MAP OF OVERDIP SLOPES THAT CAN AFFECT LANDSLIDING IN ARMSTRONG COUNTY, PENNSYLVANIA

By
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EXPLANATION

Area in which rock layers dip less than 40 feet per mile

Overdip slopes in which rock layers dip 40 to 100 feet per mile

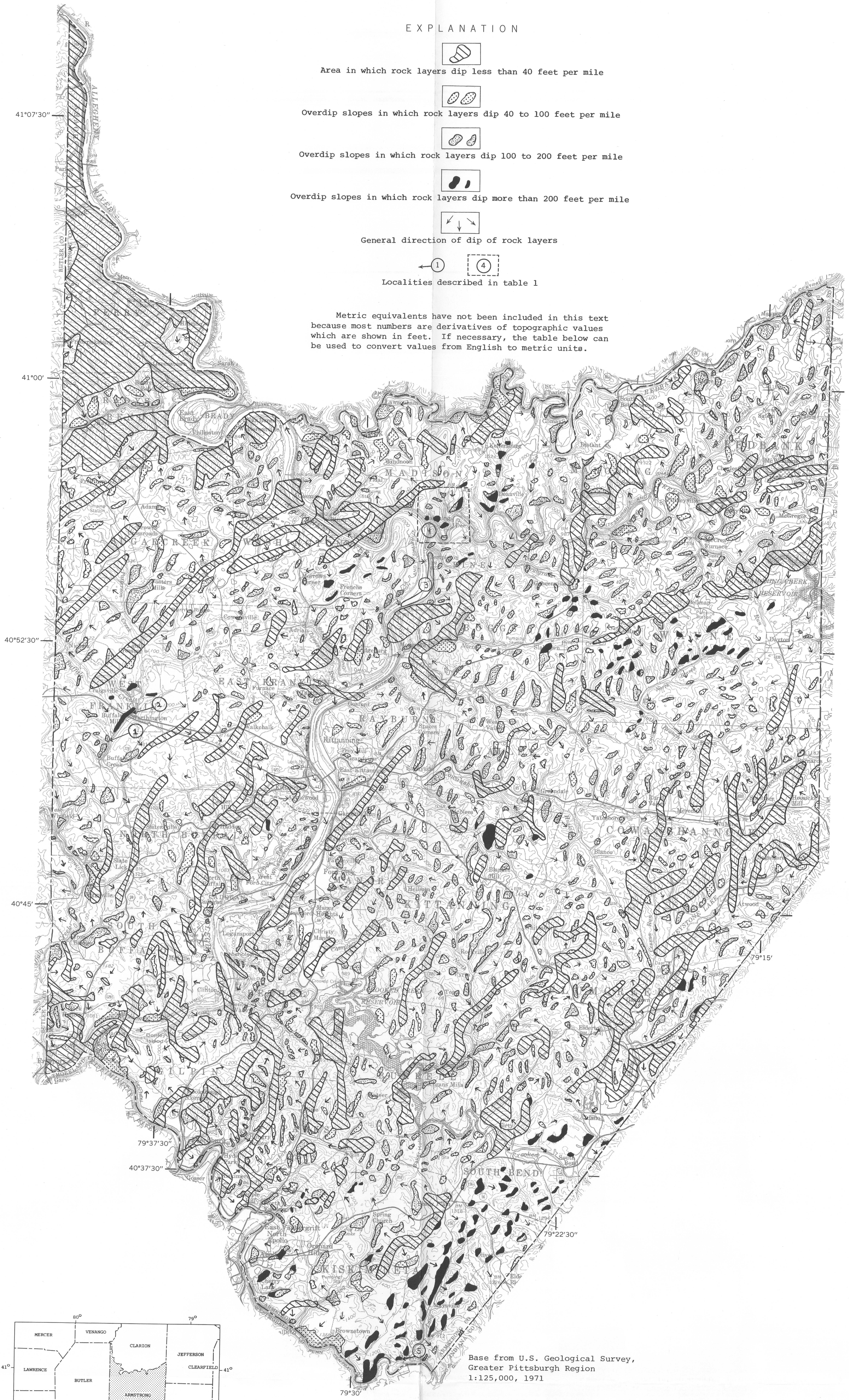
Overdip slopes in which rock layers dip 100 to 200 feet per mile

Overdip slopes in which rock layers dip more than 200 feet per mile

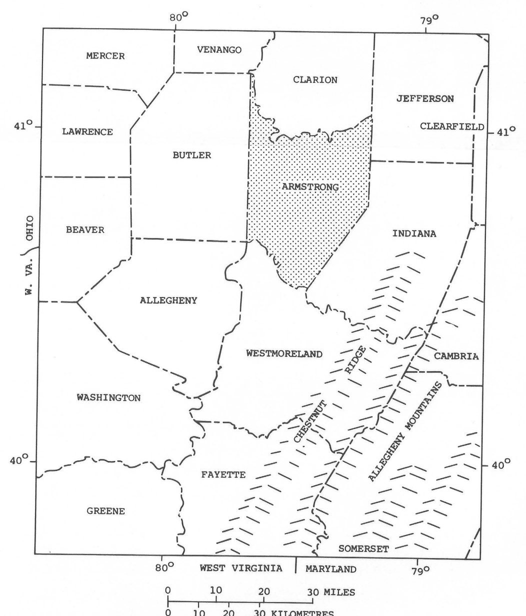
General direction of dip of rock layers

Localities described in table 1

Metric equivalents have not been included in this text because most numbers are derivatives of topographic values which are shown in feet. If necessary, the table below can be used to convert values from English to metric units.



Base from U.S. Geological Survey, Greater Pittsburgh Region 1:125,000, 1971



Index map of southwestern Pennsylvania showing location of Armstrong County

Multiply	By	To obtain
millimetres	0.03937	inches
inches	25.4	millimetres
inches	2.54	centimetres
feet	30.48	centimetres
feet	0.3048	metres
miles	1.609	kilometres
feet per mile	0.189	metres per kilometres
feet per mile	0.0189	percent of grade or metres per hectometre

SCALE 1:125 000

5 4 3 2 1 0 5 MILES

5 4 3 2 1 0 5 10 KILOMETRES

CONTOUR INTERVAL 100 FEET
DATUM IS MEAN SEA LEVEL

INTRODUCTION

Armstrong County is in west-central Pennsylvania and is a part of the Appalachian Plateaus Province of the Appalachian Highlands. It is characterized by rough terrain with steep-sided narrow valleys and broader intervening ridges that have nearly concordant summits and relatively few level surfaces. Streams and rivers may flow at levels as much as 600 feet or more below adjacent ridge crests, and flood plains of this area are mostly narrow strips along the Allegheny River and some of its tributaries. Bedrock is chiefly shale, claystone, siltstone, sandstone, limestone, and coal. The oldest rocks are the Pocono Group of Mississippian age which are overlain in succession by the Pottsville, Allegheny, Conemaugh, and Monongahela Groups of Pennsylvanian age. The rock layers have a slight regional dip to the southwest modified by gentle anticlines and synclines (fig. 1) that trend northeast. Bedrock locally is concealed by Pleistocene and Holocene valley-bottom and terrace alluvium composed of clay, silt, sand, and gravel.

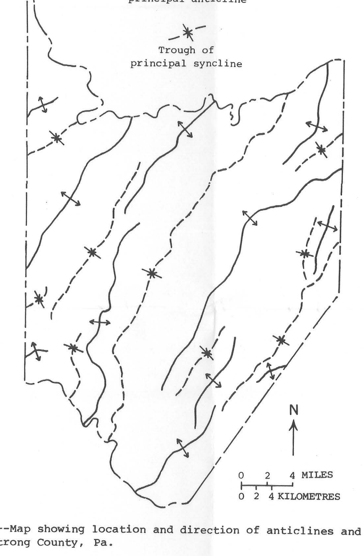


Figure 1.--Map showing location and direction of anticlines and synclines in Armstrong County, Pa.

In Armstrong County, topographic, geologic, and climatic factors combine to make many slopes susceptible to some degree of landsliding. Most slopes are in a state of equilibrium with the natural processes, chiefly stream erosion and soil creep, that shaped them. Areas of steep natural slopes often reflect hard weather-resistant underlying rocks, whereas weaker rocks tend to weather faster and form more gentle slopes. Landslides on natural slopes thus are infrequent and those that occur usually are caused by extreme conditions such as the heavy rains of tropical storm Agnes during June 1972. A state of equilibrium will continue on most slopes if they remain undisturbed by man. Undercutting, overloading, or change in the ground-water regime of susceptible slopes can and frequently does activate landslides which often occur during construction of roads and railroads, removal of forest and vegetation, and extraction of minerals. In brief, landslides are relatively rare on natural slopes, but are common on slopes that have been extensively modified by man.

Landslides caused by man in Armstrong County are relatively infrequent compared to those in the more highly urbanized Allegheny County just to the southwest. This reflects differences in population, population density, and resulting intensity of land use. According to the 1970 Census, the 652 square miles of Armstrong County contained 75,590 people with a density of 115.9 per square mile. In contrast, 1970 figures for Allegheny County are 728 square miles, 1,605,133 people, and 2,205.1 per square mile. Sixty percent of Allegheny County is urbanized. In Armstrong County 8 percent of the land is used for residential, commercial, and industrial purposes (including mineral extraction); 37 percent is for farming; 3 percent is public land and large bodies of water; and 52 percent of the land is unused. If this low intensity of land use in Armstrong County continues, areas susceptible to landsliding will not be widely modified, and the low incidence of landsliding will persist. However, a population increase of about 28,000 is projected for 1990, which implies accelerated land development. Such development could increase the incidence of landslides.

Landslide susceptibility is dependent on a number of factors. The overdip-slope map combines two of these, the attitude of rock layers and steepness of hill slopes. For a more accurate determination of susceptibility to landsliding, the overdip-slope map should be combined with maps showing other factors, which can be equally or, locally, more important. These factors are reviewed at the end of the text. Data on slopes, rock attitudes, and agricultural soils are available countywide. Detailed data on distribution of rock types, density and orientation of rock fractures, thickness of soils, and permeability of rocks are incomplete or lacking in this area. Briggs (1973) has provided a guide to geologic maps of the region. At some places data can be acquired with relative ease by onsite field investigations.

DEFINITIONS

Anticline--A fold, the core of which contains the stratigraphically older rocks; it is convex upward.

Attitude--The strike and dip of a structural surface. If a rock layer is horizontal, then its attitude is horizontal; it has no strike direction and its dip is zero.

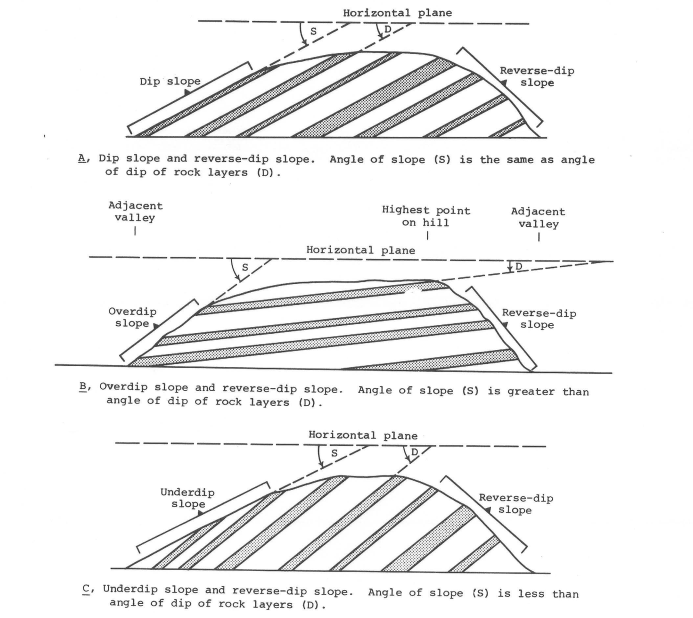
Dip--The angle that a structural surface, for example, a bedding [layering] or fault plane, makes with the horizontal, measured perpendicular to the strike of the structure. In this report, dip refers exclusively to the angle at which rock layers diverge from the horizontal.

Dip slope--A slope of the land surface, roughly determined by and approximately conforming with the direction and the angle of dip of the underlying rocks. Dip slope is a common geological term from which "overdip slope" and other modifications are derived (fig. 2A).

Overdip slope--An overdip slope is defined as a land surface sloping in approximately the same direction as, but *more steeply* than, the dip of the rock layers that crop out on that surface (fig. 2B).

Reverse-dip slope--A reverse-dip slope is defined as a land surface sloping in the opposite direction from the dip of the rock layers that crop out on that surface (figs. 2A, B, and C).

Underdip slope--An underdip slope is land sloping in approximately the same direction but more gently than the dip of the rock layers that crop out on that surface (fig. 2C).



A, Dip slope and reverse-dip slope. Angle of slope (S) is the same as angle of dip of rock layers (D).

B, Overdip slope and reverse-dip slope. Angle of slope (S) is greater than angle of dip of rock layers (D).

C, Underdip slope and reverse-dip slope. Angle of slope (S) is less than angle of dip of rock layers (D).

Figure 2.--Cross sections through a hill illustrating slope types (from Briggs, 1974).

Strike--The direction or trend that a structural surface, for example, a bedding or fault plane, takes as it intersects the horizontal. The strike is always at right angles to the direction of dip.

Syncline--A concave fold in layered rocks in which the beds on both sides dip downward toward the center. In cross section, rock layers of a tightly folded syncline would appear as the letter U.

OVERDIP SLOPE MAP

In Armstrong County, rock layers on the flanks of anticlines and synclines commonly range in dip from 40 feet per mile to greater than 200 feet per mile (about 4 percent grade). Areas where layers dip less than 40 feet per mile are in narrow zones along crests of anticlines and troughs of synclines, and in the northwest part of the county. Of the 70 percent of the county in which soil surveys were complete in 1970 (U.S. Department of Agriculture, 1970), almost half of the surface, about 204 square miles, was found to slope more than 15 percent. This combination of gentle dip of rock layers and relatively steep slopes results in widespread overdip and reverse-dip slopes. Dip slopes generally are gentle and occupy small areas and underdip slopes are relatively rare.

The overdip slope areas shown on the map have the following characteristics:

(1) Rock layers dip more than 40 feet per mile.
(2) The land surface is estimated to slope more than 15 percent.
(3) The direction in which the land surface slopes is within 45° of the direction in which the rock layers dip. For example, if the rock layers dip north, the slope of the land surface is in the northeast-north-northwest quadrant. If a land surface slopes west or east and the rock layers at that place dip north or south, there is no effective overdip slope.
(4) Topographic relief (the vertical distance from base to top of slope) is 100 feet or greater.
(5) Three overdip slope categories are differentiated on the basis of degree of dip of rock layers: 40 feet to 100 feet per mile; 100 feet to 200 feet per mile; and greater than 200 feet per mile.

Overdip slopes are not shown in areas where rock layers dip less than 40 feet per mile, because the data from which overdip-slopes were derived do not allow their accurate definition in such areas at the scale of the map.

EFFECTS OF OVERDIP SLOPES ON SUSCEPTIBILITY TO LANDSLIDING

The chief factor affecting downslope movement of rocks and soils is the force of gravity. Opposing gravity are the frictional and cohesive forces acting within the rock layers and soil, and the mechanical resistance provided by the slope. Dip, underdip, and reverse-dip slopes provide opposition to downslope movement (fig. 3) and are relatively stable unless undercut by rock weathering or by man.

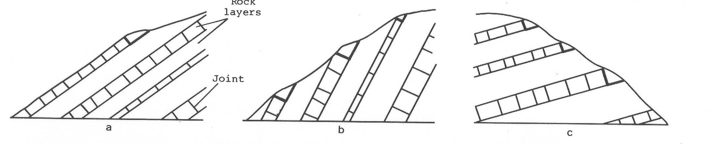


Figure 3.--Cross sections through dip (a), underdip (b), and reverse-dip (c) slopes illustrating mechanical opposition to downslope movement. Blocks of jointed hard rock are nested in V-shaped shelves (heavy lines) (from Briggs, 1974).

On the east side of the Allegheny River from Lock and Dam No. 8 to Templeton (map locality 3, table 1), steep natural slopes exist because of the nesting effect in a reverse-dip slope.

Overdip slopes do not offer such mechanical resistance to downslope movement, therefore susceptibility to landsliding increases (fig. 4). At Buffalo Mills (map locality 2), the mouth of Mahoning Creek (map locality 4), and near Avonmore (map locality 5), rock layers in overdip slopes dip more than 200 feet per mile (table 1). These slopes are prone to rock fall and other landsliding.

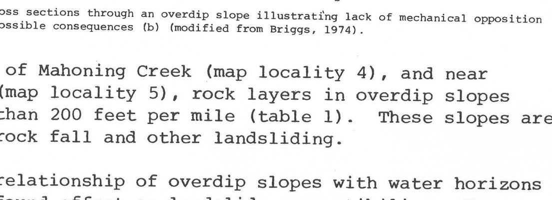


Figure 4.--Cross sections through an overdip slope illustrating lack of mechanical opposition (a), and possible consequences (b) (modified from Briggs, 1974).

The relationship of overdip slopes with water horizons has a profound effect on landslide susceptibility. Water can affect downslope movement in 4 ways:

(1) It is the primary agent during chemical weathering in weakening intergranular bonds in rocks and soils, resulting in decrease of cohesion.
(2) Water is the required raw material for frost wedging in rocks and soils during the freeze and thaw cycle of winter. This is a significant factor in temperate-zone rock decomposition and downslope movement.
(3) Water which enters the ground beneath a slope displaces air in voids decreasing surface tension and cohesion. With saturation there is an increase in the pore-water pressure and shearing resistance is further diminished. The effect is that of lubrication.
(4) Largely clay soils absorb water, adding to their weight and often expanding somewhat.

Table 1.--Localities of well-exposed features

Locality No.	Location	Feature	Stratigraphic Unit
1.	One mile south of Buffalo Mills on west side of Buffalo Creek	Spring in overdip slope where rock layers dip between 100 and 200 ft per mile.	Vanport Limestone Allegheny Group
2.	West side of Buffalo Creek at Buffalo Mills	Overdip slope in which rock layers dip more than 200 ft per mile. Rock fall hazard present.	Clarion Formation of Allegheny Group
3.	On east side of Allegheny River from Lock and Dam No. 8 to Templeton	Steep, relatively stable reverse-dip slopes in which dip of rock layers ranges from 40 to more than 100 ft per mile.	Clarion, Kittanning, and Freeport Formations of Allegheny Group, and Glenshaw Formation of Conemaugh Group
4.	Confluence of Mahoning Creek with Allegheny River (figure 8)	(A) Active rock fall area on overdip slope in which rock layers dip more than 200 ft per mile. (B) Exposure is in effect a cross section of the reverse-dip slope just south of Mahoning. Rock layers dip about 200 ft per mile. (C) Stable reverse-dip slope in which rock layers dip between 100 and 200 ft per mile.	(A) Clarion Formation of Allegheny Group (B) Pottsville Group and Clarion Formation of Allegheny Group (C) Clarion and Kittanning Formations of Allegheny Group
5.	West side of Long Run about 1/4 mile north of Avonmore	Area in which rock layers dip more than 200 ft per mile. Some rock fall hazard.	Glenshaw Formation of Conemaugh Group

In Armstrong County springs, seeps, and wet ground are common on overdip slopes [for example, along the west side of Buffalo Creek at Buffalo Mills (map locality 1, table 1)], but are less prevalent on other hill slopes and relatively rare on reverse-dip slopes. This preferred location of ground-water discharge reflects the attitude and permeability of the rock layers. Some rock layers (chiefly sandstone and limestone) are more permeable than others (siltstone and shale) and are important controls of relatively shallow ground-water movement. Permeability and attitude of rock layers combine to direct water downslope to the outcrop of more permeable layers on overdip slopes (fig. 5). The result of discharge from rock layers on overdip slopes is clearly visible in the winter when large amounts of ice accumulate on overdip roadcuts and outcrops.

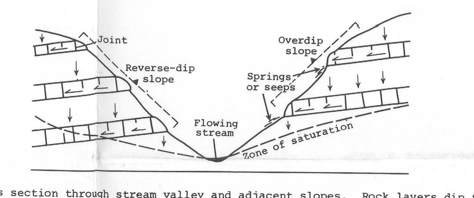


Figure 5.--Cross section through stream valley and adjacent slopes. Rock layers dip to left. Half arrows indicate probable directions of ground-water movement in more permeable layers. Short vertical arrows indicate slow percolation of ground water downward through less permeable and probably unsaturated layers. Dashed line is ground-water table below which regional topographic configuration and other factors are more important controls of ground-water movement than rock layering and attitude (from Briggs, 1974).

In contrast, relatively little ice accumulates on reverse-dip slopes. Discharge on reverse-dip slopes can occur, however, when enough head is developed in water tables perched above less permeable semiconfining layers during periods of prolonged and heavy precipitation.

Excavation by man on overdip slopes (fig. 6) can increase landslide and rock fall susceptibility, and overdip slopes can result from excavation in slopes that are not natural overdip slopes (fig. 7).

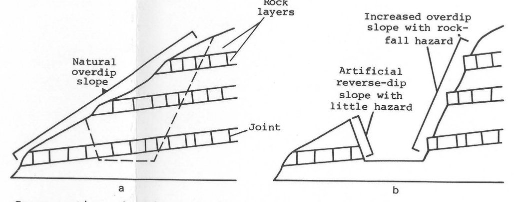


Figure 6.--Cross sections through an overdip slope illustrating natural slope and dashed outline of area to be excavated (a) and post-excavation condition with resulting increased overdip slope on right and manmade reverse-dip slope on left (b) (from Briggs, 1974).

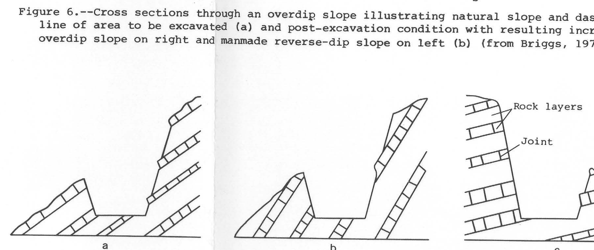


Figure 7.--Cross sections through dip slope (a), underdip slope (b), and reverse-dip slope (c) illustrating conditions following excavation. In all three examples, a manmade overdip slope has been created on the right side (from Briggs, 1974).

Other uses of map--The overdip-slope map, while designed to point out areas susceptible to landsliding can also be used as a guide for determining potential icing conditions along highways, for finding springs or shallow ground-water supplies, and for defining possible discharge areas from septic tanks, strip mines, and underground mine workings.

REVIEW OF FACTORS AFFECTING LANDSLIDE SUSCEPTIBILITY

Significant factors bearing on landslide susceptibility in Armstrong County include: (1) rock types, (2) rock layering, (3) rock fracturing, (4) attitude of rock layers, (5) composition and thickness of soil cover, (6) permeability of rocks and soils, and (7) steepness of slopes. All of these factors are interrelated. At a given place one factor may control landslide susceptibility, whereas at another place the same factor may be relatively unimportant.

(1) *Rock types*--Outcropping rocks are largely sandstone, siltstone, shale, and limestone. Coal, though only a relatively small part of the total rock volume, is widespread. Sandstone and limestone commonly are harder, more resistant to weathering, and tend to crop out on many slopes as ledges and cliffs. Siltstone and shale are softer, less resistant to weathering and usually are poorly exposed.

(2) *Rock layers*--Layers commonly are 1 to 5 feet thick, but thickness ranges from less than 1 inch to greater than 30 feet in places. Some rock layers are continuous over a number of miles, but most sandstone layers, for example, probably grade laterally into another rock type in shorter distances.

(3) *Rock fractures*--Faults are fractures along which rocks on one side are offset from rocks on the other side. Faults are relatively rare in Armstrong County. Joints are fractures that can be tight or open and along which little or no evidence of movement can be seen. The harder rock layers, sandstone and limestone, are well jointed in outcrop with joints commonly 1 to 10 feet apart. Joints in siltstone and shales range from a few inches to more than 10 feet apart, but are chiefly tight rather than open. Most joints are more or less perpendicular to the plane of rock layering. Joints contribute to landslide susceptibility by providing planes of weakness along which rocks tend to fail (fig. 4), and are also an important factor in rock permeability (fig. 5).

(4) *Attitude of rock layering*--In southwestern Pennsylvania, west of Chestnut Ridge (index map), rock attitude is most critical to landsliding on overdip slopes. Most rock layers dip at such small angles that their attitudes can best be measured in feet per mile rather than in degrees or in percent grade. In some areas, layers dip more than 200 feet per mile (about 2°, or 4 percent grade), but most layers have gentler dips and locally are horizontal. In contrast, from Chestnut Ridge eastward into the Allegheny Mountains (index map), dips of as much as 20° (about 37 percent grade, or 1,900 feet per mile) are common.

(5) *Soil cover*--Soils are composed chiefly of fine-grained mineral constituents derived from rock decomposition during weathering. For engineering and geological purposes, soil applies not only to materials resulting from rock weathering in place, but also to masses of fragmented and decomposed rock particles that have been transported and redeposited elsewhere. Colluvial soils are those transported by gravity, soil creep, frost action or local wash, and alluvium is deposited by a flowing stream of water. Both can be subject to landsliding.

In Armstrong County, soils of the hilltops are relatively thin, less than 6 feet thick in many areas. Soils of hill slopes are absent where bedrock crops out, are relatively thin on many upper slopes, and are made up of more than 20 feet of colluvium near and at the base of many slopes. Valley-bottom soils generally have nearly flat surfaces and are not a significant factor in most landsliding.

Most soils contain a large proportion of silt and clay; some soils are composed entirely of clay; and others are relatively coarse grained, containing large proportions of sand and rock fragments. The composition of a soil reflects the composition of the rock from which the soil was derived. Most soils are loose to moderately cohesive. They will not stand long on steep slopes, and are subject to landsliding if affected by undercutting, overloading, or other processes. Clayey soils are usually friable when dry and relatively low in weight per unit volume. When wetted, they absorb water and so become heavy and plastic; depending on their mineral composition, they may expand and become very slippery.

(6) *Permeability of rocks and soils*--Permeability as used here is the capacity of bedrock and soil to transmit water. Sandstone in southwestern Pennsylvania is often moderately permeable; water may pass around grains of sand through intergrain voids in many of these rocks. In addition, sandstone layers may have closely spaced joints that facilitate passage of water. Solid unfractured limestone is more or less impermeable, but most limestone layers are permeable because they are closely jointed, and these joints commonly are enlarged by solution and removal of minerals by moving ground water. In contrast, siltstone and shale are fine grained, inherently less permeable than most coarser grained rocks, and joints in siltstone and shale layers commonly are relatively tight. Thus, sandstone and limestone layers in Armstrong County are more likely avenues for movement of ground water than are siltstone and shale layers. Similarly, most sandy and rocky soils are appreciably more permeable than are soils composed largely or entirely of clay.

Because water is a key agent in susceptibility to landsliding, permeability of rocks and soils, or the relative lack of it, is of particular importance.

(7) *Steepness of slopes*--Almost half of the land surface in Armstrong County slopes more than 15 percent (about 8 1/2°), and this large incidence of steep natural slopes is a leading factor in the prevalence of landslides.

SOURCES OF DATA

The overdip slope map was prepared by combining the attitudes of rock layering shown on the structure contour map of the Greater Pittsburgh region (Wagner and others, 1975) and the slopes and relief shown on the regional topographic map (U.S. Geological Survey, 1:125,000, Greater Pittsburgh Region, 1971). Additional data on slope and relief was from 7 1/2-minute quadrangle topographic maps at the scale of 1:24,000. The dip slope definition is from Bryan (1922, p. 87). Landslide terminology is from Sharpe (1938).

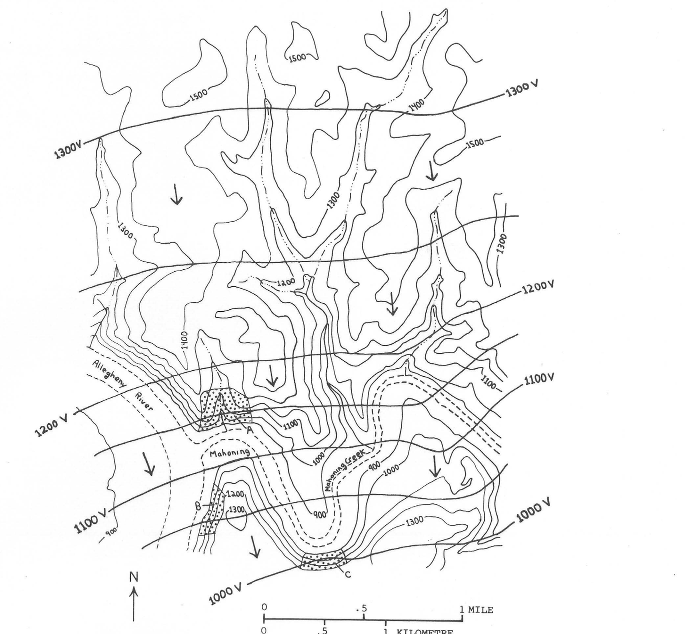


Figure 8.--Enlargement of the confluence of Mahoning Creek and the Allegheny River (table 1, locality 4), showing generalized topography (contour interval, 100 feet) and geologic structure (datum, top of Vanport Limestone; contour interval, 50 feet). Arrows indicate direction of dip of rock layers. Patterned areas A, B, and C are described in table 1, locality 4. Note influence of structure on stream alinement on the north side of Mahoning Creek (streams trend parallel to dip direction).

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