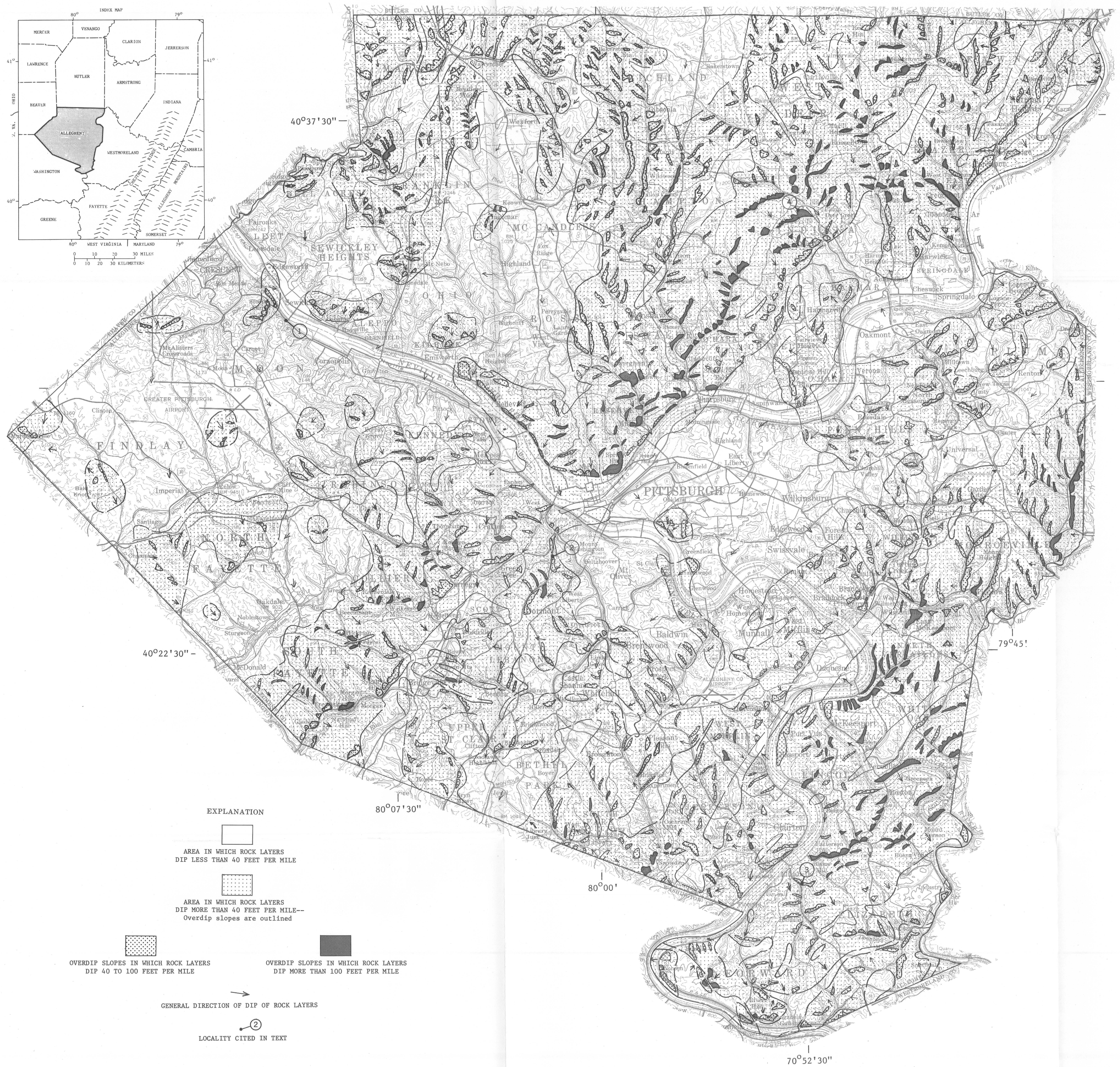


EXPLANATION

AREA IN WHICH ROCK LAYERS DIP LESS THAN 40 FEET PER MILE

AREA IN WHICH ROCK LAYERS DIP MORE THAN 40 FEET PER MILE--Overdip slopes are outlined

OVERDIP SLOPES IN WHICH ROCK LAYERS DIP 40 TO 100 FEET PER MILE

OVERDIP SLOPES IN WHICH ROCK LAYERS DIP MORE THAN 100 FEET PER MILE

GENERAL DIRECTION OF DIP OF ROCK LAYERS

LOCALITY CITED IN TEXT

Base from U.S. Geological Survey, 1:125,000, Greater Pittsburgh region, southwestern Pennsylvania, 1971

SCALE 1:125 000
5 4 3 2 1 0 5 MILES
5 4 3 2 1 0 10 KILOMETERS
CONTOUR INTERVAL 100 FEET
DATUM IS MEAN SEA LEVEL

INTRODUCTION

By the time that southwestern Pennsylvania was colonized, natural processes active for millions of years had shaped the land into a largely equilibrium condition. That is, most gentle slopes on valley sides were gentle because the rock and earth underlying the slopes would not support steeper gradients under natural conditions. And many relatively steep slopes were steep because they were underlain by harder and more durable rocks. It is likely that landslides were relatively infrequent events under these natural conditions and that stream erosion and soil creep were the chief processes acting to modify the landscape.

The equilibrium of many slopes is a tenuous thing, however, and is readily upset. In the course of settlement, forests largely were destroyed for fuel, construction materials, and agriculture, so that slopes no longer were stabilized by tree roots; water-infiltration and water-runoff characteristics were changed. Urbanization resulted in ill-advised location of buildings, rearrangement of earth materials, and armoring of surfaces by the addition of impervious road and building materials. Development of railroad and highway routes required cuts that oversteepened many slopes, and fills that remain prone to failure. Strip mining has created widespread similar effects. Mine waste dumps are subject to failure, and surface subsidence owing to underground mining also has affected slope stability.

The works of man have changed a region where failures of natural slopes probably were infrequent into one in which slope failures, at rates ranging from rapid to almost imperceptible, are common. No definitive inventories have been made, but by general consensus about 90 percent of the landslides in Allegheny County in recent years resulted from disturbance of slopes by man through undercutting or overloading, or from changing the ground-water regime, or from fills or waste dumps deposited by man. The remaining 10 percent were on virtually unmodified natural slopes; they resulted chiefly from oversteepening of slopes by stream erosion, from stress conditions such as those caused by the very heavy rains of tropical storm Agnes in June 1972, or from natural denudation of vegetation by fire or disease.

Few large landslides, those involving many thousands of cubic yards of earth and rock, have been recorded. Many relatively small landslides have taken place, some causing only minor damage or inconvenience, others damaging one or a few dwellings so that their abandonment became necessary. Although large landslides are a hazard at certain sites, on a county-wide basis the small landslide is the consistent hazard. Relatively few individual small landslides each cause thousands of dollars in damages, but if it were possible to identify and analyze all small landslides during the last decade, one might well find that the total costs for clean up, repair, and replacement amounted to millions of dollars.

A number of factors affect landslide susceptibility in Allegheny County. Two of these, the attitude of rock layers and the steepness of hill slopes, are combined to produce the overdip slope map. Other factors can be equally or locally more important in defining whether a given slope is landslide prone. The last part of the text treats the most significant factors briefly and systematically.

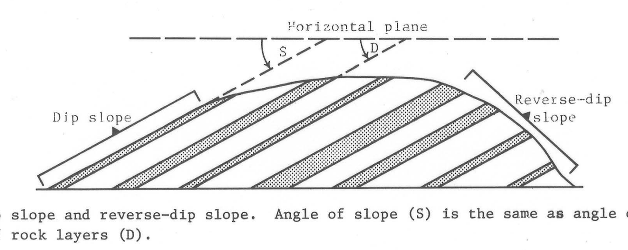
DEFINITIONS OF ATTITUDES AND SLOPES

DIP--"The angle that a structural surface, e.g. a bedding /layering/ or fault plane, makes with the horizontal, measured perpendicular to the strike of the structure."[1] In this report, dip refers exclusively to the angle at which rock layers diverge from the horizontal.

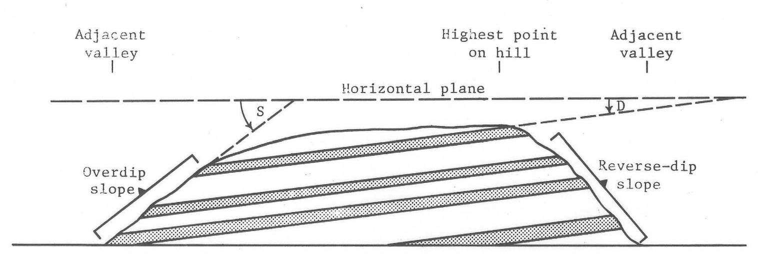
STRIKE--"The direction or trend that a structural surface, e.g. a bedding or fault plane, takes as it intersects the horizontal." The strike is always at right angles to the direction of dip.

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.

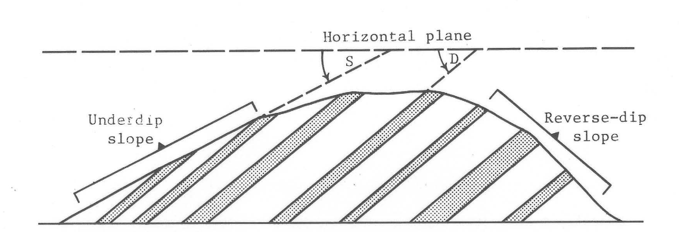
DIP SLOPE--A dip slope is "a slope of the land surface, roughly determined by and approximately conforming with the direction and the angle of dip of the underlying rocks."[1] Dip slope is a common geological term from which "overdip slope" and other modifications are derived. A dip slope is shown on figure 1A.



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 1.--Cross sections through a hill illustrating types of slope.

OVERDIP SLOPE--An overdip slope is here 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. An overdip slope is shown on figure 1B.

UNDERDIP SLOPE--An underdip slope is here defined as a land surface sloping in approximately the same direction but more gently than the dip of the rock layers that crop out on that surface. An underdip slope is shown on figure 1C.

REVERSE-DIP SLOPE--A reverse-dip slope is here defined as a land surface sloping in the opposite direction from the dip of the rock layers that crop out on that surface.[2] Reverse-dip slopes are shown on figures 1A-C.

OVERDIP SLOPE MAP

What the map shows.--In southwestern Pennsylvania west of Chestnut Ridge (see index map), layers of rock composed chiefly of sandstone, siltstone, shale, and limestone and subordinate coal and underclay are gently dipping. Dips of 40 ft per mile or more are quite common, but dips steeper than 200 ft per mile (about a 4 percent grade) are relatively rare. In comparison, most land surfaces slope at more than 4 percent, and valley sides commonly slope at 25 percent or more. Thus, in this area, dip slopes are very gentle and relatively common and underdip slopes are rare. Many slopes are overdip or reverse-dip slopes, but slopes in which rock layers are virtually horizontal or do not dip in the same or opposite direction as the slope of the land surface are also common.

The overdip slope areas shown on the map have the following characteristics:
(1) Rock layers dip more than 40 ft per mile.
(2) The land surface is estimated to have a greater than 15 percent grade (about 800 ft per mile).
(3) The direction in which the land surface slopes is within 45° of the direction in which rock layers dip. For example, if rock layers dip south, the slope of land surface is in the southwest-south-southeast quadrant. Further, 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 greater than 100 ft.

Overdip slopes in which rock layers dip more than 100 ft per mile are shown separately from those in the 40 to 100 ft per mile range. Overdip slopes where rock layers dip less than 40 ft per mile are not shown, because such very gentle dips cannot be defined accurately at the scale of the map on the basis of available information. Moreover, they are believed to be of relatively minor significance. Arrows show general directions of dip of rock strata.

Overdip slopes and landslide susceptibility.--Overdip slopes can contribute to landsliding in two principal ways.

The force of gravity is opposed along the dip of rock layering in slopes that are not overdip (fig. 2). In figure 2 blocks of jointed (fractured) hard rock are shown to be

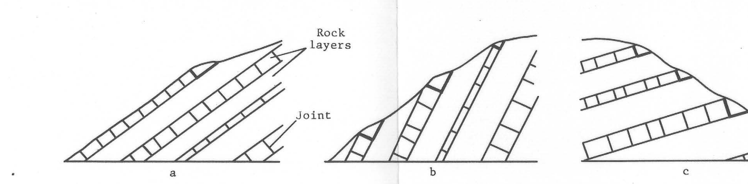


Figure 2.--Cross sections through dip (a), underdip (b), and reverse-dip (c) slopes illustrating nesting of blocks of hard rock. Blocks of jointed hard rock are nested in V-shaped shelves (heavy lines).

nested in V-shaped shelves. Unless undercut, these blocks cannot move down slope. On the south side of the Ohio River at the Sewickley Bridge (locality 1 on map) this nesting phenomenon is effective in preserving a slope. Here a very steep highway cut was excavated in a naturally steep reverse-dip slope. Even though the reverse dip is less than 40 ft per mile, the highway has not been threatened by significant rock falls or other failures.

No such mechanical opposition to down-slope movement is present on overdip slopes, as is shown in figure 3.

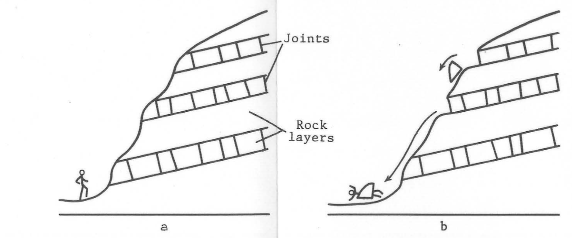


Figure 3.--Cross sections through an overdip slope illustrating lack of mechanical nesting (a), and possible consequences (b).

The other effect of overdip slopes on landslide susceptibility relates to water and, though less direct, probably is more critical than the first.

Springs, seeps, and wet ground are common on overdip slopes in Allegheny County, but are less prevalent on other hill slopes and are relatively rare on reverse-dip slopes. This preferential location of ground-water discharge on overdip slopes suggests that the attitude of rock layering and the fact that some rock layers (chiefly sandstone and limestone) are more permeable than others (siltstone and shale) are important controls of relatively shallow ground-water movement. They combine to direct water down gradient (in effect, down stream) to the outcrop of the more permeable layers on overdip slopes (see fig. 4).

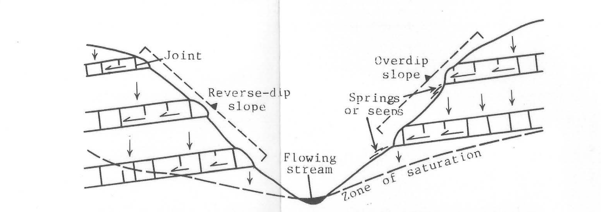


Figure 4.--Cross section through stream valley and adjacent slopes. Rock layers dip to left. Half arrows indicate probable directions of ground-water movement in more permeable layers. Short vertical arrows indicate slow percolation of ground water downward through less permeable and probably unsaturated layers. Dashed line is ground-water table, below which the regional topographic configuration and other factors are more important controls of ground-water movement than rock layering and attitude.

Enough head can develop in water tables perched above less permeable, semiconfining layers to cause discharge on reverse-dip slopes, particularly during periods of heavy and continuous precipitation. However, the magnitude of this discharge commonly is appreciably less than on overdip slopes. This is well illustrated in winter by striking ice accumulations on overdip-slope walls of many roadcuts excated along the strike of rock layering; on opposing reverse-dip-slope walls relatively little ice accumulates.

Water effects landslide susceptibility in three ways. In the freeze-and-thaw cycle of winter, water is the required raw material for frost wedging in rock and soil, a significant factor in temperate-zone rock decomposition and down-slope movement; in any season water is a lubricating fluid and weathering agent, either in the rock layers, in the zone where soil rests on rock, or in the soil itself; and if soils are largely clay and thus retain water, this water contributes added weight, which with lubrication can trigger down-slope movement of earth and rock.

A good example of down-slope movement on an overdip slope is on the east side of U.S. Hwy 19, Banksville Road, about 1.7 miles south-southwest of the Point in Pittsburgh (locality 2 on map). Here an earth and rock mass slowly encroaches on the highway. Material is removed from the toe of the mass periodically in order to keep the highway clear, with the effect that further movement in inevitable. Another example is a large active slope failure on the northeast side of Pa. Hwy 51, 0.6 mile southeast of the Monongahela River bridge at Elizabeth (locality 3 on map). Other factors doubtless also are active in both these cases, but it is probable that neither landslide would have started if the slopes present had not been overdip slopes.

The highest point on some hills is closer to the valley on the reverse-dip-slope side of the hill than to the valley on the overdip-slope side (fig. 1B). During general rains more than half the water falling on such hills will run off over or infiltrate the soil and rock of the overdip-slope side. A good example of this kind of asymmetrical ridge is between Shafers Run and Blue Run at Dorseyville (locality 4 on map), where rock layers dip more than 100 ft per mile to the southeast.

Excavations on overdip slopes can increase landslide hazards, especially as regards rock falls (fig. 5), and overdip slopes can result from excavations in land surfaces that are not natural overdip slopes (fig. 6).

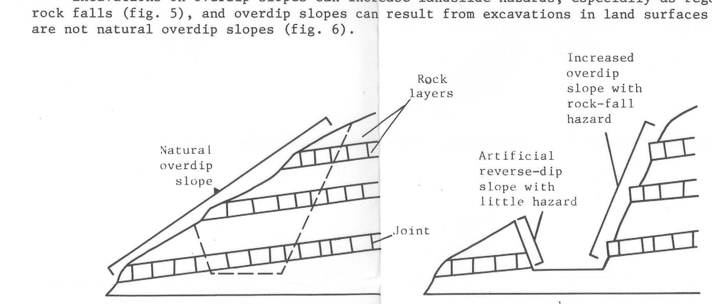


Figure 5.--Cross sections through an overdip slope illustrating natural slope and dashed outline of area to be excavated (a) and post-excavation condition with resulting increased overdip slope on right and manmade reverse-dip slope on left (b).

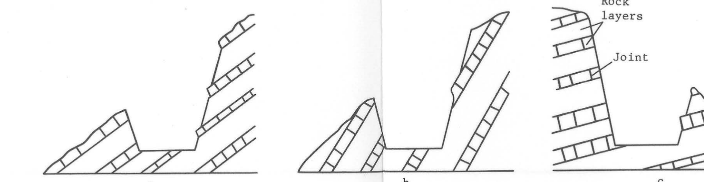


Figure 6.--Cross sections through dip (a), underdip (b), and reverse-dip (c) slopes illustrating conditions following excavation. In all three examples, a manmade overdip slope has been created on the right side.

Extrapolation from the map.--Overdip slopes combine only two of many factors bearing on landslide susceptibility. If the overdip-slope map is then combined with maps showing other factors, areas of relative landslide susceptibility can be determined more accurately. Data on slopes, rock attitudes, and agricultural soils are available for countywide landslide susceptibility analysis, but data are incomplete or lacking on distribution of rock types, density and orientation of rock fractures, thickness of soils (in the engineering sense), and permeability of rocks. In addition, there have been no large-scale systematic measurements of pressures created during slow, almost imperceptible movement of rock and earth. Until a large part of these data have been acquired and analyzed, countywide knowledge of landslide susceptibility will remain inexact.

At some places, however, these data are available or can be acquired with relative ease by onsite field studies. For more precise knowledge of the effects of overdip and other slopes in such limited areas, it is recommended that investigators follow the analytical method used to develop this countywide map. That is, they should combine rock attitude information, which is generally adequate and available in published geologic reports or which can be obtained in greater detail at the site, with the more detailed slope information on 7½-minute quadrangle topographic maps. Briggs (1973) has provided a guide to geologic maps of the region.

Other uses of the map.--Overdip-slope maps can also be used for purposes other than landslide-susceptibility studies. They are guides to favorable areas for the locations of springs, thus shallow ground-water supplies. Similarly, they indicate areas where contaminated water from septic tank fields or where acid or heavily mineralized waters from old mine workings are more likely to discharge. In addition, an overdip slope adjacent to a highway is an indicator that the highway may be subject to excessive icing during winter.

SOURCES OF DATA AND ACKNOWLEDGEMENTS

The overdip slope map was prepared by combining the attitudes of rock layering shown on the structure contour map of Allegheny County (W. E. Edmunds, unpub. data) and the slopes and relief shown on the regional topographic map (U.S. Geological Survey, 1:125,000, Greater Pittsburgh region, 1971). Frequent reference also was made to 7½-minute quadrangle topographic maps at the scale of 1:24,000.

Discussions on landslide factors with Harry F. Ferguson, U.S. Army Corps of Engineers, Dorothy Radbruch-Hall, U.S. Geological Survey, and Raymond L. Newbury, U.S. Department of Agriculture Soil Conservation Service, were of considerable value. Movement of ground water in the flat-lying and gently dipping rocks in hills of the Appalachian Plateau was treated by Robison (1964, p. 14-16). Ground water-landslide relations were described by Berryhill and others (1971, p. 42-43). In addition, data were gained from Wagner and others (1970). The dip-slope definition is from Bryan (1922, p. 87). Landslide terminology is from Sharpe (1938).

REVIEW OF FACTORS AFFECTING LANDSLIDE SUSCEPTIBILITY

Significant factors bearing on landslide susceptibility in Allegheny County include: (1) rock types; (2) nature of 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.

1. Rock types.--Outcropping rocks are largely sandstone, siltstone, shale (or claystone), and limestone. Coal, though only a relatively small part of the total rock volume, is widespread and significant. Sandstone and limestone commonly are harder, more resistant to weathering, than are siltstone and shale. This differential weathering explains why sandstone and limestone crop out on many slopes as ledges and cliffs, whereas siltstone and shale are rarely well exposed except in cut banks of streams, in other very steep natural slopes, and in manmade exposures such as highway cuts.

2. Rock layering.--The rocks form layers commonly 1 to 10 ft thick, but in places layers exceed 30 ft. For example, a 2-ft layer of limestone may rest on 7 ft of shale which in turn rests on a sandstone layer 10 ft thick. It is also common to find that a layer of shale as thin as 1 inch lies between two layers of sandstone each many feet thick. If a shale layer is decomposed to some depth by weathering, then overlying hard rock is no longer supported and tends to move down slope in response to gravity.

Some rock layers are continuous over a number of miles, but most sandstone layers, for example, probably grade laterally into another rock type, perhaps siltstone, in shorter distances, and some conspicuous lateral changes are seen within a single outcrop.

3. Rock fractures.--Two types of rock fracture occur: faults, fractures along which rocks on one side are offset from rocks on the other side; and joints, fractures, some tight, some open, along which little or no evidence of movement can be seen. Faults are relatively rare in southwestern Pennsylvania. The harder rock layers, sandstone and limestone, are well jointed in outcrop, with joints commonly one to several feet apart. Joints in siltstone and shale layers are generally many feet apart and are chiefly tight rather than open. Most joints are more or less perpendicular to the plane of layering.

Joints contribute to landslide susceptibility, for if rock layers were not jointed, their tendency to fail when underlying rocks are removed would be less. Joints are also an important factor in rock permeability.

4. Attitude of rock layering.--In southwestern Pennsylvania west of Chestnut Ridge (index map), 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 of grade. In some areas, layers dip more than 200 ft 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 ft per mile) are common.

In southwestern Pennsylvania, rock attitude is most critical to landsliding on overdip slopes (see map and text).

5. Soil cover.--Soils are composed chiefly of fine-grained mineral constituents derived from rock decomposition during weathering. However, soil mean different things to different people. For example, to a soil scientist, soil supports plant life and has undergone near-surface zonation resulting from the interaction of climate and living matter, conditioned by slope and relief. An agricultural soil rarely is more than 6 ft deep and may rest on and be developed from a parent material that is itself decomposed rock. In contrast, to an engineer, soil includes all unconsolidated material above hard bedrock, and so includes the parent material of many agricultural soils. Only where depth to bedrock is relatively shallow will there be virtual agreement between a soil scientist and an engineer as to thickness and composition of a soil. For present purposes, soil is used in the engineering sense; it 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. Examples of transported soils are colluvium and alluvial terrace deposits, both of which can be subject to landsliding.

In southwestern Pennsylvania, soils of the hill tops are relatively thin, less than 6 ft 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 ft of colluvium near and at the base of many slopes. Valley-bottom soils generally have nearly flat surfaces and so are not a significant factor in most landsliding; they may exceed 100 ft in thickness.

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, for a sandstone will weather to a sandy soil, a shale to a clayey soil, and hard blocky rocks may weather to a rocky soil. Because soils result from weathering of rock particles, they commonly are finer grained near the surface than they are at depth. 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 when dry commonly are friable and relatively low in weight per unit volume. When wetted, clay soils retain water and so become heavier, become plastic, and depending on their mineral composition may 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 commonly is moderately permeable; water may pass around grains of sand and through intergrain voids in many of these rocks. In addition, sandstone layers may have closely spaced joints that facilitate passage of water. Although limestone is fine grained and is inherently more or less impermeable, 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 are commonly widely spaced and relatively tight. Thus, sandstone and limestone layers in southwestern Pennsylvania 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 landslide susceptibility, permeability of rocks and soils, or the relative lack of it, is of particular importance.

7. Steepness of slopes.--Allegheny County is a land of hills and ridges each of which is more or less the same height as its neighbor. Separating these hills are valleys through which streams and rivers flow at levels commonly 300 to 400 ft and locally more than 600 ft below adjacent ridge crests. The valley walls are relatively steep; slopes of 25 percent (about 14°) or greater occupy more than one-tenth of the area. This large incidence of steep natural slopes is a leading factor in the prevalence of landslides.

Relative importance of factors.--All of the above factors are interrelated. At a given place one factor may be the chief control of landslide susceptibility, whereas at another place the same factor may be less important than others. For example, where a major stream is undercutting its bank, oversteepening will occur and slope failure ultimately will ensue, whether the bank material is rock or soil; where a thick soil cover becomes saturated with water, failure may occur even on relatively gentle slopes. Some reverse-dip slopes, contrary to what might be expected, are the consistent landslide hazards because of natural or manmade steepness or excessive rock fracturing; some overdip slopes, on the other hand, may be less susceptible to landsliding because only one type of rock is present.

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[1] Definition from Gary, Margaret, and others, eds., 1972, Glossary of geology: Washington, D.C., Geol. Institute, 805 p.
[2] This term approximates "scarp slope" of classical geomorphology, but by definition a scarp slope is on the opposite side of a cuesta from a dip slope, which is not the rule in southwestern Pennsylvania.

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

By
Reginald P. Briggs

1974

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