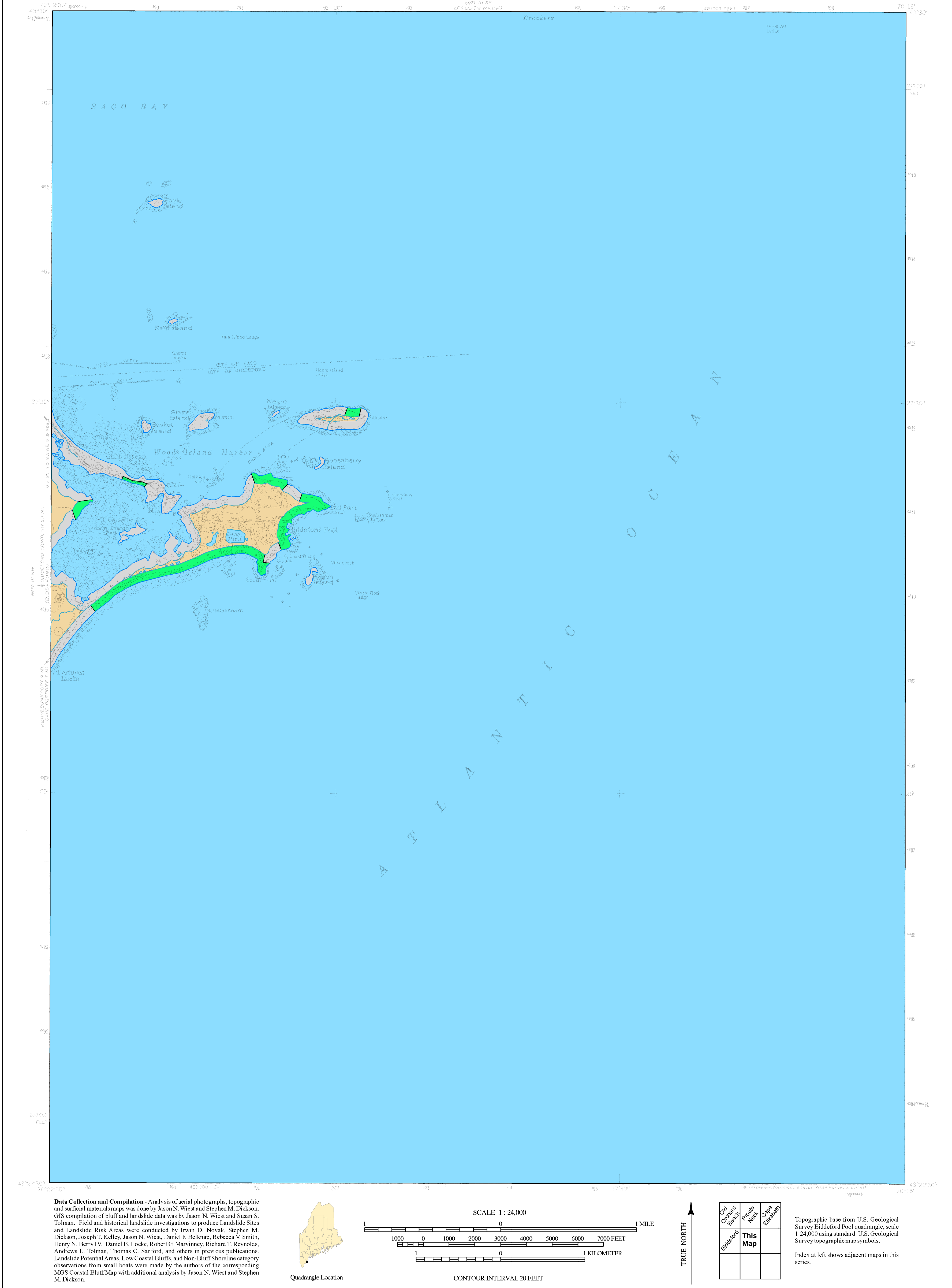


Coastal Landslide Hazards



Biddeford Pool Quadrangle, Maine

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Introduction

Landslides are the rapid movement of earth materials downslope under the force of gravity. Many landslides have occurred along the Maine coast in the last few centuries, and more landslides will happen in the future. Based on history and field evidence, a variety of scenarios and possible events, from large to small and fast to slow, can threaten property and, in a few cases, put human life at risk. It is not possible to predict exactly when and how large the next coastal landslide will be. Landslides have occurred frequently enough that geologic analysis and informed land use can lead to risk reduction and improved emergency response.

This map provides an introduction to understanding landslide risk and guidance on what steps to take if the risk of a landslide is a concern in a particular coastal area. Landslides can occur in high coastal bluffs composed of muddy sediment. This landslide hazards map describes the internal stability of sediment bluffs. A companion map, entitled *Coastal Bluffs*, describes the processes and stability of the face of a bluff. The coastal bluff maps provide additional information about the slope, shape, and amount of vegetation covering a coastal bluff and the adjacent shoreline. These factors are directly related to the susceptibility of the bluff face to ongoing erosion.

The Life Cycle of a Coastal Maine Landslide

Sea level is gradually rising along the coast of Maine (Kelley and others, 1996). This rise in the ocean allows waves to erode beaches and flats at the base of coastal bluffs (see Figure 2A). Over time, erosion removes material from the base of a coastal bluff and steepens the face of the bluff (Figure 2B). Sediments at the base of the bluff stabilize it, and when they are removed, the bluff is no longer in equilibrium. Only the strength of the material within the bluff holds the bluff in place. Continued erosion or lubrication of the bluff materials by ground water may overcome this internal resistance, particularly in clay bluffs, and result in a landslide (Figure 2C). A landslide restores the equilibrium of the bluff, and the slumped materials support a new bluff face with a gentler profile (Figure 2D). Erosion, however, is a continuing process because the level of the sea is rising, and coastal waves and currents immediately begin to remove the edges of the displaced sediment. Eventually, erosion destroys the equilibrium of the bluff and leads to another landslide, repeating the cycle shown at right.



Figure 1. A clay bluff on the north shore of Rockland Harbor failed in 1996. This landslide formed a new scarp about 200 feet landward of the original top of the bluff in just a few hours. Two homes were destroyed as a result of this catastrophic slide (see Berry and others, 1996).

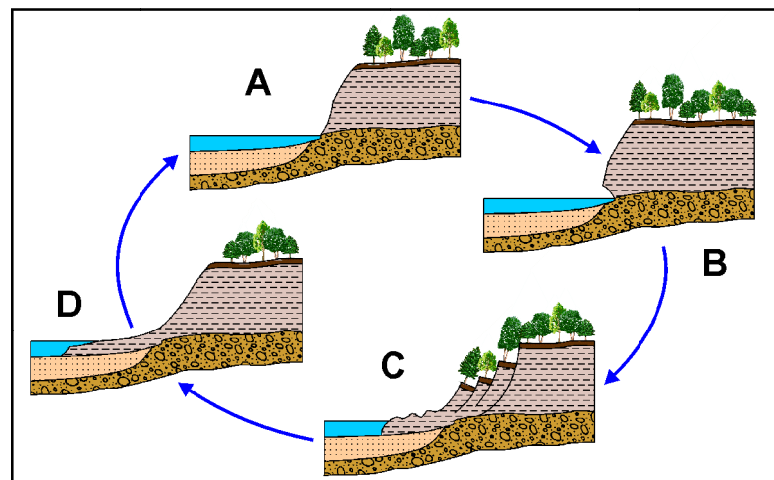


Figure 2. Life cycle of a landslide on a bluff composed of sediment (modified from Kelley and others, 1989).

Evidence of Ground Motion and Instability on a Coastal Bluff

Careful observation of the land surface, vegetation, and shape of a coastal bluff reveals evidence of instability. Starting at the top of a bluff, an irregular or arcuate edge can indicate past landslides or areas of increased coastal erosion (Figure 3). When a weak point on a bluff fails, the slide moves inward into the slope face forming a curve around the original point of failure. Tension cracks may form near a weak zone where the soil surface is moving downslope (Figure 4). These cracks appear as splits in the ground where the soil and vegetation have moved apart. Cracks may be visible along the top edge of the bluff or on the bluff face itself. On the slope of a bluff, a hummocky land surface or terraces indicate past slumping or landslides (Figure 5). Unvegetated slump scars or slopes are obvious evidence of rapid soil movement. A bowl-shaped slope often shows the location of a former landslide, with the center of the bowl as the area of greatest failure. Distorted vegetation provides evidence of soil creep or former landslides. Tree trunks curved near their base are evidence of downslope movement (Figure 6). Trees tilted at different angles are evidence of former slides or undercutting by erosion. At the base of a bluff, toppled trees and bare roots are evidence of erosion that steepens the bluff (Figure 7). Undercutting and steepening of the bluff may destabilize the slope and lead to increased erosion and possibly a landslide. Lobes or terraces of sediment in the intertidal zone are often remnants of old landslides. Although the evidence of earth movement listed above cannot predict a landslide, it is used to recognize unstable shorelines. This landform evidence is related to factors listed below that influence landslide risk.



Figure 3. The shape of the top edge of a bluff can be an indicator of landslide risk. Clay bluffs often fail at points of weakness. Such a "slump" can expand into a larger landslide that cuts into the bluff and forms a curve around the original point of failure. Multiple slides and slumps will form an irregular or arcuate top edge to the bluff as shown in the photo above. Bluffs made of coarse materials or sand have a more even upper edge caused by a more constant rate of erosion along the bluff face.



Figure 4. Downslope forces within a bluff cause surface layers to stretch. When the tension becomes great enough, a crack forms and the pressure is released. These "tension cracks" may form on the top edge of the bluff or on the bluff slope itself. They indicate instability and motion within the bluff. Some cracks are deep and extend below the soil layer.



Figure 5. Terraces on a hummocky land surface on the slope of a bluff can indicate a former landslide. Terraces can be the surface of downsloping blocks which moved during a slide. Vegetation on the surface of these blocks may be tilted in various directions. The irregular land surface may also occur in a bowl-shaped depression below an arcuate top edge of the bluff, additional evidence of a former landslide.



Figure 6. Soil "creep" or downslope movement of soil on a slope, will cause tree trunks to tilt toward the base of the slope. As a moving tree continues to grow, the trunk will curve as the tree tries to right itself and grow toward the sun. Landslides will also cause tree trunks to become curved.



Figure 7. Wave erosion at the base of a bluff removes slope sediment and steepens the bluff. Erosion has undercut the trees in the photo above and caused them to tilt toward the ocean. This steepening reduces the stability of the bluff, and a landslide may result. Ongoing sea-level rise along the Maine coast will cause wave erosion at the base of coastal bluffs and continue to make some coastal bluffs at risk of experiencing a landslide.

Factors Influencing Landslide Risk

BLUFF CHARACTERISTICS

Height. The height of a bluff can generally indicate landslide risk. While sediment strength depends on several factors, the thicker the sediment deposit, the more likely its weight will cause subsurface movement or slippage that leads to a landslide. The risk of a landslide increases when mud bluffs have a height of twenty feet or more. In general, the higher the exposed bluff face the greater the risk of a landslide.

Sediment type. Earth material that makes up a coastal bluff influences the risk of a landslide occurring. Clay and silt (muddy) sediment is the most unstable material that can make up a bluff. These fine-grained sediments are weak and prone to moving in the form of slow-motion creep, moderate-sized slumping, or large landslides. Sand and gravel deposits tend to be stronger and better drained than muddy sediment. Landslides can occur in coarse-grained bluffs although they are less frequent than muddy landslides along the Maine coast.

Slope. Coastal bluffs have a relatively steep ocean-facing slope. The angle of a bluff face varies due to factors such as the sediment type and rate of erosion at the base of the bluff. Slope is also affected by the history of slumps and landslides at the site. Some slopes are uniformly straight while others are terraced or uneven due to earth movements. In general, the steeper the slope, the easier it is for gravity to initiate a landslide.

Vegetation. Types, shapes, and distribution of vegetation above and on a bluff face can be used as an indication of site stability. In areas where the soil has shifted, either due to previous landslides or to gradual surface creep, many tree trunks can become tilted or twisted in the same direction. Curved tree trunks near the roots often indicate land movement down the face of a bluff. Large trees on the bluff face may be moved by wind and resulting root motion may loosen bluff sediment. Natural vegetation that consists only of small shrubs and trees may indicate recent bluff erosion or a landslide.

Bedrock. Crystalline rock or ledge is much more stable than any sediment bluff and not likely to erode or slide. The elevation of bedrock at the shore and inland beneath a bluff is important in determining landslide risk. Bedrock exposures along the shoreline may slow erosion and make sediment less susceptible to landsliding. Beneath a sediment bluff, bedrock may rise toward the surface and reduce the overall thickness of sediment and thus reduce the risk of deep-seated movement below the ground surface.

NATURAL CONDITIONS

Waves, tides, and sea level. Several marine processes affect the risk of landslides along a coastal bluff. A gradual, but ongoing rise in sea level at a rate of about an inch per decade is causing chronic erosion along the base of many bluffs. As sea level rises, wave action and coastal flooding can reach higher and farther inland and scour more sediment from a bluff. Sea ice erodes tidal flats and the base of bluffs by abrasion and freezing sediment in ice blocks. Erosion can increase a bluff slope and make it more susceptible to landsliding. Tides are also important in washing away eroded bluff sediment which helps wave action move inland. Storms that create wind, waves, and flooding can cause more extreme erosion at the base of a bluff, increase the bluff slope, and make a landslide more likely.

Surface water. The amount, type, and location of surface water can influence bluff slope stability and may contribute to some landslides.

Wetlands, ponds, and streams above the bluff can supply water to the bluff face and also to the ground water. The elevation or topography of the land surface determines which way surface water will flow. Water that runs over the face of a bluff can wash sediment to sea, increase the bluff face slope, and weaken the remaining sediment holding up the bluff. Removal of sediment from the bluff face can increase the risk of a landslide.

Ground water. Ground water inland of a bluff comes from surface sources, such as rain or a stream, uphill in the local watershed. Ground water tends to flow horizontally beneath the surface and may seep out the face of a bluff. Seeps and springs on the bluff face contribute to surface water flow and destabilize the bluff. In addition, a high water table can saturate and weaken muddy sediment and make the ground more prone to slope failure.

Weathering. Weathering in clay and silt can change the strength of bluff sediment and stability of the bluff face. Drying of clay can increase resistance to sliding. The seasonal cycle of freezing and thawing of the bluff face can lead to slumping after a thaw.

Earthquakes. Landslides can be triggered by earthquakes. Ground vibration loosens sediment enough to reduce the strength of material supporting a bluff and a landslide results. Most landslides triggered by earthquakes in sediment like that found in Maine have been of Richter magnitude 5 or more. These are relatively rare events, but a few have occurred in historical time.

HUMAN ACTIVITY

Land use. Human activity and land use may contribute to or reduce the risk of a landslide. Actions that increase surface water flow to a bluff face, watering lawns or grading slopes, add to natural processes destabilizing the bluff face. Surface water, collected by roads, driveways, patios, and lawns flows toward and down the bluff face. Walkways down the face of a bluff can lead to greater erosion from foot traffic or the concentration of surface water flow. Both surface and ground water above a bluff can be supplied by pipes, culverts, surface drains, and septic systems. Increased water below ground can weaken a bluff and contribute to internal weakness that leads to a landslide. Greater seepage of water out the bluff face can also increase the risk.

Clearing of vegetation from the bluff face can lead to greater bluff erosion and a steeper bluff that is more prone to landslide. Vegetation tends to remove ground water, strengthen soil with roots, and lessen the impact of heavy rain on the bluff face.

Adding weight to the top of a bluff can increase the risk of a landslide. Buildings, landscaping, or fill on the top of the bluff can increase the forces that result in a landslide. Saturating the ground with water that drains the water table also adds weight. Even ground vibration, such as well drilling or deep excavation, may locally increase the risk of a landslide.

Shoreline engineering in the form of seawalls, rip rap, or other solid structures is sometimes used to reduce wave erosion at the top of a bluff. In some settings, engineering can increase the rate of beach or tidal flat erosion and lower the shore profile over time. This intertidal erosion can undermine engineering and result in less physical support of the base of the bluff by natural sediment. Where engineering ends along a shore, erosion can become worse on adjacent properties. Engineering alone cannot prevent some large landslides.

In general, human activities that increase the amount or rate of natural processes may, in various ways, contribute to landslides risk.