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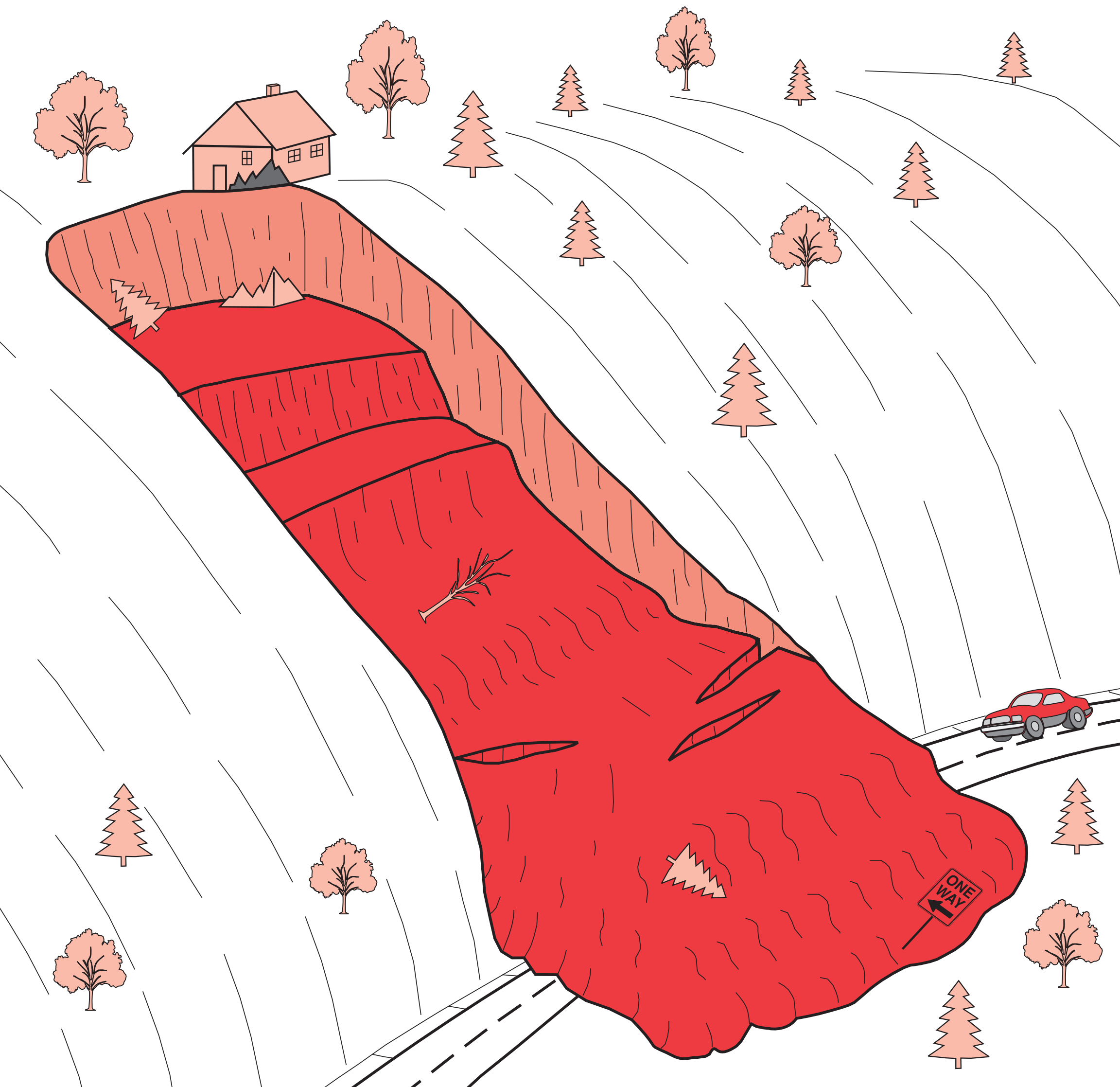
Educational Series 9

LANDSLIDES IN PENNSYLVANIA



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Educational Series 9

Landslides in Pennsylvania

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This publication is a revision of the landslide portion of Educational Series 9, *Geologic Hazards in Pennsylvania* (1979) by J. Peter Wilshusen (deceased). That edition of ES 9 was among the first efforts to bring geologic hazards in Pennsylvania to the attention of the general public in a succinct, easy to read, and understandable format. The other two parts of the original ES 9 are now covered in ES 10, *Earthquake Hazard in Pennsylvania,* and ES 11, *Sinkholes in Pennsylvania*.

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LANDSLIDES IN PENNSYLVANIA

INTRODUCTION

Landsliding is a natural geologic process involving the movement of earth materials down a slope. As such, it helps shape the landscape of Pennsylvania (Figure 1). Landsliding is also a significant geologic hazard. Landslides cause damage to utilities, buildings, and transportation routes, which, in turn, creates travel delays and other side effects. Fortunately, deaths and injuries due to landslides in Pennsylvania are rare. Almost all of the known landslide-related deaths have occurred when rockfalls or other slides along highways have involved vehicles.

A landslide is the movement of an unstable mass of rock, ***unconsolidated*** earth, or debris down a slope. The rate of landslide movement ranges from rapid to very slow. A landslide can involve large or small volumes of material. The principal types of movement are falling, sliding, and flowing, but combinations of these are common. Material can move in nearly intact blocks or be greatly deformed and rearranged. The slope may be nearly vertical or fairly gentle.

Natural factors affecting slope stability include the following: rock and soil characteristics such as strength, ***permeability,*** and the presence and orientation of fractures and other discontinuities; slope steepness and orientation; precipitation and other sources of water; the presence of old landslides; and oversteepening of slopes by stream or lake erosion. Human-induced factors include removal of support on lower slopes, increasing the load on upper slopes, and alteration of surface and subsurface drainage. Landslides occur when the balance between the pull of gravity on material on a slope and the forces (friction and strength of material) acting to hold it in place is upset by some change. These changes, or ***triggers,*** are commonly either increased water content or rearrangement of the load on the slope. Earthquakes can be a landslide trigger in many areas of the world, but are not known to cause landslides in Pennsylvania. The cause of a landslide is nearly always a combination of effects working together.

Many of our hillsides show evidence of past landslides in remnant bits of slumped bedrock or extensive deposits of ***colluvium*** on lower slopes. Most of these deposits developed tens of thousands

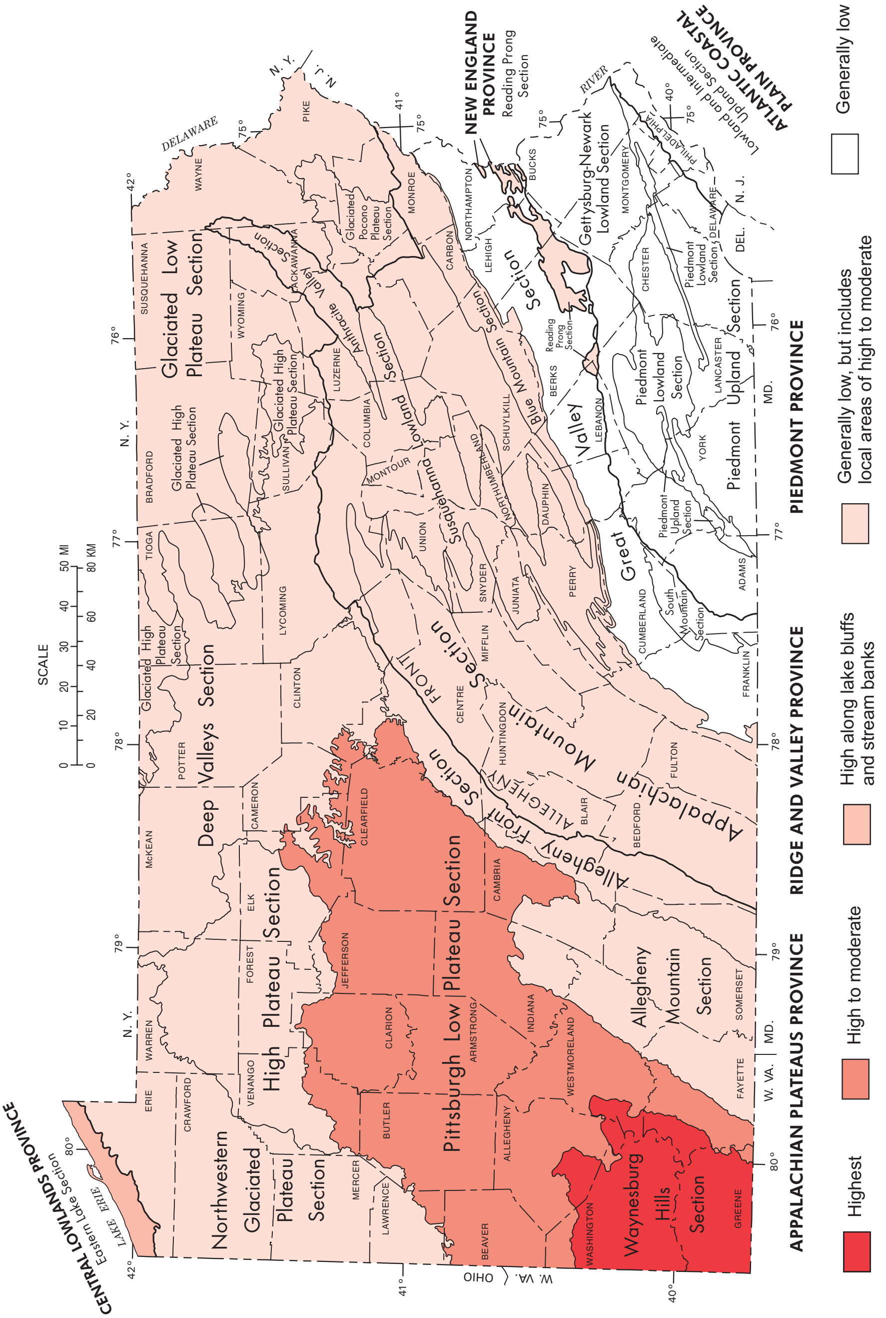


Figure 1. The physiographic provinces and sections of Pennsylvania, and landslide susceptibility.

of years ago when glacial ice occupied parts of our continent, and the climate beyond those ice sheets was colder and harsher than today. However, ***weathering*** and landsliding are ongoing processes, and although the rates of activity have slowed because of the milder climate of today, the same forces continue to operate.

LANDSLIDE CLASSIFICATION

Landslides are classified by the type of material involved and the type of movement. Additional criteria are the rate of movement and the water content of the material; these two are commonly related. Movement rates range from inches over many years to many feet per second. Table 1 shows a basic classification of landslides. Material can be rock or ***soil.*** Soil is further divided into ***debris,*** which contains pieces of rock, and ***earth,*** which is primarily sand, silt, and clay. Debris may also include other components, such as trees and construction materials. There are three types of movement, as follows: falls, in which loose material falls or bounces down a slope; flows, in which material is distorted and moves as a fluid; and sliding, in which the landslide involves relatively undeformed material moving along a discrete surface. Flows can be further classified by their rate of movement. Very rapid flow down a steep slope (usually involving very wet material) is an ***avalanche,*** and extremely slow flow deformation is known as ***creep.*** Slides are divided into two groups based on the shape of the slip surface. In translational slid-

Table 1. *Types of Landslides in Pennsylvania*

Type of movement		**Type of material**		
		Bedrock	Engineering soil	
			Coarse-grained	Fine-grained
Fall		Rockfall		
Slide	Translational	Rockslide	Debris slide	
Slide	Rotational	Rock slump	Slump	
Flow	Rapid		Debris avalanche	Mudflow
Flow			Debris flow	Earthflow
Flow	Slow	Rock creep	Talus creep	Soil creep

ing, material moves on a flat surface. If the surface is curved so that the material rotates back into the slope as it slides, it is called a ***slump.***

Classification is useful mostly as a tool in thinking about how and why landslides occur, and many real-world slides do not fit into neat categories. Nonetheless, the classification presents a system for describing slide occurrences that is reasonably complete. In the following sections, each landslide type is further described, and its geologic setting in Pennsylvania is discussed.

Rock Creep

Description

Rock creep is the slow, gravity-driven, downslope movement of rock fragments created by near-surface weathering (Figures 2 and 3). Rock creep is imperceptibly slow and can be measured only by repeated observations over a long period of time. Repeated freezing and thawing is a major cause of rock creep. Other causes include (1) the growth of plant roots in tiny fractures; (2) the expansion and contraction of soil and rock with changing temperature; and (3) the repeated opening and closing of ***desiccation*** (drying) cracks. All these factors act to shift particles slowly downslope.

Occurrence

Rock creep is widespread and occurs on many slopes. It can take place on both gentle and steep slopes throughout the state. It plays a role in forming and moving soils on slopes. Rock creep is more pronounced in broken rock that occurs with small- or mixed-size fragments. Movement caused by freezing-thawing and wetting-drying cycles is more effective in the smaller spaces of such material than in accumulations of large blocks and boulders.

On a number of mountainsides, especially in the Ridge and Valley physiographic province, large areas of closely packed angular boulders blanket the steep slopes (Figure 4). Although their appearance is dramatic and suggests instability, in most cases they are stable. As long as the slopes remain undisturbed by works of humans (particularly the removal of material from the base of the slope), the rocks generally stay in place, wedged one against the other, forming tight boulder nests of interlocking pieces that have apparent long-term stability.

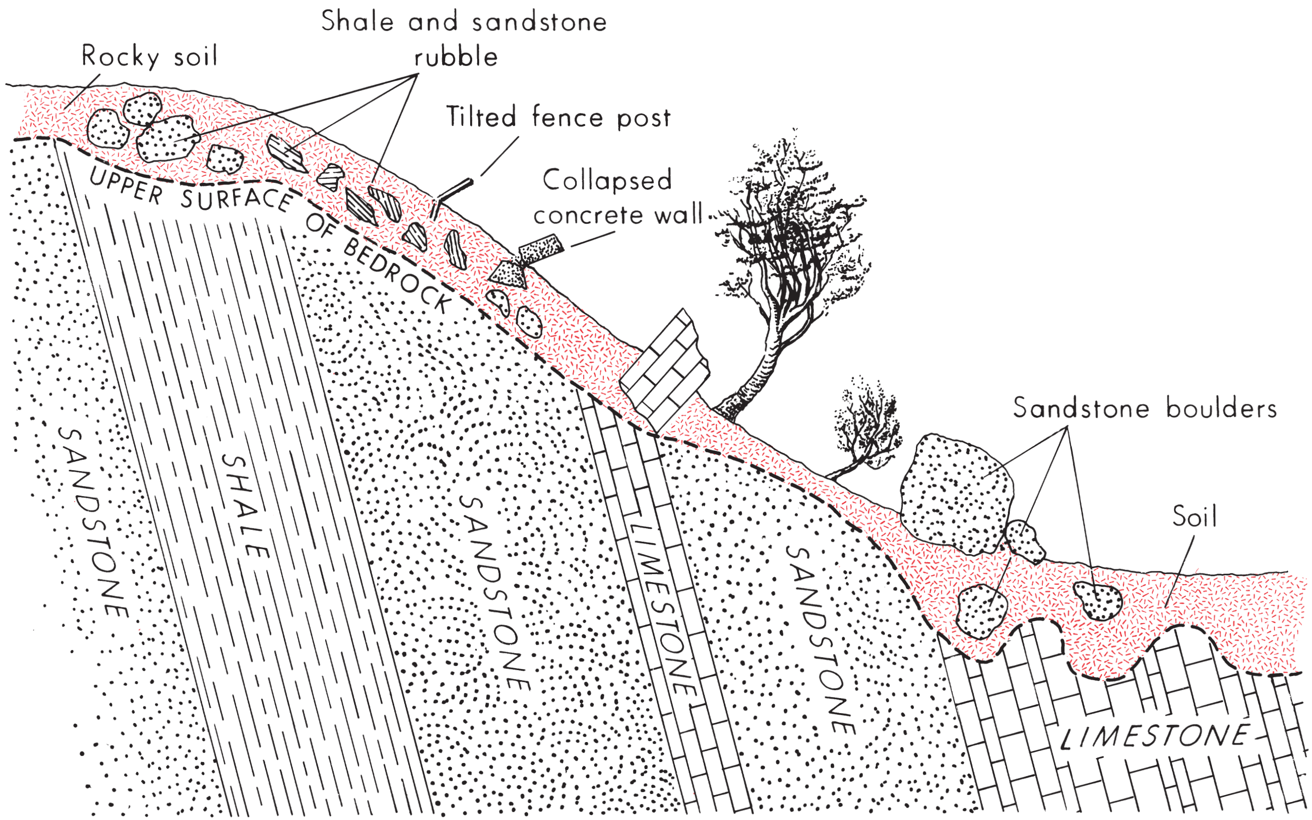


Figure 2. Characteristics of rock and soil creep shown in a cross section of a hillside. Sandstone boulders near the top of the hill have weathered away from the parent rock along fractures and have moved downhill. Similarly, shale fragments are in the soil downhill from their source rock. In the middle of the hillside, a limestone block has tilted downhill. Near the toe of the slope, several sandstone boulders from above are buried or partially buried in soil that overlies limestone. These situations are typical of conditions found along the crests of narrow ridges in the Ridge and Valley province.

Figure 3. Rock creep. The nearly vertical texture of the fresh rock in the lower part of the photograph is in contrast to the upper material, which has been reoriented by rock creep and now is oriented from upper left to lower right. Downslope is to the left. Photograph by W. D. Sevon.

Figure 4. A dense accumulation of angular sandstone boulders forming a steep slope. As long as the slope is not disturbed, the accumulation commonly remains in a relatively stable configuration because there are no small rock fragments and soil between the boulders, and water drains freely from the hillside.

Talus Creep

Description

Talus creep is closely related to rock creep. Talus is rock waste at the foot of a cliff or steep slope. It is loose rock rubble that has been separated from the rock face above by weathering and that has accumulated by rockfall (explained below) on the slope below (Figure 5). It thus builds up as a wedge-shaped deposit. Wherever talus occurs there will be talus creep, and the same mechanisms that cause rock creep are the active agents of movement.

The downslope movement of talus is augmented by loading at the top. Pieces that fall from the steep slope may settle near the top of the talus rubble. Their weight is an added impetus to downslope movement. Talus on the lower slope has a larger percentage of fine material, which allows downslope movement by creep.

Soil Creep

Description

Almost every soil-covered slope shows slow downhill movement in response to gravity. The rate of soil creep depends upon the steepness of the slope, the type of soil, the moisture content, and climatic conditions. Soil creep is active even on forested slopes. Surface evidence of soil creep is commonly quite noticeable. Fence posts tilted downhill, fence rows displaced downslope, curved tree trunks, and turf rolls are all common evidence of soil creep (Figure 6). Trees become concave upslope as tree growth responds to downslope movement

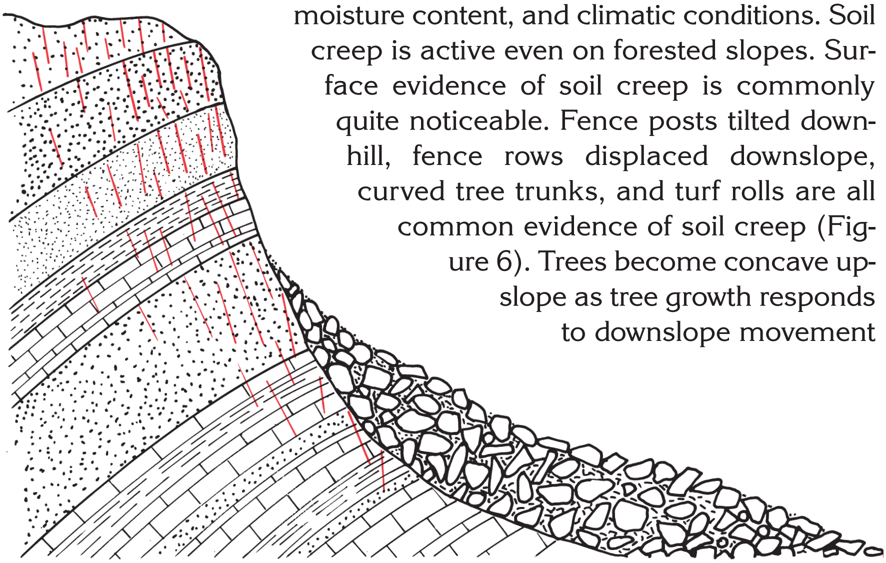


Figure 5. A cliff face and a talus accumulation at the foot of the cliff. Rock fragments break away along fractures, which are shown in color.

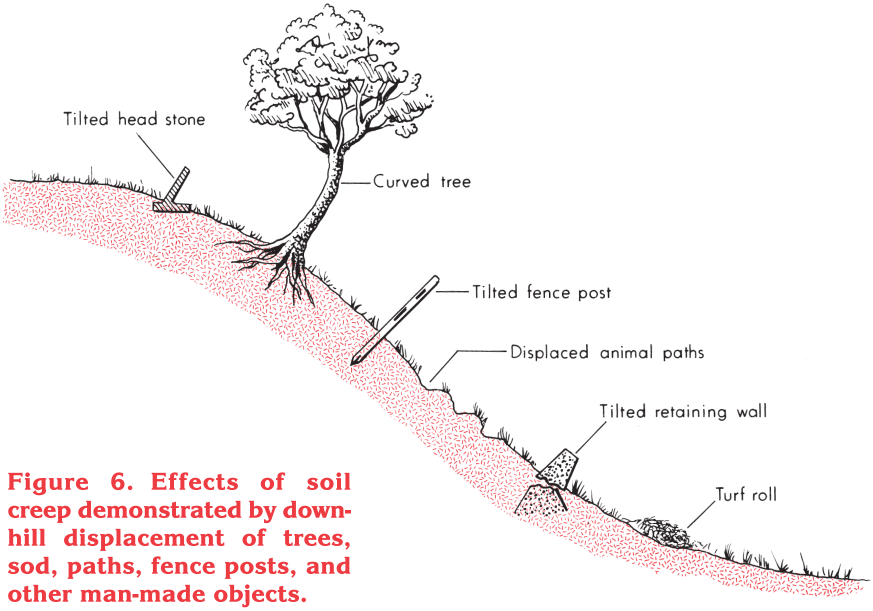


Figure 6. Effects of soil creep demonstrated by downhill displacement of trees, sod, paths, fence posts, and other man-made objects.

so that the tree is bent toward the source of light, trying to remain vertical.

There are several causes of soil creep. Water infiltration followed by freezing and thawing plays a major role in downslope movement. Other forces causing movement are alternating heating and cooling, desiccation cracking when dry, moisture changes, wedging by growing plants, burrowing by animals, and chemical decomposition. Gravity causes all these forces to produce downslope movement. Results of the freeze-thaw cycle are apparent on many slopes. As moisture in the soil freezes, particles are lifted in a direction perpendicular to the slope. Then, as the ground thaws, these same particles settle downward by gravity, coming to rest at a point lower on the slope. By this mechanism, a layer of soil near the surface will move at a faster rate than the soil at greater depths. However, the slow movement created has substantial effect, and as surface layers are loosened, deeper layers are affected. Soil creep may accelerate into more rapid flow when the water content of a soil is greatly increased or other conditions affecting slope stability are changed. Creep alone is not usually a serious geologic hazard, but over time it is capable of damage such as breaking sewer and water lines and toppling unsupported walls. Creep may also lead to conditions that result in more drastic slope failure.

Occurrence

Creep occurs on most slopes and is widespread throughout the state. However, on most hillsides it does not lead to catastrophic slope failure. In cases where creep triggers more pronounced movement, the underlying causes of slope instability are already present. These causes are the same as those at the roots of most other landslides, which are weak zones in rock or soil, barriers to free drainage of water, and fractures or other discontinuites in otherwise strong material.

Earthflow

Description

Earthflow is a rapid mass movement characterized by downslope flow of soil over a discrete basal surface (Figure 7). Bedrock movement is not involved. The soil is composed mostly of sand and smaller particles. The basal surface is more or less parallel to the ground surface in the lower portion of the flow. There are generally three distinct parts of an earthflow: (1) a source area; (2) a central section of broken and disrupted soil that has open fissures across the flow; and (3) a lower section of raised hummocky ground. Earthflow is typically the slowest moving of the three types of rapid flow that occur in Pennsylvania.

Conditions causing earthflow are variable but are most favorable where soil above an ***impermeable*** bedrock surface or clay layer becomes saturated with water. Water fills all of the pore space in the soil. This adds weight to the mass and reduces the strength of the soil. The pressure of additional water that cannot drain away forces the grains to move apart, further reducing the strength of the soil and resulting in slope failure even on a gentle incline.

Occurrence

Earthflow is primarily a problem in southwestern Pennsylvania, being most prevalent in areas where shallow soils are developed on steep slopes that have clay-rich bedrock. Most natural earthflows in Pennsylvania occur in the Waynesburg Hills and Pittsburgh Low Plateau sections of the Appalachian Plateaus province. In parts of the Waynesburg Hills section, nearly all the slopes show evidence of ancient or recent earthflow. Most individual earthflows are small—at most a few hundred feet long and wide—but multiple earthflows, sometimes of different ages, can combine to create large areas of instability. Movement of an individual earthflow is commonly inter-

Figure 7. Earthflow, characterized by downslope movement of wet soil that acts as a thick, viscous fluid. Photograph by J. L. Craft.

mittent, and periodic downslope movement may continue for years after the initial failure. Typically, the slide will move during wet times and appear to stabilize when it is dry.

Debris Flow and Debris Avalanche

Description

Debris flow is similar to earthflow but involves soil having a mix of grain sizes from mud and sand to cobbles and boulders (Figure 8). It moves as a fluid, and the material is being continually deformed. Depending on the amount of water involved and the steepness of the slope, the rate of movement can be slow to very rapid. The movement of wet concrete is a good analogy for debris flow. It can continue to move slowly over a long period of time, and its movement is commonly intermittent, as in earthflow.

Debris avalanche is a type of debris flow involving very rapid movement of very fluid material on a long, steep slope. A debris avalanche commonly removes all the loose rock, soil, and vegetation in its path, leaving a long, narrow scar and an accumulation of material at the toe (Figure 9). Debris avalanche scars in Pennsylvania are commonly a few tens of feet wide and a thousand or more feet long. Because they move very fast, with little warning, debris avalanches are potentially the most dangerous type of landslide in Pennsylvania. Evidence of the force of debris avalanches includes boulders caught in branches of trees, bark stripped off trees along the edge of the scar, and damaged roads and buildings. Once a debris avalanche occurs, it is usually many years before enough soil accumulates in the scar for a similar event to take place in the same location.

Mudflow is a term for a very rapid, very fluid movement of fine-grained soil material that does not contain large rocks. The effects of mudflows are similar to those of debris avalanches; however, large mudflows are not common in Pennsylvania.

Occurrence

Most debris avalanches are triggered by very heavy rainfall on slopes that are already nearly saturated. High-rainfall events associated with hurricane Diane in 1955 and tropical storm Agnes in 1972, and flood-producing rains in Johnstown in 1977, triggered debris avalanches in Pennsylvania. Intense local thunderstorms, rain causing rapid melting of deep snow, and breaks in high-volume pipelines have all produced debris avalanches. If enough rain falls, debris avalanches may occur on any long, steep slope that has loose, stony soil. Susceptible slopes occur in many parts of the Ridge and Valley and Appalachian Plateaus provinces.

Figure 8. Debris flow in glacially derived sediments along Lake Erie bluffs.

Figure 9. This long, narrow scar was created by a debris avalanche. Forest vegetation and most of the soil was stripped away from the upper and middle parts of the slide and deposited lower on the slope.

Slump

Description

Slump is rotational sliding of rock or unconsolidated material that moves as a unit and is characterized by a curved slip surface. The rotation of the moving mass is around a horizontal axis. The slumped mass is tilted backward into the slope, forming a ***scarp*** at the top and a bulge at the toe (Figures 10, 11, and 12). The surface of rupture and slippage is concave upward, and the slumped material is not greatly deformed. Formation of a semicircular slip surface is typically an indication that the material is not composed of layers having different strengths. Artificially placed materials

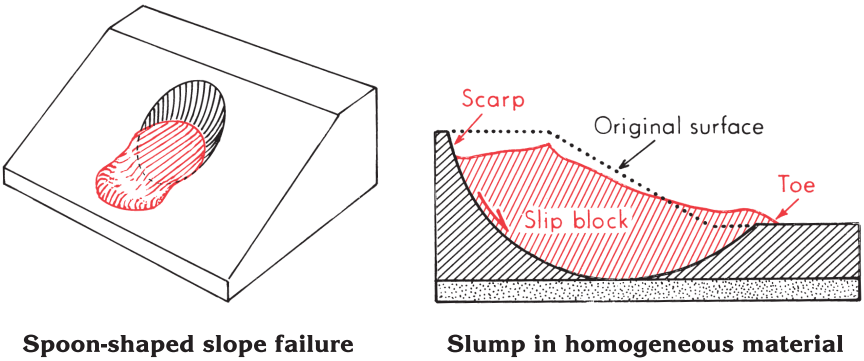


Figure 10. Internal movement and generalized configuration of the surface of rupture characteristic of slump failure.

such as fill and mine waste typically fail by slumping. Slump failure commonly occurs in thick, uniform soil and weathered rock, but it may also occur in bedrock. Most identified large bedrock slumps are very old but can still be active or can be easily reactivated. Slump is most commonly caused by (1) increased moisture content, which decreases strength; (2) removal of support at the toe of a slope; (3) adding material at the top of a slope; or (4) construction of a cut or filled slope that is too steep for the materials involved to be stable (Figure 13). Slump failures can be relatively

Figure 11. Slump failure and the steep scarp at the head above the disrupted ground. Photograph by R. P. Briggs.

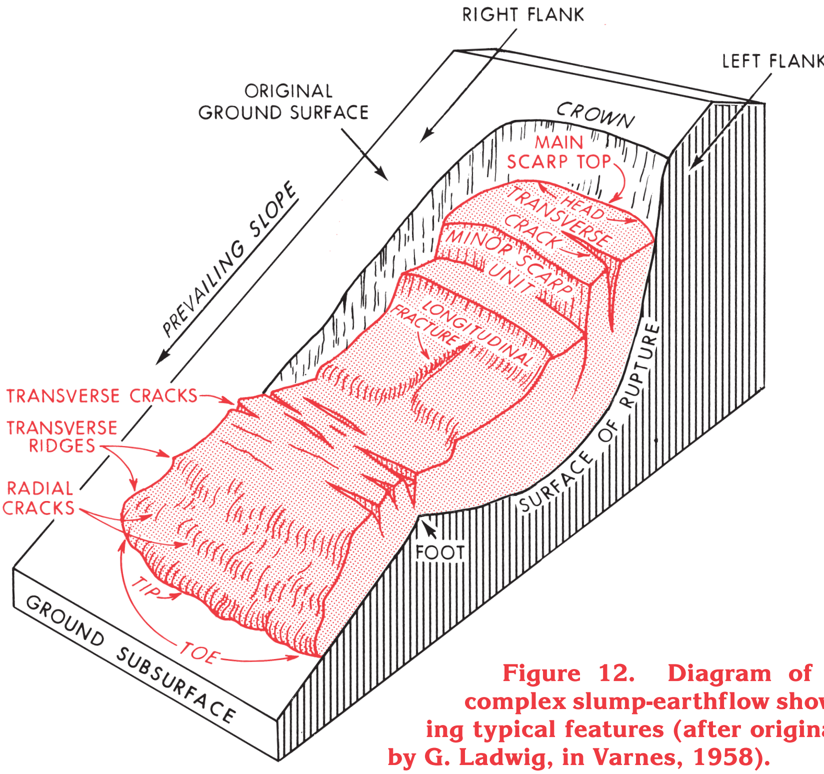


Figure 12. Diagram of a complex slump-earthflow showing typical features (after original by G. Ladwig, in Varnes, 1958).

small, involving several tens of cubic yards, or they can be 1,000 feet or more in width and length.

Occurrence

Slump and slumping in combination with other types of landsliding is common in western Pennsylvania and occurs to some extent on many hillsides throughout the state. Many of the hillsides have thick accumulations of colluvium on the lower slopes. In parts of southwestern Pennsylvania where the bedrock includes weak claystone, colluvium more than 60 feet thick has been measured. This material is very prone to slump failure, as the high incidence of landslides shows. Human activity increases the problems, and the combination of geology and the fact that it is a major urban area makes greater Pittsburgh one of the most severely affected landslide regions in the United States.

Slump in stream-bank sediments (Figure 14) is very common, especially along larger streams and rivers that have extensive floodplain deposits. Erosion along the edge of a stream channel removes material and oversteepens the bank, which then fails by slumping.

Figure 13. Small slump in the cut portion of a recent cut-and-fill slope. The slumped material is a thick claystone between layers of stronger rock.

The stream typically removes the slumped material, setting the stage for a repeat performance.

In the northern part of Pennsylvania, glacier ice once dammed many of the streams. Thick deposits of clay were laid down in the resulting lakes. The ice and lakes are now gone, but the clays remain, sometimes covered by other sediments. These clays are very prone to slumping, especially as streams remove material from the toe, or as roads and buildings are constructed on the upper parts.

Bluffs along the shore of Lake Erie in northwestern Pennsylvania fail by periodic slumping as well as by other types of movement. The bluffs are 30 to 170 feet high, and are mostly composed of unconsolidated sediment of glacial origin. The wave action of the lake removes material at the base of the bluff face, and the bluff face slumps, slides, and flows in response.

Old bedrock slumps are known from valley sides of many of the large rivers and streams of Pennsylvania. Most of these probably

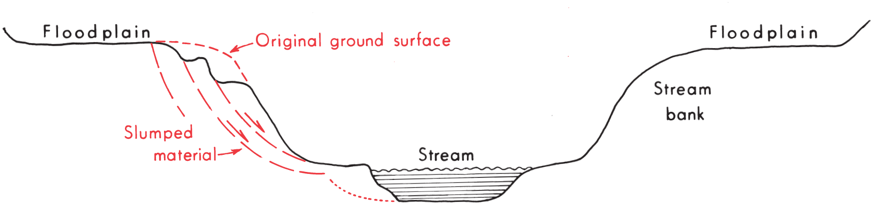


Figure 14. Slumping along a stream bank.

developed when river erosion deepened the valley beyond a critical point. Most do not show signs of active movement, but they can be reactivated by construction activities or high-moisture conditions. There are almost certainly many more old bedrock landslides that have not yet been recognized.

Debris Slide and Debris Fall

Description

Debris slide is the rapid sliding movement of unconsolidated, coarse soil in which the material slides as one or more discrete units. In this type of sliding, the surface along which movement occurs is generally an inclined layer of weak, impermeable soil or the top of the bedrock. The weak layer may be saturated with water and very soft, and firmer material rides along on top as the soft material is deformed. Debris fall is the relatively free falling of unconsolidated earth and rock debris from a vertical or overhanging cliff.

Soil and weathered rock typically move slowly down a slope by creep to a point at which a slope increases in steepness. A debris slide results after the material reaches the steeper section. If the slope is vertical, the resulting mass movement is debris fall. Other triggering causes for debris slides are increased soil-moisture content, especially if weak clay material is present near the failure surface, and excavation or loading on the slope.

Occurrence

Debris slides and debris falls, either individually or in combination, are common in many areas of Pennsylvania. Colluvium, which covers most of the slopes in the commonwealth, is prone to debris slide, especially if disturbed. Shallow debris slides are common in the Ridge and Valley and Appalachian Plateaus provinces, especially where roads have been cut into steep slopes. Many small debris slides probably go unnoticed in wooded areas where they do not affect human activity.

Rockslide

Description

Rockslide is the movement of newly detached segments of bedrock sliding on bedding, joint, or fault surfaces or any other surface of separation. Significant bedrock characteristics that determine the susceptibility of a hillside to rocksliding are (1) the position of bedding, joint, and fault surfaces with respect to the hillside slope (Figure 15); (2) the extent of weathering; and (3) the presence of water- or ice-filled fractures in the rock.

Layered sedimentary rocks, which occur in most of Pennsylvania, are particularly prone to rockslide when the layers have been folded so that they are no longer horizontal. Where the dip of the bedding planes and fracture surfaces is in the same direction as but less steep than the angle of a slope surface, rocksliding can readily occur. A rock slope subject to considerable weathering can have a large amount of loose rock built up on it, and this material can eventually slide.

One of the main triggering agents of slides is increased water content, which can reduce friction along potential slide surfaces. As in other types of landslides, many rockslides begin to move during or immediately after heavy rainstorms. Increased water alone, however, is not the only initiating factor. The presence of a relatively weak rock layer on top of an impermeable layer creates a situation where the weak layer is easily saturated with water. This is illustrated in Figure 16. Relatively thick, fractured sandstone and shale bedrock overlies carbonaceous shale and claystone. The bedrock dips gently toward the slope face. Water from rain or melting snow can percolate down through the sandstone and shales, but slows when it reaches the fine-grained claystone below. As water saturates the rock units above the claystone, water pressure increases in the pore spaces in the rock and water concentrates at the top of the claystone. The claystone becomes soft and slippery when it is wet, and develops into a potential surface of slippage. Now, any triggering agent, such as a vibration or sudden increase in precipitation, will allow all the water-saturated rock above the claystone to break away and slide suddenly toward the valley.

Occurrence

Rockslide is common across most of the Appalachian Plateaus and Ridge and Valley provinces in Pennsylvania. It is particularly likely to occur where dipping rock layers contain interbedded sandstones and shales or claystones, and where highway or other construction activity results in steep slopes being cut into such rocks.

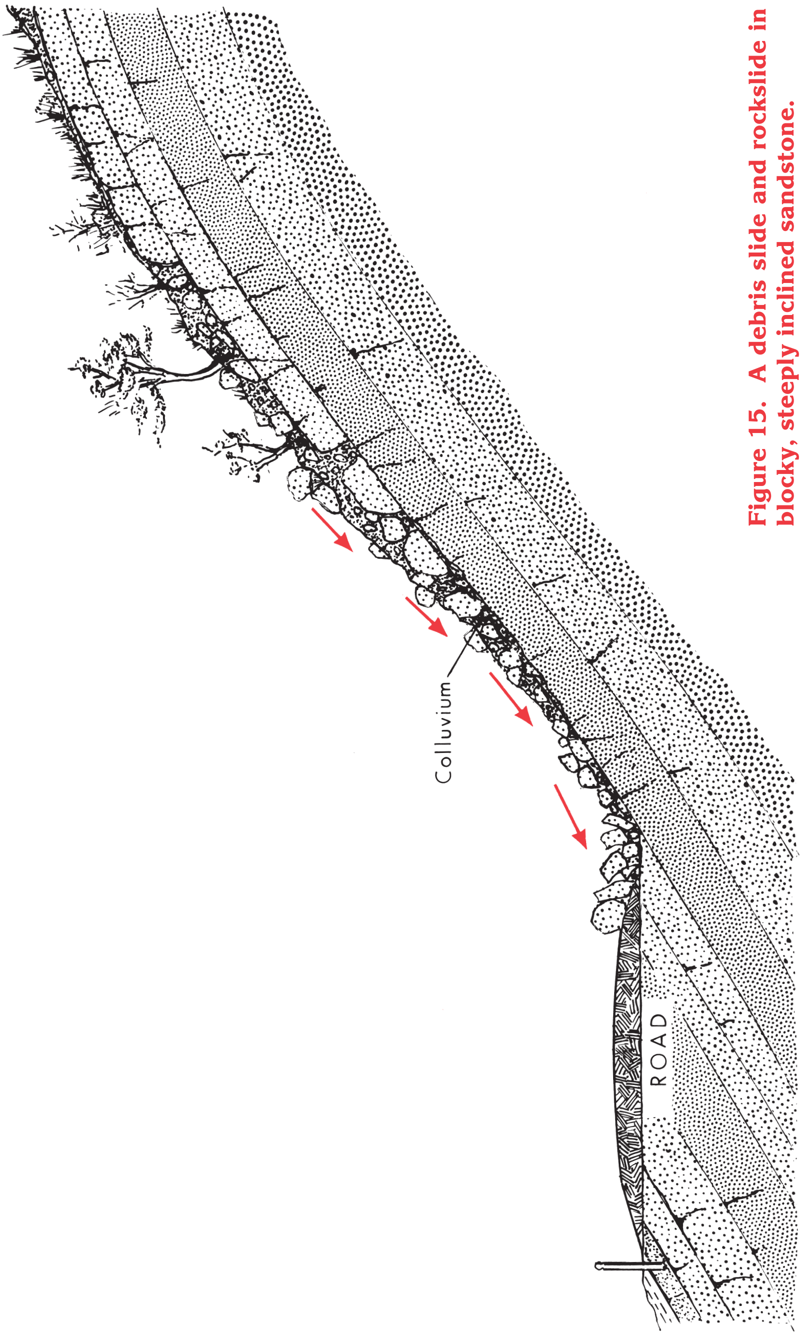


Figure 15. A debris slide and rockslide in blocky, steeply inclined sandstone.

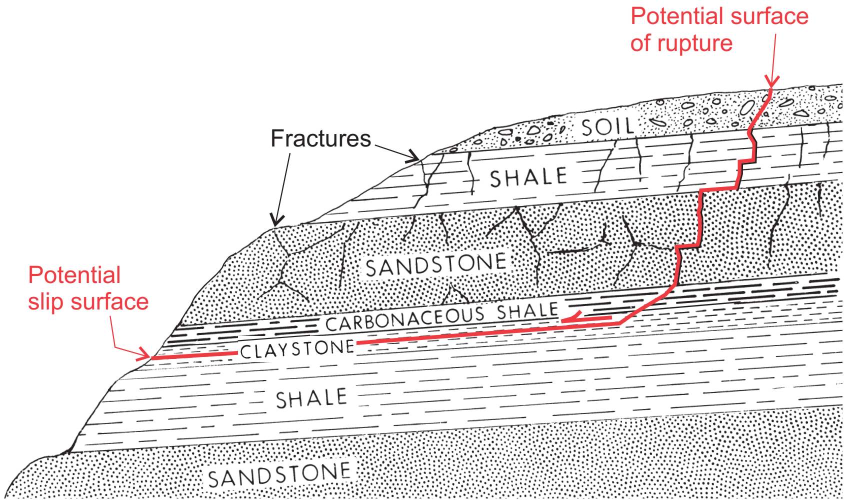


Figure 16. The fractured sandstone and shale in this rock slope is likely to slide along a slip surface in the soft claystone layer. The unit can move as a single large block, or it can break up into many small ones. The numerous fractures will contribute to the breakup of the rock and allow water to enter the rocks and reduce their strength.

Figure 17. Sandstone bedrock in this highway cut dips steeply from right to left. Blocks in the top layer of rock have broken loose from the intact rock and are slowly sliding downslope along a bedding surface. A wide drop zone keeps the rock from sliding onto the highway.

Southwestern Pennsylvania has a very high occurrence of rockslide because of the high clay content of many of the rocks. Other areas particularly prone to natural rockslide because of dipping rocks (Figure 17) are the Appalachian Mountain and South Mountain sections of the Ridge and Valley province, the

Pocono Plateaus section of the Appalachian Plateaus province, and the Reading Prong section of the New England province.

Some very large, old rockslides are known in the Ridge and Valley section. They occur along major streams that have eroded the base of the slope, and are similar to the rock slumps discussed earlier, except that the slide surface is planar rather than curved.

Rockfall and Soil Fall

Description

Rockfall is the free falling of a newly detached unit of bedrock of any size from a cliff, steep slope, cave roof, or rock arch. Rockfall can occur as a single event or as a series of single, intermittent events over a considerable period of time. Rockfall is most active in the spring after freeze-thaw cycles have loosened pieces of rock along joints and bedding-plane fractures, allowing them to fall from a steep slope or cliff face (Figures 18 and 19). Susceptibility to rockfall depends mostly on the spacing and orientation of fractures, bedding, and other discontinuities in the rock. Soil fall is the similar falling of unconsolidated soil, but is much less common than rockfall because soil rarely stands in a steep enough slope for fall to occur.

Occurrence

Rockfall can occur from any nearly vertical or overhanging rock face. It is most common in those parts of Pennsylvania that have many steep hillsides, but it may occur in any of the physiographic areas. However, since most natural slopes are not steep enough for fall to occur, rockfall is mostly limited to areas where stream erosion or human activity removes support at the base of a slope.

Stream banks, highway and railroad cuts, old mine and quarry areas, and other human-made steep slopes are typical settings. The age of a cut is a factor in rockfall. Many fresh cuts seem quite stable, but after a number of years, the rocks weather, fractures grow wider and deeper, and blocks loosen. This is a natural process, but one not always anticipated by people traveling or working below the cuts.

A combination of rockslide and rockfall is not unusual, especially in the Plateau, where soft, easily eroded shales are commonly overlain by more resistant sandstone or siltstone. Erosion of the thick shale near the base of the steep hillside undercuts the more resistant units, removing support from beneath them and allowing them to fall or slide to the toe, as illustrated in Figure 18.

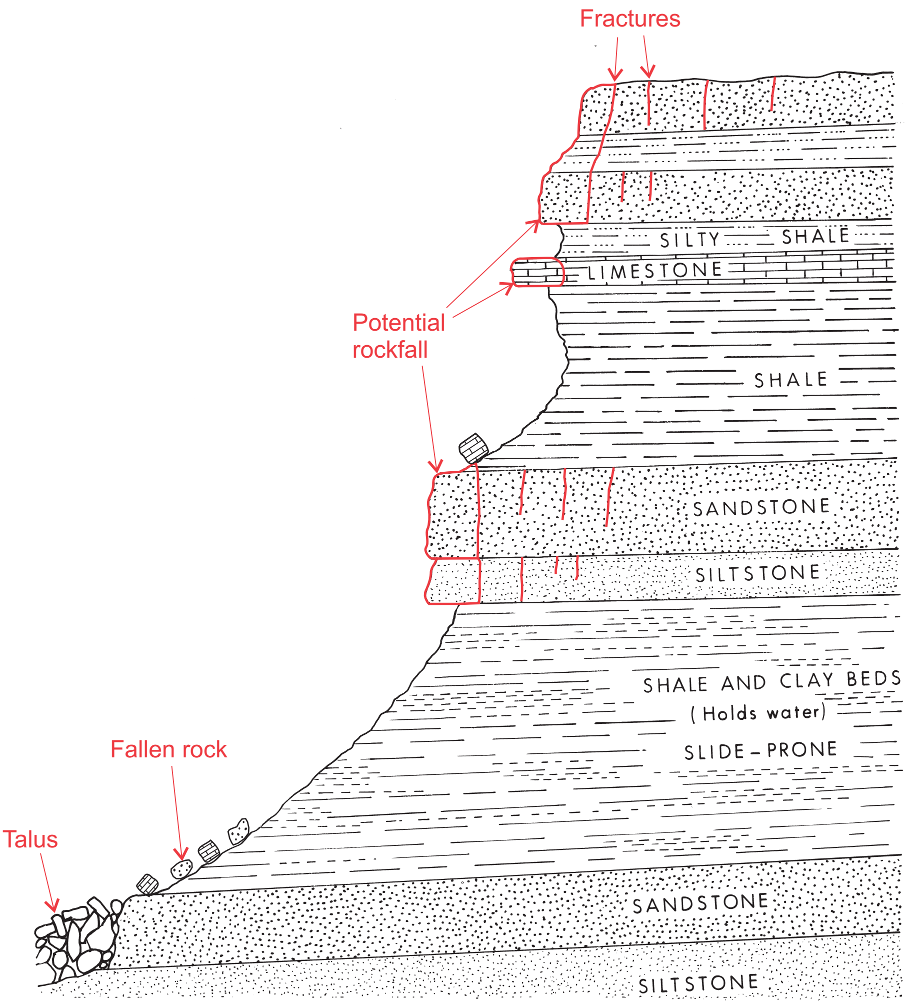


Figure 18. Shale and clay layers weather and erode more easily than stronger sandstone, siltstone, and limestone beds. The stronger layers are left unsupported and separate along fractures, leading to rockfall.

As indicated above, soil rarely stands naturally in a steep enough face to be a hazard. Soil fall is common only in excavations and along some stream and lake banks.

Composite Landslides

Composite landslides show more than one of the classic types of movement. Both earth slumps and debris slides typically also involve flow movement in their lower sections. Many debris ava-

Figure 19. Rockfall from a cliff face into a stream channel. Note how the rock has fallen away along near-vertical joints, forming fresh cliff faces. Photograph by J. L. Craft.

lanches begin with a small area of slump or slide at the head. The deposits of an old debris flow may be reactivated as a smaller area of slumping or sliding. The head scarp of a slump may fail again, producing a progressive series of slumps migrating upslope. Composite landslides are probably more common than examples of "pure" types. It is difficult to sort natural occurrences into neat categories, but trying to do so makes it easier to understand how they are caused.

Human-Induced Landslides

Although landslides do occur naturally, human activities are involved in causing a great many of them in Pennsylvania. Human-caused landslides can be of any of the above types, and usually involve a natural component as well. The human activities are similar to the common natural triggers for landslides, and include removal of support at the toe, addition of material at the top, or addition of water, which reduces the strength of the slope materials. An additional factor, particularly common in southwestern Pennsylvania, is building on naturally unstable ground and on old landslides and slide scars. In many cases, a landslide that has moved once will start to move again with greater ease, because the clay and other materials along the surface of rupture have been smoothed and smeared, and original friction is reduced. Also, fractures and cracks on the surface of an old slide allow water to enter the material, thus reducing its strength and adding weight.

The human-induced landslides that are most often seen are in roadcuts along hillsides (Figure 20). Modern roadcuts are generally designed with slide prevention in mind, but there are all too often unexpected conditions, such as an unknown concentration of groundwater flow, unexpected weak rock layers, or undetected fractures, that lead to failure of what was thought to be a stable slope.

Figure 20. Slump failure of a road on a cut-and-fill slope.

Virtually all types of landslides from creep to rapid flow to rockslide and rockfall can be observed along Pennsylvania's highways. Many are minor, requiring little or no special maintenance. Others are massive failures that interrupt construction or temporarily close a completed road to traffic. On a four-lane highway under construction in Blair County in the 1970s, for example, 250,000 cubic yards of mountainside slid rapidly onto a completed portion of the roadway. The cost to remove it was more than $300,000.

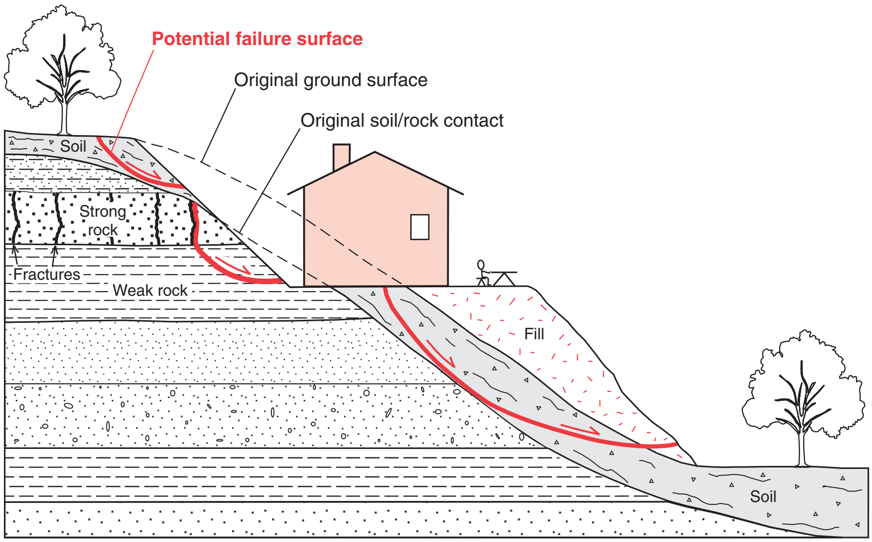


Figure 21. Some possible effects of the cut-and-fill technique of slope modification. In the steep excavated face above the house, both soil and rock can fail because of lost support. Below the house, the additional load from carelessly placed fill may trigger slump failure of the underlying soil. Cutting and filling also allows water to enter slope materials, and can block free drainage of water from the lower slope.

Other types of construction and land modification may affect landslide occurrence as well. The placement of fill to modify a slope is a common trigger (Figure 21). The placement of fill on a slope adds to the load on what may be marginally stable materials. If the fill consists of weak, clay-rich material, or is not installed in compacted layers, it may slide or settle, affecting anything built on it. There are numerous examples throughout the state of cracked and damaged buildings, driveways, parking lots, and so on, which are located on unstable fill that is undergoing progressive failure by creep or slumping. In too many cases, unhappy homeowners may be left with cracking walls, breaking pipes, and tight windows and doors, and they may have little or no recourse to remedial measures. Failure may be complete (Figure 22), causing the total loss of a home.

The placement of fill over old landslides has set off many additional slides, particularly in southwestern Pennsylvania where old landslides cover a large portion of the land. In one case, failure to

Figure 22. A new home that was severely damaged, and eventually totally destroyed, by slope failure. The remains of the home (since demolished) are at the head of an active slide developed in fill material placed on top of old landslide materials. Photograph by J. L. Craft.

recognize the presence of an old slide led to the necessity of a $4.25 million dollar repair on a major highway.

Construction activities on the lower parts of slopes can trigger slides that move down onto the construction area. The foundations of the new facilities are sound, but they can be damaged or overwhelmed by advancing soil, rock, and debris moving downslope.

The last major way that people cause slope failures is by changing the drainage or moisture conditions of a slope. Careless placement or maintenance of drains can allow water to enter a slide-prone area, but more subtle actions can also have an effect. Cutting a road across a slope may intercept surface drainage and lead it to a new area, or the roadcut may block groundwater flow and cause a water buildup. Water lines, sewers, and drains may function well when they are new, but over time, soil creep and normal settling can cause leaks and low places that collect moisture. Trees and other plants remove a tremendous amount of water from the soil during the growing season. Clearing a forested slope may lead to the presence of moisture and loss of soil strength that tree roots had been contributing to the soil.

Since the time that people started building roads and excavating for foundations in Pennsylvania, geologic conditions have changed very little, but technology has changed considerably. Large excavating machinery has been developed that can take massive slices from hills and mountains. We regularly regrade areas for housing and business development, and highway cuts and fills of enormous scale allow us to build in areas that would have been unthinkable with the hand- and horse-operated equipment of the 1800s, or even the power equipment of the mid-1900s. Before this ability to move mountains, man-induced landslides were not as great a problem as they are today, because development usually conformed to the existing topography. In most areas, the first settlement used the easy-to-develop land, and later growth was forced to the less desirable sites. Continuing growth will lead to an even greater need to address landslide hazards in planning and construction in many areas of Pennsylvania.

EFFECTS AND COSTS OF LANDSLIDES

No one really knows how many landslides occur each year in Pennsylvania or how much damage they cause. There is no formal reporting system, but a few efforts have been made to determine totals. In a 1986 study, more than 700 recent and active landslides in Allegheny County were identified. U.S. Geological Survey (USGS) landslide-inventory maps indicated thousands of landslides in Allegheny and Washington Counties. A 1991 list from the Pennsylvania Department of Transportation (PennDOT) showed that there were 226 problem landslides in Allegheny County, 45 in Beaver County, 77 in Armstrong County, and 26 in Tioga County. A USGS landslide-inventory map showed more than 1,200 recent and 900 old slides on one 7.5-minute quadrangle map in Greene County. A study by the Pennsylvania Geological Survey included the identification of 480 recent and active landslides and nearly 1,000 of old or unknown age in the Williamsport 1- by 2-degree map area in north-central Pennsylvania.

Landslides cause damage to transportation routes, utilities, and buildings and create travel delays and other side effects. Fortunately, deaths and injuries due to landslides in Pennsylvania are rare. Almost all of the known deaths due to landslides have occurred when rockfalls or other landslides along highways have involved vehicles. Storm-induced debris flows are the only other type of landslide likely to cause death and injuries. Most Pennsylvania landslides are moderate to slow moving and damage things rather than people.

One small landslide in 1990 that involved a broken petroleum pipeline is an extreme example of the costs of related damages. Spilled petroleum products entered a major river, causing city water systems to shut down. Identified costs of repair of the landslide damage, cleanup of the spill, technical investigations, legal and court costs, and environmental fines were approximately $12 million. Incalculable costs included the loss of productivity while people stayed at home because of closed businesses or to care for children normally in schools that had been closed due to lack of a water supply, costs for the National Guard to deliver water to neighborhoods, costs to the pipeline company and its customers due to business loss for several months. Although this example is extreme, “associated damages” such as this occur with many landslides.

Most damages are less expensive, but significant. “Backyard” landslides, common in the Pittsburgh area, are usually repaired incompletely or not at all. Cost estimates of several hundred thousand dollars for stabilization and repair of a landslide affecting two or three properties are typical. With repair estimates exceeding the value of the properties, abandonment is a frequent “solution.” Homeowners’ insurance usually does not cover landslide damage, although insurance may cover some business situations.

The state transportation department and large municipalities have substantial costs due to landslide damage and to extra construction costs for new roads in known landslide-prone areas. One PennDOT estimate in 1991 showed an average of $10 million per year in landslide-repair contracts across the state and a similar amount in mitigation costs in grading projects. A number of highway sites in Pennsylvania are in need of “permanent” repair at estimated costs of $300,000 to $2 million each.

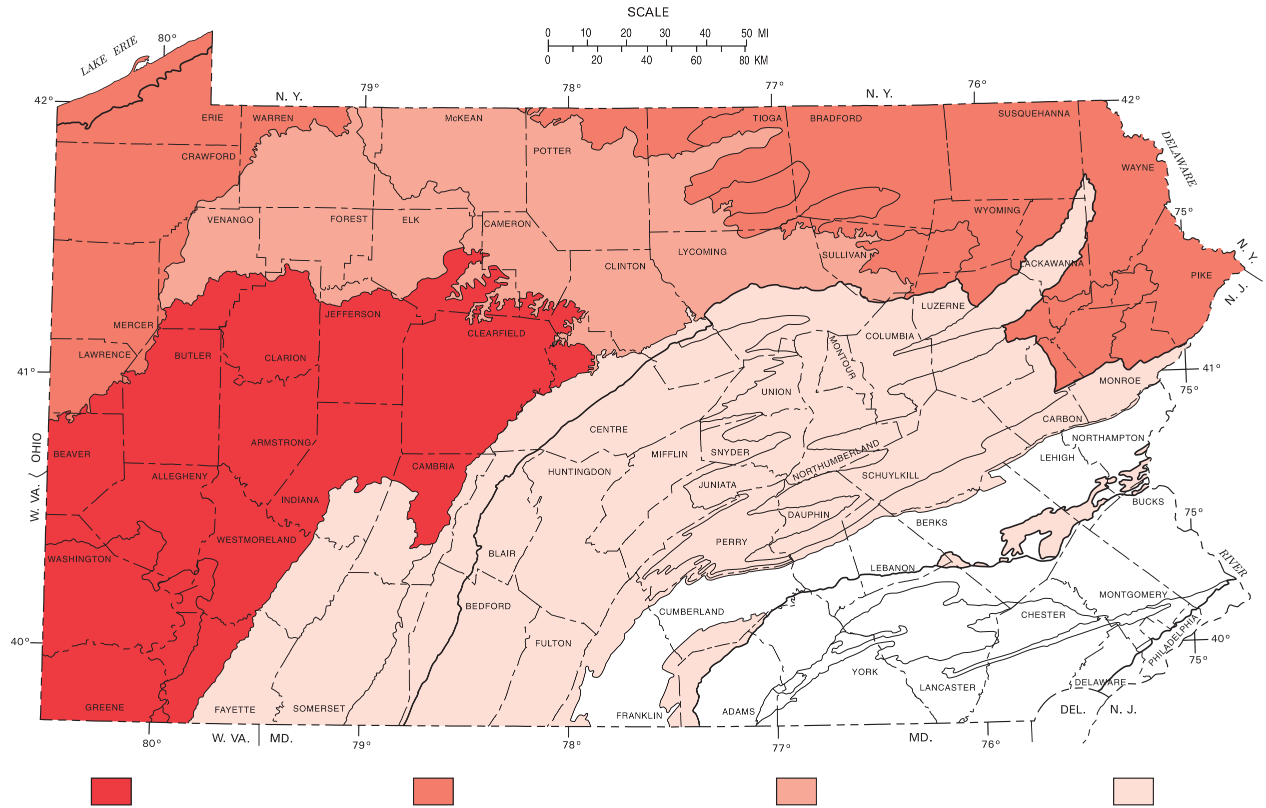
A USGS study found that total public and private costs of landsliding in Allegheny County averaged at least $4 million per year from 1970 to 1976. Information about estimating landslide costs was collected in 2003 as part of another USGS-funded project. It was found that documented minimum costs for Allegheny County for 2001 and 2002 together were $3 million in public costs and $650,000 from private funds.

LANDSLIDE PREVENTION AND SOLUTIONS

The easiest way to avoid landslide hazards is to keep construction and development out of landslide-prone areas. This is not very realistic in the modern world, so the next best way is to be aware of the hazards and prepare for them. Safe construction in landslide areas is possible, but additional costs of detailed site investigation and design of specially engineered facilities can be high.

Recognizing the existence of the hazard is the most important step in controlling it. Once recognized, the hazard potential may be reduced by (1) limiting development in the highest hazard areas, and (2) requiring special construction practices in other areas. Maps showing generalized slide-prone areas are available for much of Pennsylvania (Figure 23). When a site is being considered for a project, a specific investigation of the site and surrounding area is necessary for construction design. Lack of knowledge about ground conditions at and near sites has resulted in many slope failures and has led to expensive repairs. Repairs of a construction-related landslide can cost many times more than the original project.

Before undertaking remedial measures, the cause of a slide must be understood. Efforts to stabilize a slide or slide-prone slope may involve a variety of approaches, as follows: (1) modification of drainage; (2) the building of a retaining structure at the toe, using a variety of materials; (3) partial removal of slide-prone material and replacement with more stable material; (4) total removal of slide material; or (5) a combination of these. Controlling surface and subsurface drainage is always an important part of slide prevention and stabilization. Drains may be installed around the head and sides of a potential slide to direct surface runoff away from the unstable area. Drains installed within the unstable material can help to dry it. Drainage is commonly combined with other methods to control unstable ground, the most common method of which is the support of the toe of the slope. Deeply embedded steel posts and heavy mesh fencing along the toe have been particularly effective at keeping rockslides and rockfalls from entering roadways and other areas. Periodic removal of material is important to keep these barriers acting effectively. Where landslides occur in otherwise stable ground that has been altered by construction, the control of mass movement is commonly easier to accomplish than it is in areas of naturally unstable ground. Where a natural geologic hazard exists, designing around it or leaving it undisturbed has given the best results.



Flat-lying or gently dipping clay-rich rocks, colluvial soils, and old landslides. Earthflows, debris flows, slumps, and rockslides common.	Flat-lying or gently dipping sedimentary rocks, thick glacial and colluvial soils. Slumps and debris flows in thick soils; debris avalanches and rockslides on steep slopes having thin soil.	Flat-lying sedimentary rocks, thin soil cover on steep slopes, some thick colluvial and glacial soils. Debris avalanches, debris flows, and debris slides; slumps in thick soils.	Folded sedimentary rocks and colluvial soil on slopes. Rockslides, debris slides, and debris avalanches; slumps on lower slopes and stream banks.

Figure 23. The distribution of types of landslides most likely to occur in different geologic settings in Pennsylvania. Stream-bank slumps, soil creep, and rockfall/rockslide combinations on cut slopes can occur throughout Pennsylvania. See Figure 1 for physiographic province and section names.

Even though careful engineering investigation goes into the design of most roads and the foundations of most structures, it is all too common for conditions in soil and rock to be different than what was planned for before construction began. Geologic investigation of sites before and during construction is a critical aspect of safe building in landslide-prone areas.

CONCLUSION

Landslides are a very significant geologic hazard throughout most of southwestern Pennsylvania and in certain other parts of the state. They are a moderate to minor problem in still other areas that have steep to moderate slopes. Some kinds of landslides (primarily riverbank slumps and construction-related slides) can occur in any area if local conditions are "right."

Deaths and injuries due to landslides are uncommon in Pennsylvania; however, the average annual direct and indirect cost of Pennsylvania landslides is easily in the tens of millions of dollars. As people continue to develop more land, landslides are likely to be a greater problem unless we work to prevent them. Education, awareness, and planning are the most valuable tools in preventing damage and injury from landslides. In many cases, problem areas can be anticipated and avoided. In other instances, appropriate engineering and construction measures can allow safe development in landslide areas, although usually at a greater economic cost. The extra costs of planning and construction modifications are much less than the potential losses to property and lives from landslides.

Some information (see below) is available to help identify potential landslide problem areas. A few local governments have adopted landslide consideration as part of their local zoning and building codes, based on this or similar information. This booklet and the references below are intended as general guides, and determinations about the stability of a particular site should always be made by someone qualified and knowledgeable about landslides and the local geology. Pennsylvania law requires that anyone practicing geology in the state be a Registered Professional Geologist.

Landslides, like other geologic hazards, are a natural phenomenon. They only become a problem when they interfere with human activities. An understanding of their occurrence and causes is the first step to living safely in landslide areas in Pennsylvania.

GLOSSARY

Bedrock. A general term for the solid rock that underlies soil or other unconsolidated, superficial material.

Bedding plane. The surface separating individual layers in sedimentary rocks.

Colluvium. Weathered material that has been transported downslope by gravity.

Desiccation. Drying up or dehydration. In soils, desiccation commonly causes cracks to develop.

Dip. The angle that a rock surface makes with the horizontal.

Joint. A surface of fracture or parting in a rock other than a bedding plane.

Permeability. The ability of a material to allow fluid to pass through it.

Scarp. A cliff or steep face produced by differential movement of adjacent blocks along a slide plane.

Talus. Rock fragments of any size or shape derived from and lying at the base of a cliff or very steep, rocky slope.

Trigger. Immediate or final cause, as distinct from other contributing causes.

Unconsolidated material. Loose material that is not cemented, compacted, or otherwise made into rock.

Weathering. The breakdown of rocks and minerals by physical and chemical processes near the earth's surface.

MORE INFORMATION ON LANDSLIDES[1]

Web Sites

Kansas Geological Survey—*Landslides in Kansas*
www.kgs.ku.edu/Publications/pic13/pic13_1.html

Ohio Geological Survey—*Landslides in Ohio*
www.ohiodnr.com/geosurvey/geo_fact/geo_f08.htm

U.S. Geological Survey
landslides.usgs.gov/index.html

West Virginia Geological Survey—*Homeowner's Guide to Geologic Hazards*
www.wvgs.wvnet.edu/www/geohaz/geohaz3.htm

[1]Web addresses are subject to change.

Books and Other Publications

If your local library does not have these, it can obtain them through interlibrary loan from a larger public or university library.

General information on landslides (Ordering information for the first two books can be found at www.aipg.org.)

Creath, W. B., 1996, Homebuyers' guide to geologic hazards: Westminster, Colo., American Institute of Professional Geologists, 30 p.

Nuhfer, E. B., Proctor, R. J., and Moser, P. H., 1993, Citizens' guide to geologic hazards: Westminster, Colo., American Institute of Professional Geologists, 134 p.

Spiker, E. C., and Gori, P. L., 2000, National landslide hazards mitigation strategy—A framework for loss reduction: U.S. Geological Survey Open-File Report 00–450, 49 p.

Turner, A. K., and Schuster, R. L., eds., 1996, Landslides—investigation and mitigation: Washington, D. C., National Academy Press, Transportation Research Board Special Report 247, 673 p.

Varnes, D. J., 1958, Landslide types and processes, *in* Eckel, E. B., ed., Landslides in engineering practice: National Research Council, Highway Research Board Special Report 29, p. 20–47.

Maps of 1- by 2-degree quadrangles as shown in Figure 24 (Letters following each reference correspond to those in the figure.)

Davies, W. E., Olmacher, G. C., and Pomeroy, J. S., 1978, Landslides and related features, Ohio, West Virginia, and Pennsylvania—Canton 1 by 2 degree sheet: U.S. Geological Survey Open-File Report 78–1057, 118 maps. [D]

Delano, H. L., and Wilshusen, J. P., 1999, Landslide susceptibility in the Williamsport 1- by 2-degree quadrangle, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Environmental Geology Report 9, 192 p. [A]

Hackman, R. J., and Thomas, R. E., 1978, Landslides and related features, Ohio, West Virginia, and Pennsylvania—Clarksburg 1 degree by 2 degree sheet: U.S. Geological Survey Open-File Report 78–1056, 128 maps. [E]

Pomeroy, J. S., 1981, Landslides and related features, Pennsylvania—Warren 1 degree by 2 degree sheet: U.S. Geological Survey Open-File Report 81–238, 112 maps. [B]

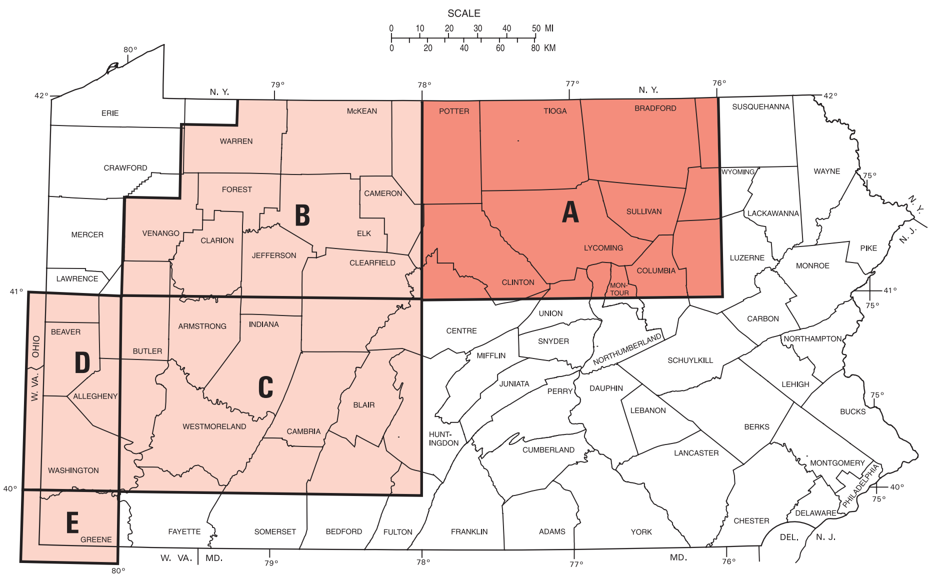


Figure 24. The darker color shows the area for which a landslide-susceptibility map was prepared by the Pennsylvania Geological Survey; the lighter color shows areas for which landslide-inventory maps were prepared by the U.S. Geological Survey. Letters correspond to references listed on the previous page and below.

Pomeroy, J. S., and Davies, W. E., 1979, Landslides and related features, Pennsylvania—Pittsburgh 1 degree by 2 degree sheet: U.S. Geological Survey Open-File Report 79–1314, 128 maps. [C]

Other maps and reports that have information about landslides in Pennsylvania

Briggs, R. P., 1974, Map of overdip slopes that can affect landsliding in Allegheny County, Pennsylvania: U.S. Geological Survey, Miscellaneous Field Studies Map MF–543, scale 1:125,000.

Briggs, R. P., Pomeroy, J. S., and Davies, W. E., 1975, Landsliding in Allegheny County, Pennsylvania: U. S. Geological Survey Circular 728,18 p.

Highland, L. M., ed., 2006, Estimating landslide losses—preliminary results of a seven-state pilot project: U.S. Geological Survey Open-File Report 2006–1032, 11 p., pubs.usgs.gov/of/2006/1032/.

Kohl, W. R., 1976, Map of overdip slopes that can affect landsliding in Armstrong County, Pennsylvania: U.S. Geological Survey, Miscellaneous Field Studies Map MF–730, scale 1:125,000.

Pomeroy, J. S., 1978, Map showing landslides and areas most susceptible to landsliding, Butler County, Pennsylvania: U.S. Geological Survey, Miscellaneous Field Studies Map MF–1024, 2 sheets, scale 1:50,000.

________ 1980, Storm-induced debris avalanching and related phenomena in the Johnstown area, Pennsylvania, with references to other studies in the Appalachians: U.S. Geological Survey Professional Paper 1191, 24 p.

________ 1982, Landslides in the Greater Pittsburgh region, Pennsylvania: U.S. Geological Survey Professional Paper 1229, 48 p.

________ 1982, Mass movement in two selected areas of western Washington County, Pennsylvania: U.S. Geological Survey Professional Paper 1170–B, 17 p.

________ 1986, Map showing slope movements in the Oak Forest quadrangle, Greene County, southwestern Pennsylvania; U.S. Geological Survey Miscellaneous Field Studies Map MF–1794, scale 1:24,000.

________ 1986, Slope movements in the Warren-Allegheny Reservoir area, northwestern Pennsylvania: U.S. Geological Survey, Bulletin 1650, scale 1:50,000.

Pomeroy, J. S., and Davies, W. E., 1975, Map of susceptibility to landsliding, Allegheny County, Pennsylvania: U.S. Geological Survey Miscellaneous Field Studies Map MF–685B, 2 sheets, scale 1:50,000.

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