower foothills; and
- ice-cored moraines, which occur at the outlets of glaciated mountain valleys but are of limited extent and are not included in this discussion.

The rocky residual soils are well-drained, have deep active layers, and are relatively thaw stable. The soils on colluvium, typical of mid to lower slopes, tend to be highly organic, saturated, and have abundant ice wedges and segregated ice near the permafrost table. Pleistocene loess tends to be extremely ice-rich with massive ice extending to depths of 20–30 m. Because of the massive ice, deep thermokarst lakes are common. Probable response of each of these specific environments is discussed separately below.

Rocky ridges probably will undergo little geomorphic change under a warmer and wetter climate. The already well-drained soils will remain well-drained and thaw stable. The active layer will likely increase, and taliks may develop on some south-facing slopes, but this will have little effect on surface hydrology. Under drying conditions, little change is expected.

Colluvium-mantled hillsides are likely to be very sensitive to climate warming. Because the active layer is underlain by ice-rich permafrost, thaw slumps are likely to become abundant on the sloping surfaces. The slumping will expose new soil to plant colonization and contribute abundant sediment to small streams. Gullies



are likely to become common where water flow through ice-wedge networks causes the ground surface to collapse. The gullies will then contribute to channelization of flow and drying of intervening ridges. In some areas, water-tracks may deepen without deeper gully formation, but still serve to channel suprapermafrost groundwater flow. On very gentle slopes, ice-wedges are likely to degrade without prominent gully formation.

Landscapes characterized by the presence of extremely ice-rich loess (yedoma) of late Pleistocene age are highly sensitive to warming and have the potential for drastic change. Yedoma is abundant across the lower foothills and may occupy roughly 20% of the overall foothills landscape. In places, such as along the lower Colville River, the yedoma has only 0.5–1 m of soil covering 10–25 m of ice. The degraded yedoma landscape of the Seward Peninsula may provide a good example of how the landscape could be altered by widespread degradation. First, thermokarst develops in the network of shallow Holocene ice wedges near the surface of the permafrost. Second, the thermokarst troughs and pits expand into thermokarst ponds and lakes that thaw into the underlying massive ice. Expansion of the thermokarst lakes and drainage networks cause the lakes to drain, forming a thaw lake plain. The process is likely to take hundreds to thousands of years.

Figure 4.5. A conceptual model of the Arctic Foothills region of northern Alaska illustrating the potential consequences of permafrost degradation on hillslope processes.

