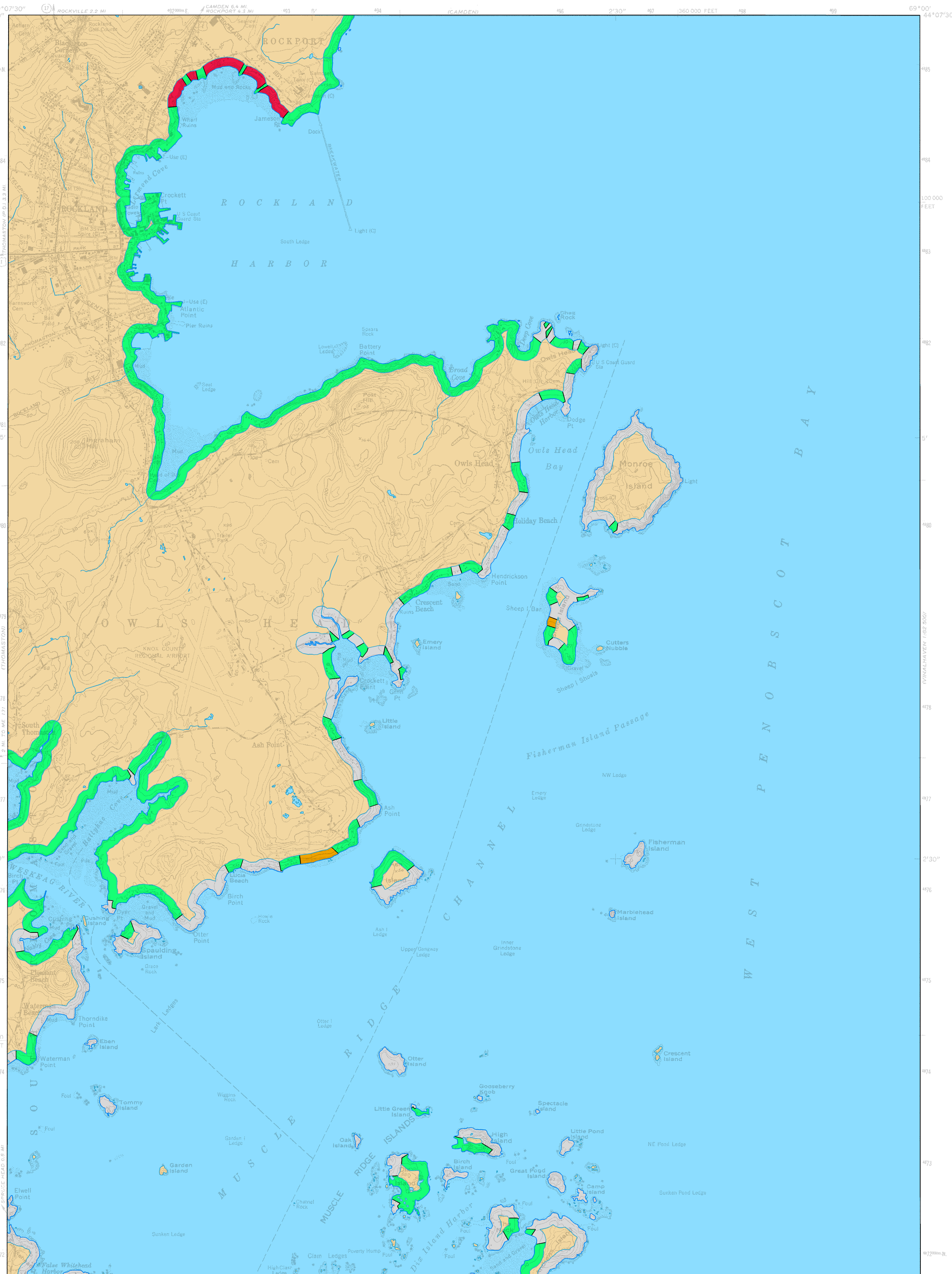
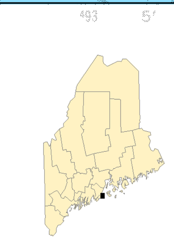
Coastal Landslide Hazards



Data Collection and Compilation - Analysis of aerial photographs, topographic and surficial materials maps was done by Jason N. Wiest and Stephen M. Dickson. GIS compilation of bluff and landslide data was by Jason N. Wiest and Susan S. Tolman. Field and historical landslide investigations to produce Landslide Sites and Landslide Risk Areas were conducted by Irwin D. Novak, Stephen M. Dickson, Joseph T. Kelley, Jason N. Wiest, Daniel F. Belknap, Rebecca V. Smith, Henry N. Berry IV, Daniel B. Locke, Robert G. Marvinney, Richard T. Reynolds, Andrews L. Tolman, Thomas C. Sanford, and others in previous publications. Landslide Potential Areas, Low Coastal Bluffs, and Non-Bluff Shoreline category observations from small boats were made by the authors of the corresponding MGS Coastal Bluff Map with additional analysis by Jason N. Wiest and Stephen M. Dickson.



Quadrangle Location

SCALE 1 : 24,000

1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

CONTOUR INTERVAL 10 FEET

TRUE NORTH

	Camden	
Thomaston	This Map	
Tenants Harbor	Hewett Island	

Topographic base from U.S. Geological Survey Rockland quadrangle, scale 1:24,000 using standard U.S. Geological Survey topographic map symbols.

Index at left shows adjacent maps in this series.

Coastal Bluffs: On this map, a bluff is defined as a steep shoreline slope formed in sediment (loose material such as clay, silt, sand, and gravel) that has three feet or more of vertical elevation just above the high-tide line. Cliffs or slopes in bedrock (ledge) surfaces are not sedimentary bluffs and are not subject to significant erosion in a century or more, although some may experience rockfalls. Beaches and dunes do not form bluffs, except along the seaward dune edge as a result of erosion. This map does NOT identify erosion trends on beaches or sand dunes.

Note: The landslide hazard classification is indicated by a colored, patterned band extending landward from the shoreline (dark blue line). The width of the band does NOT indicate the distance inland that a landslide may occur. This distance is difficult to predict and will vary from site to site. The colored buffer is for illustration purposes only. Due to variations in coastal geology, not all units in the explanation below will appear on this map.

Landslide Site - Location of known or interpreted coastal landslide. Includes historically recorded landslides and slides interpreted from air photos.

Landslide Risk Area - Earth features indicate conditions that may be suitable for a landslide to occur. Features often include a steep or arcuate scarp, slump blocks, sediment lobes, or uneven land surfaces. Bluff sediments are usually muddy and twenty feet or more in thickness.

Potential Landslide Area - Shoreline with a sedimentary coastal bluff twenty or more feet high. These bluff areas have not had field investigations that are necessary to evaluate the risk of a landslide. However, some similar high coastal bluffs have experienced landslides.

Low Coastal Bluff - Shoreline with a sedimentary coastal bluff that has less than twenty feet of relief immediately adjacent to the shoreline. Some bluffs over twenty feet in height are included in this map unit if the bluff face is not steep. In general, low coastal bluffs are not at risk of failing in the form of a landslide.

Non-Bluff Shoreline - Coastal areas without extensive sedimentary bluffs. Corresponds to the no-bluff unit on MGS Coastal Bluff Maps.

Unmapped Shoreline - These sites generally are in the inland reaches of estuaries or beyond the scope of the field effort in this region.

Who to Contact for More Information

It is important to realize that the coast of Maine is constantly being eroded. Coastal bluffs that show no evidence of erosion today may be endangered in the future as rising sea level continues to erode sediments at the base of a bluff. If you are concerned about ground movement on a coastal bluff, contact the Maine Geological Survey for more information helpful in evaluating the characteristics of coastal property. In addition to this landslide hazard map, a companion map series entitled **"Coastal Bluffs"** describes the stability and characteristics of Maine's shoreline. Maps showing topography, sediment composition, ground-water characteristics, and bedrock are also available in many areas. Survey geologists will explain the content of each of these maps.

If you find indications of ground movement on your coastal bluff, you may want a professional geologist or engineer to investigate your property. To reduce the risk of a landslide, these professionals may recommend re-sloping the bluff face, diverting water flow, armoring the toe of the bluff, or planting erosion-resistant vegetation.

Building or engineering on Maine's coastal bluffs are subject to the Natural Resources Protection Act and the Mandatory Shoreland Zoning Act. Permits from the Department of Environmental Protection may be required for any bluff modifications. Local Town Code Enforcement Officers will give advice on local requirements.

Maine Geological Survey
Information available: maps showing landslide hazards, coastal bluffs, surficial geology, surficial materials, ground-water, bedrock, USGS topographic maps; geologists explain maps and coastal processes
Contact: Maine Geological Survey at address shown in title block, or visit the MGS website and search your location.

Geological Consultants
Information available: studies of specific property: ground-water studies, soil mechanics, coring of bluff, mapping of site, risk analysis, recommendations about hazard reduction and slope remediation
Contact: consult local yellow pages under geologists or environmental services

Engineers
Information available: plans to reduce hazard, ground-water diversion, shoreline engineering, slope alteration, soil mechanics, risk analysis
Contact: consult local yellow pages under engineers - environmental or environmental services

Maine Department of Environmental Protection
Information available: information on state laws including the Natural Resources Protection Act, Shoreland Zoning, and the permit process
Contact: on the internet: http://www.state.me.us/dep/blwq/
phone: 800-452-1942 or 207-287-7688

Town Code Enforcement Officers
Information available: provide advice on Shoreland Zoning and other municipal requirements
Contact: local town office or
http://www.state.me.us/living/cities/index.html

Related Maps

Daly, J. F., Sinson, D. A., Bryant, M., Barnhardt, W. A., Dickson, S. M., and Kelley, J. T., 2000, Coastal bluffs in the Rockland quadrangle, Maine: Maine Geological Survey, Open-File Map 00-82.

Smith, G. W., 1974, Surficial geology of the Rockland quadrangle, Maine: Maine Geological Survey, Open-File Map 74-16.

Other Sources of Information

American Planning Association, Landslide hazards and planning:
http://planning.org/landslides/index.asp

Amos, J., and Sandford, T. C., 1987, Landslides in the Presumpscot Formation: An engineering study: Maine Geological Survey, Open-File Report 87-4, 68 p.

Berry, H. N., IV, and others, 1996, The April 1996 Rockland landslide: Maine Geological Survey, Open-File Report 96-18, 55 p.

Devin, S. C., and Sandford, T. C., 1990, Stability of natural slopes in the Presumpscot Formation: Maine Geol. Survey, Open-File Rept. 90-24, 75 p.

Kelley, J. T., and Dickson, S. M., 2000, Low-cost bluff-stability mapping in coastal Maine: Providing geological hazard information without alarming the public: Environmental Geosciences, v. 7, no. 1, p. 46-56.

Kelley, J. T., Dickson, S. M., Belknap, D., 1996, Maine's history of sea-level changes:
http://www.state.me.us/doc/nrimc/pubedinf/factsht/marine/sealevel.htm

Kelley, J. T., Kelley, A. R., and Pilkey, O. H., 1989, Living with the coast of Maine: Duke University Press, 174 p.

Novak, I. D., 1987, Inventory and bibliography of Maine landslides: Maine Geological Survey, Open-File Report 87-3, 27 p., map (1:500,000).

Novak, I. D., 1990, Air photo reconnaissance of slope failures in the Presumpscot Formation, Cumberland County, Maine: Maine Geological Survey, Open-File Report 90-22, 4 p., map (1:50,000).

U.S. Geological Survey, Geologic hazards: Landslides:
http://landslide.usgs.gov/index.html

Methods of Mapping Landslide Hazards

Landslide Site - Includes the following: (1) Locations based on historical records and eyewitness accounts. In general, these earth movements have occurred in the last three centuries. (2) Locations based on interptetation of aerial photography. The age of these features is usually unknown. Some may have formed in the last few years, others in the last century, and some possibly sometime in the last few thousand years.

Landslide Risk Area - Includes the following: (1) Observations from land corroborated with geomorphology observed on air photos, sediment types shown on surficial geologic maps, and both elevation above sea level and steepness of bluff slopes shown on topographic maps. Bluff sediments are usually muddy and twenty feet or more in thickness. The slope on the bluff face appears steep and similar to areas where there have been landslides in the past. (2) Observations from a small boat. Primarily steeply-sloping sediment bluffs that were visually estimated to be twenty feet or more in elevation. Other instability characteristics included unvegetated slopes on the bluff face; leaning, fallen, or crooked tree trunks; and visible slump deposits at the base of the bluff near the high-tide line. The site may be adjacent to previous landslides. In this second category, aerial photographs were not used nor were the surficial geologic materials investigated.

Potential Landslide Area - This determination was based on the presence of a bluff as indicated on MGS Coastal Bluff Maps, the proximity of a twenty-foot topographic contour to the shoreline (similar to areas adjacent to previous landslides) and geomorphology visible in air photos. These bluff areas have not had field investigations to fully evaluate landslide risk.

Low Coastal Bluff - This determination was based on the presence of a bluff as indicated on MGS Coastal Bluff Maps and the proximity of a twenty-foot topographic contour to the shoreline. By comparison with bluffs adjacent to previous landslides, these areas are less steep than those that have shown a tendency to fail due to weakness in the earth landward of the top of the bluff.

Non-Bluff Shoreline - This shoreline type was determined by visual observation from a small boat and corresponds to the no-bluff unit on MGS Coastal Bluff Maps. These shorelines can be composed of bedrock, salt marshes, beaches and dunes, or low-lying sediments without the presence of a bluff more than three feet high and 150 feet long. Within this category there may be short shoreline segments that contain bluffs. These small coastal bluffs are not illustrated on this map.

Unmapped Shoreline - In some locations, access to a shoreline was limited so some areas remain unmapped. These sites generally are in the inland reaches of estuaries or beyond the scope of the field effort in this region.

Rockland Quadrangle, Maine

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Maine Coastal Program

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Maine Geological Survey

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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.

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).

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 at the foot of the bluff 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.

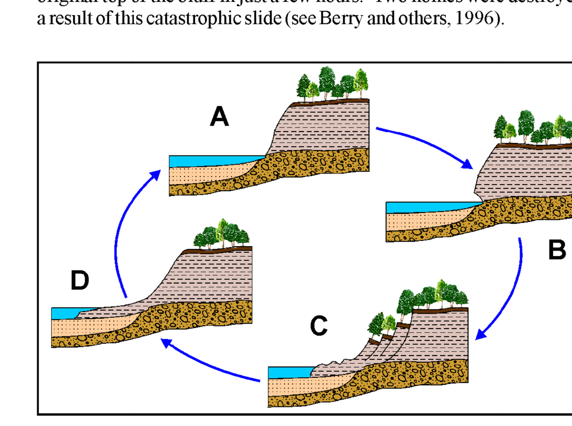

Figure 2. Life cycle of a landslide on a bluff composed of sediment (modified from Kelley and others, 1989).

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 downsope 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.

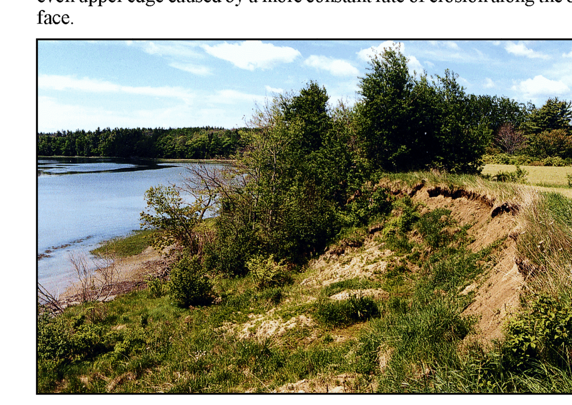

Figure 5. Terraces or a hummocky land surface on the slope of a bluff can indicate a former landslide. Terraces can be the surface of downdropped blocks which moved during a slide. Vegetation on the surface of these blocks may be tilted in various directions. The irregular land surface may also occur 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 face. 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 roofs, driveways, paths, 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 raises 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 toe 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 landslide risk.