Storm-Induced Debris Avalanching and Related Phenomena in the Johnstown Area, Pennsylvania, with References to Other Studies in the Appalachians

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1191

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By JOHN S. POMEROY

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A study of storm-induced mass-movement forms

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By JOHN S. POMEROY

ABSTRACT

Several hundred debris avalanches, debris slides, slumps, earthflows, and combinations of the various types took place as a result of 30 cm of rain that fell during a 9-hour period, July 19–20, 1977, in an area of about 60 to 70 km^2 that lies north, northeast, and east of downtown Johnstown, Pa. Before this rainstorm, the soil had been well saturated by above-normal rainfall earlier in the month.

The most conspicuous mass-movement type was the debris avalanches, which reached a maximum of 300 m in length and 25 m in width and had head scarps in colluvium as high as 4 m. They were formed along mostly planar to gently concave upward colluvial 20° (35-percent) to 40° (85-percent) slopes. The less conspicuous slump-earthflows began on more moderate slopes.

Because of their greater clay content, colluvial soils derived from the Allegheny and Conemaugh Groups of Pennsylvanian age were more susceptible to the rapid mass movement than were those formed from the older rocks of Mississippian and Pennsylvanian age. A relatively dense pattern of mainly debris avalanches along the steep northwest-facing slope above the Little Conemaugh River northeast of Franklin appeared at least in part to be controlled by lithologic factors coupled with an overdip slope conducive to the formation of seeps.

The actual movement of regolith in the debris avalanching took place in two phases: first, limited planar or rotational sliding extending downhill a short distance away from the head scarp, and second, flowage caused by spontaneous liquefaction.

INTRODUCTION

THE STORM OF JULY 1977

On the night of July 19–20, 1977, torrential rains fell upon southern Cambria County and adjacent counties. The intensity of the nine-hour rainfall (nearly 23 cm in Johnstown and as much as 30 cm 16 km to the north and northeast) exceeded the infiltration capacity of the soil, causing heavy surface runoff which resulted in property damage of more than $300 million over a seven-county area. Rainfall of this magnitude should occur an average of only one time in 5,000–10,000 years (Jenkins and Baker, 1977, p. 7), but could not have been predicted, despite the presence of synoptic features favoring thunderstorm activity—well-above-normal moisture, unstable airmass, and low-level convergence (U.S. National Oceanographic and Atmospheric Administration, 1977a, p. 27).

Flooding was not restricted to the Conemaugh River and adjacent tributaries, but also caused tremendous damage in upland areas drained by ephemeral creeks, particularly from Johnstown eastward to the higher parts of the Allegheny escarpment. The failure of six earthen dams, one of which (Laurel Run dam) held 100 million gallons, further contributed to the flooding. A hydrologic report of the flood was prepared by Brua (1978).

In the local and Pittsburgh newspapers, I saw no mention of any slope movement in the Johnstown area, nor was any mass movement documented in a popular report by Jenkins and Baker (1977). Obviously, attention was turned to the much more serious widespread flooding and its effect on property and human lives. Apparently no one was killed or injured because of any form of mass movement. The heaviest rainfall took place in a less densely populated area of the region.

A reported 253 km of road and 22 bridges were closed, and the spans of 15 of the bridges were destroyed. The State highway department (Penn DOT) estimated that the damage to the roads amounted to $35 million. An estimated 50,000 people in the seven-county area were left homeless, and 76 persons were killed by the flash flooding.

PRESENT INVESTIGATION

The Johnstown area was studied during a 3-day period in late April 1977 as part of an inventory of mass movements in western Pennsylvania (Pomeroy and Davies, 1975; Briggs and others, 1975; Pomeroy, 1978) and, more specifically, in the Pittsburgh 2° quadrangle. Field inspection was preceded by an analysis of high-altitude aerial photographs and by a review of previous geologic and soils investigations. Few recent mass movements were found.

The Johnstown region was visited very briefly several days after the July 19-20, 1977, storm and again in the fall of 1977.

During early 1978, I examined large-scale (1:6,000 to

1:10,000) post-storm aerial photographs, and in late April 1978 I made a 10-day field study north and northeast of Johnstown. Later, post-storm (July 22, 1977) 1:12,000-scale black-and-white aerial photographs, which cover most of the area within the 30-cm isohyet, were obtained from a consulting firm and were field checked in late 1978.

ACKNOWLEDGMENTS

The author is indebted to L. Robert Kimball and Associates, Consulting Engineers and Architects, Ebensburg, Pa., particularly Eugene Sam, for making available, at a minimum cost, aerial photographs taken by Kimball 2 days after the storm (Figs. 10, 14, 15). The maps could not have been compiled without these 1:12,000-scale black-and-white photographs. Larger scale (1:6,000) black-and-white aerial photographs of the Hinckston Run area taken by Kimball a few months before the storm were useful in comparison studies.

Earlier, the author had examined post-storm photographs from other sources, but these photographs were restricted to specific areas and included only parts of the area of interest. Thanks are extended to J. P. Wilshusen (Pennsylvania Geological Survey), who informed me of the availability of Pennsylvania Department of Transportation photographs, and D. E. Wilbur, Chief, Photogrammetry and Surveys, Penn DOT, for allowing me to view 1:6,000-scale black-and-white photographs at the Middletown office.

Acknowledgment is extended to William Rhodes and Frank Wolle of the Environmental Protection Agency at the Photographic Interpretation Center in Warrenton, Va., for permission to view rolls of color transparencies at a scale of 1:10,000.

Thomas Taylor, Chief, Surveys Branch, U.S. Army Corps of Engineers, Pittsburgh, granted me access to 1:6,000-scale color aerial photographs taken for the Corps by Greenhorne and O'Mara of North Huntingdon, Pa.

The staff of the David A. Glosser Memorial Library in downtown Johnstown kindly directed the author to newspaper accounts of the 1977 storm and flood.

GEOLOGIC SETTING

Johnstown lies within the Appalachian Plateaus just 26 km west of the Allegheny Front (fig. 1). Maximum relief (approximately 300 m) in the study area (fig. 2) is east of the Little Conemaugh River gorge between Johnstown and Mineral Point.

Phalen (1910) and Phalen and Martin (1911) prepared geologic reports of the Johnstown 15-minute quadrangle including 1:62,500-scale maps, which are the only sources of geologic data, as no recent geologic maps exist

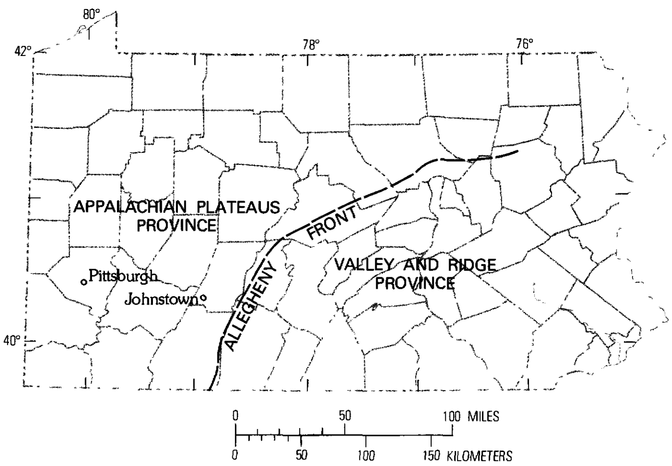
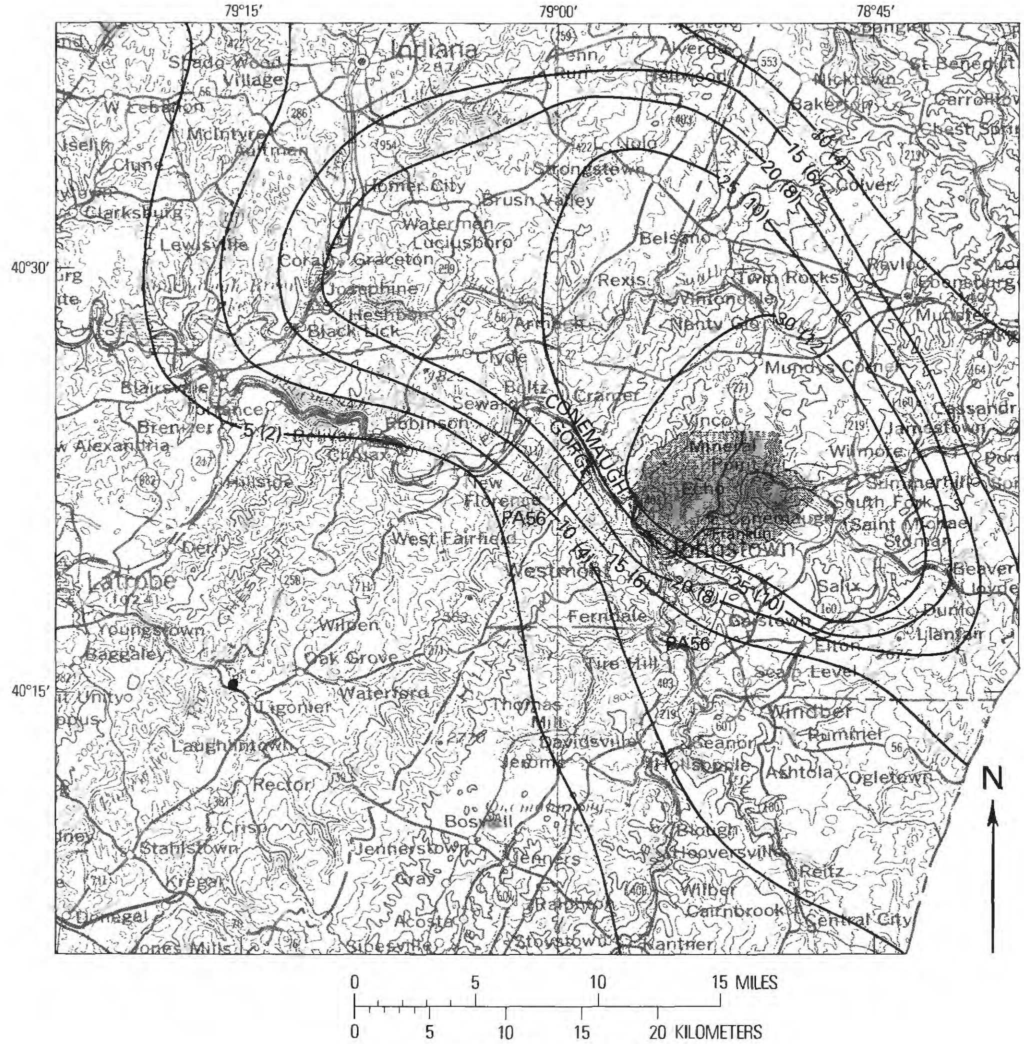


FIGURE 1.—Index map of Pennsylvania showing locations of Johnstown, the Allegheny Front, and county boundaries.

of the Johnstown area. Bedrock units within the area of study include, from oldest to youngest—the Pocono Sandstone and Mauch Chunk Shale of Mississippian age, and the Pottsville, Allegheny, and Conemaugh Groups of Pennsylvanian age. The bedrock is almost horizontal to very gently dipping. Two major northeast-trending folds include the Johnstown syncline, whose axis is just slightly west of Hinckston Run, and the Ebensburg anticline, whose axis is 1.5 km east of Mineral Point (fig. 3). Cyclic repetition of shale, siltstone, sandstone, coal, mudstone, limestone, and claystone is found in outcrops of the Allegheny and Conemaugh Groups between the ridge west of Hinckston Run eastward to the first conspicuous bend in the Little Conemaugh River northeast of Franklin. The Conemaugh Group generally occupies all but the lowest parts of the slopes. To the east, the Conemaugh Group underlies only the uppermost parts of the hills, and the exposed stratigraphic section extends downward to the Pocono Sandstone. The Allegheny Group contains several minable beds of coal.

TERMINOLOGY

As defined by Sharpe (1938, p. 74), debris slides "include all cases of rapid downward movement of predominantly unconsolidated and incoherent earth and debris in which the mass does not show backward rotation but slides or rolls forward, forming an irregular hummocky deposit which may resemble morainal topography." A debris avalanche has a larger water content, "has a long and relatively narrow track, occurs on a steep mountain slope or hillside in a humid climate, and is almost invariably preceded by heavy rains" (Sharpe, 1938, p. 61). A later classification of these two mass-movement types by Varnes (1958) resembles that of



EXPLANATION

—25 (10)— Isohyet showing precipitation (inches) based on rainfall data from National Weather Service and U. S. Corps of Engineers

Area discussed in report

FIGURE 2.—Map showing Johnstown region, total rainfall for the July 19–20, 1977, storm, and area discussed in report.

Sharpe (1938), but Varnes (1958, p. 36) stated that debris slides (and less commonly debris avalanches) may have slump blocks at their heads and that the moving mass of a debris slide breaks into smaller and smaller parts as it advances toward the foot. Both authors stated that the moving mechanism for debris slides is "sliding" and for debris avalanches is mostly "flowage."

However, many investigators have difficulties in differentiating the two terms. Most workers, including the author, who have studied debris avalanches, have recognized that sliding is the movement that takes place in the higher part of the landform and that flowage is the main movement in the lower segments, but the boundary between these two movements can rarely be recognized. Rapp (1963, p. 196) stated that because the actual rapid mass movements are seldom observed and because their processes are often transitional, the classification and terminology cannot be definitely established. Yatsu (1967, p. 396) wrote that "a hard and fast classification of mass movements can neither be given nor make sense because its practical application to the actual or natural phenomena encounters great difficulties." Hutchison (1968, p. 688) stated that "rigorous classification is hardly possible." Blong (1973) attempted without success to apply numerical taxonomic techniques to identify the most suitable morphological

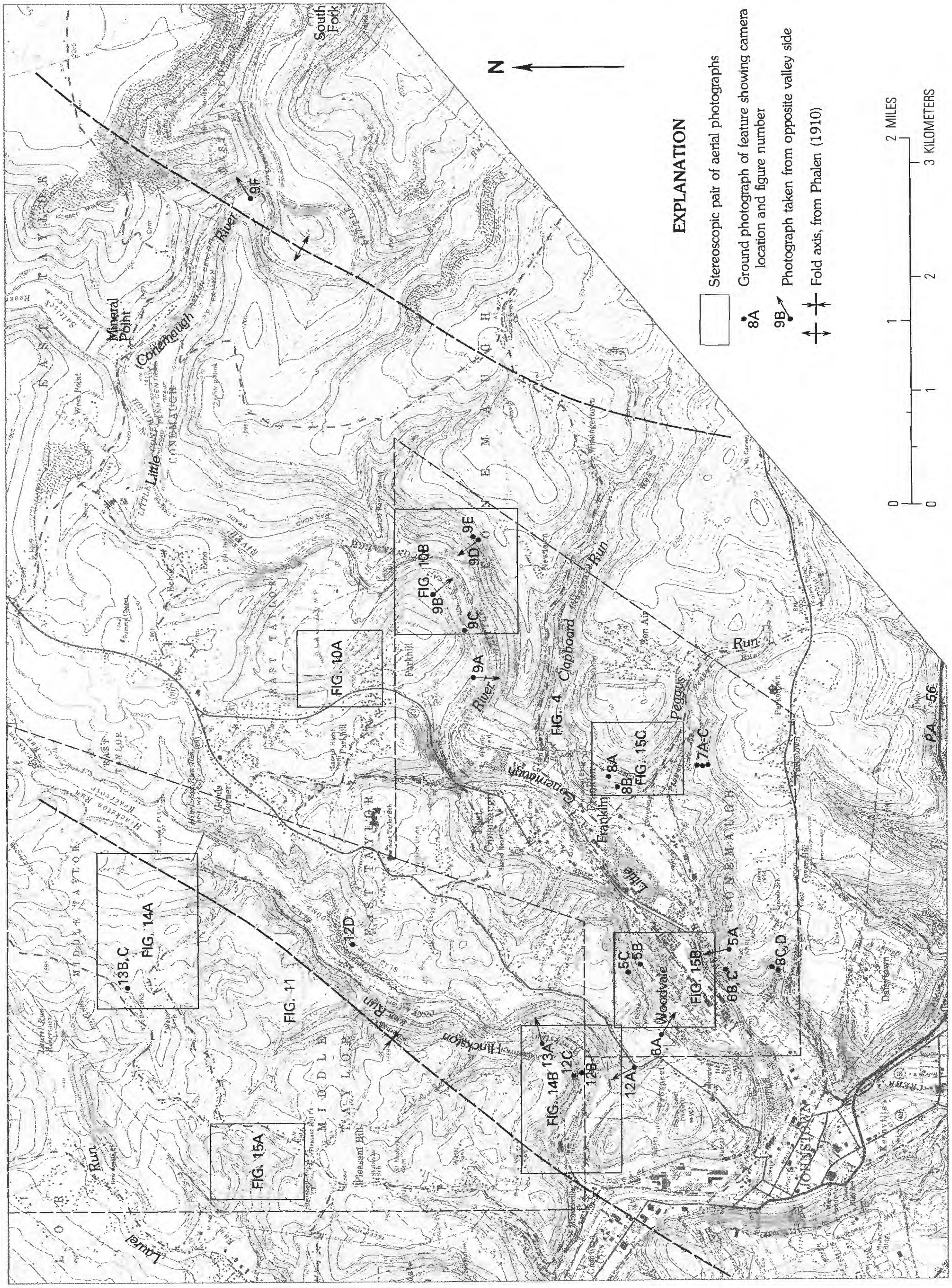


FIGURE 3.—Index map showing locations of areas represented in figures 4–15.

factors for a classification of debris slides, avalanches, and flows.

Although many workers in the Eastern United States have used "debris avalanche" (Flaccus, 1958; Gryta, 1977; Hack and Goodlett, 1960; Scott, 1972; Stewart, 1952; Stringfield and Smith, 1956; Williams and Guy, 1971; Woodruff, 1971), other investigators (Bogucki, 1970, 1976, 1977; Ratte and Rhodes, 1977; Schneider, 1973) have preferred the term "debris slide" to "debris avalanche." "Debris slides" include "debris avalanches" as used by Davies (1968, p. 89–90) in a discussion of Appalachian natural features.

In the present investigation I have found that differentiation of mass movement forms and classification as either debris slides or debris avalanches are not always possible because of the reconnaissance nature of the work and the lack of well-defined criteria for classification purposes. However, mass-movement features such as the relatively small storm-induced "soil slips" along highway and railroad cuts (fig. 9D) and in pasture and grasslands (fig. 13*B*, *C*) are best designated as debris slides because sliding is the mechanism of movement. Excellent examples of debris avalanches are present along the Little Conemaugh River (figs. 5, 6, 7, 9*A*, *D*, *E*, *F*) and the Hinckston Run (fig. 13*A*) and characteristically follow long linear narrow paths. Flowage is the principal mechanism of movement. Differentiation generally can be made on the basis of the morphology of the mass-movement form.

"Landslide" has been widely used as an all-inclusive term for almost all types of slope movements "including some that involve little or no sliding" (Varnes, 1978, p. 11). For example, the contributors to one study of landslides (Coates, 1977, p. 5) agreed that movements involving falling, sliding, and flowing could be included as landslides.

In this report, I have used the term "mass movement" rather than "landslide" except for movements that involve only sliding. Varnes (1978, p. 11) pointed out the desirability of formulating precise definitions of terms, especially for the term "landslide."

OCCURRENCE AND CHARACTERISTICS OF MASS MOVEMENT

Most of the storm-induced mass movement took place within the area of the 25-cm (10-inch) and 30-cm (12-inch) isohyets (fig. 2), the greatest number of slope-movement forms being on slopes above the Little Conemaugh River (fig. 4) and Hinckston Run (fig. 11), which are northeast and north of downtown Johnstown, respectively (fig. 3). Less activity, mostly in the form of debris slides, occurred on cut slopes along the west side of the Conemaugh River Gorge above and below Pennsylvania 56 and 8 to 13 km southeast and east of Johnstown above U.S. 219.

LITTLE CONEMAUGH RIVER AREA

Mass movement above the Little Conemaugh River and adjacent tributaries will be discussed in three segments—Johnstown to Franklin, Franklin to Mineral Point, and Mineral Point to South Fork. Approximate slope-movement measurements are given.

JOHNSTOWN TO FRANKLIN AREA

Nearly half the storm-induced mass movement along the Little Conemaugh River took place within the Johnstown to Franklin area and included several notable debris avalanches (fig. 4). These avalanches showed characteristics similar to those in other areas of Appalachia and of the world in that they can be divided into three sections: (1) the source or head-scarp area, (2) the track or middle zone, and (3) the depositional zone. At the time of measurement, debris avalanche A-1 (figs. 4, 5, and 15*B*) was 20 m wide at its head and extended across the road to a total distance of 150 m from its head. Although the head of the debris avalanche was 20 m wide, part of the avalanche stopped 30 m downslope from the head, and the average width was thus reduced to 10 m. The slope of the hill is planar, and its average grade is 60 percent (30°). The head scarp was 1.5 m high and was at the approximate boundary of a young woodland and a brush-covered surface. No rotational movement at the head was evident; therefore, the surface of rupture was probably along a planar surface in the colluvium possibly curving upward to intersect the surface. Persons living below the foot end of the debris avalanche reported that the earth movement took place at about 2 a.m. during the highest intensity of the storm and that they were alerted by sounds of moving rock, which was in part transported by flowing mud. Although the thickness of regolith removed was as much as 1.5 m at the head, it diminished downslope; at the road, the thickness of the regolith was considerably less than half that removed at the head (fig 5*B*).

The path of another major debris avalanche (A-2, fig. 4, 15*B*), which took place 0.1 km to the southwest, was roughly 100 m long and averaged 12 m wide; the avalanche stopped short of the road. The terminus of the avalanche was along a gentler 40-percent-grade (22°) slope in a mass of tangled trees, where, in places, an accumulation of 1.5 m of colluvial debris rested against larger trees. The 2.5-m-high head scarp was found in young woodland that has a 50-percent-grade (27°) planar slope, but the slope steepens to 60 percent (30°) about 15 m below the head scarp. Rotational movement

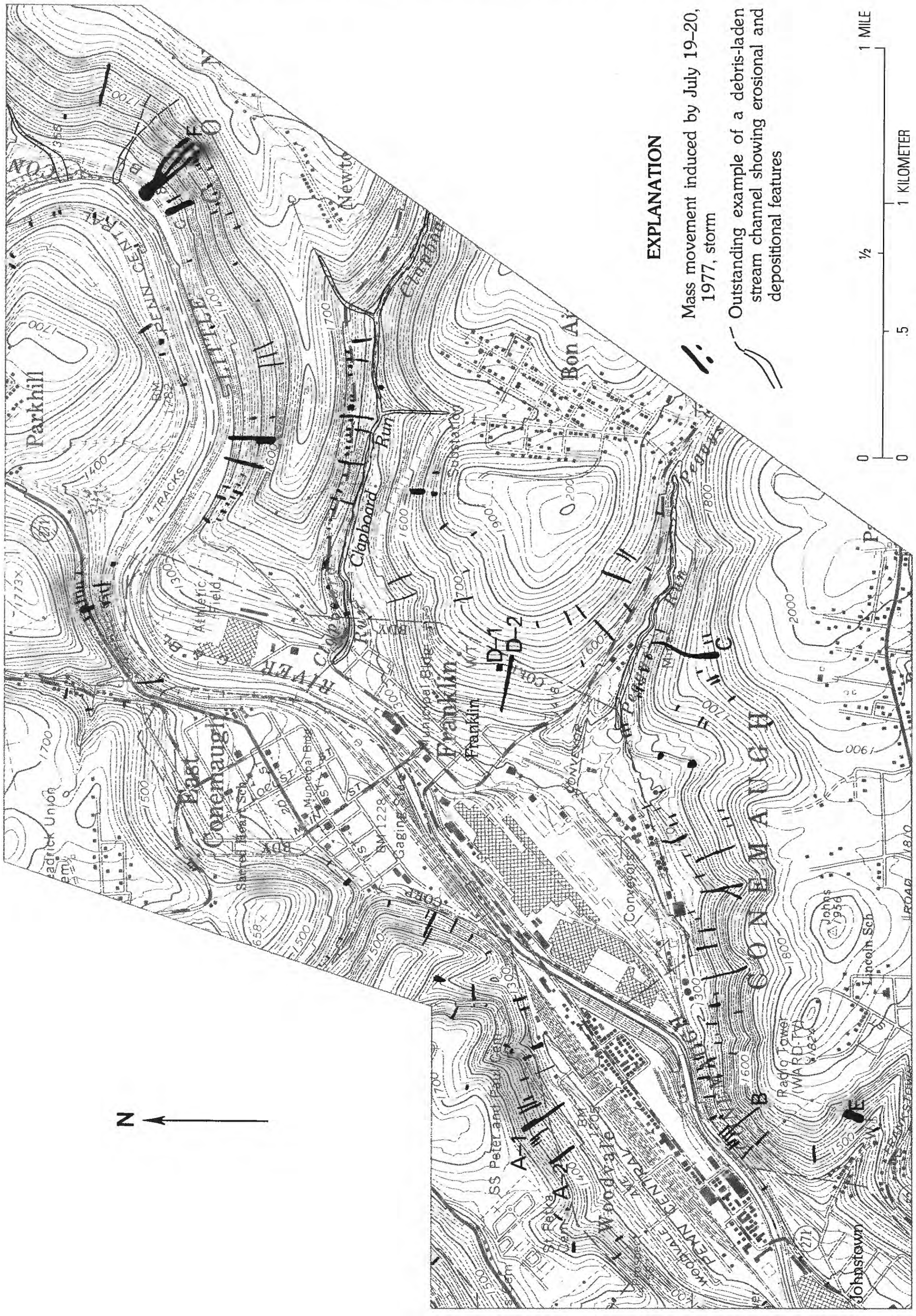


FIGURE 4.—Localities of storm-induced mass movement along Little Conemaugh River northeast of Johnstown.

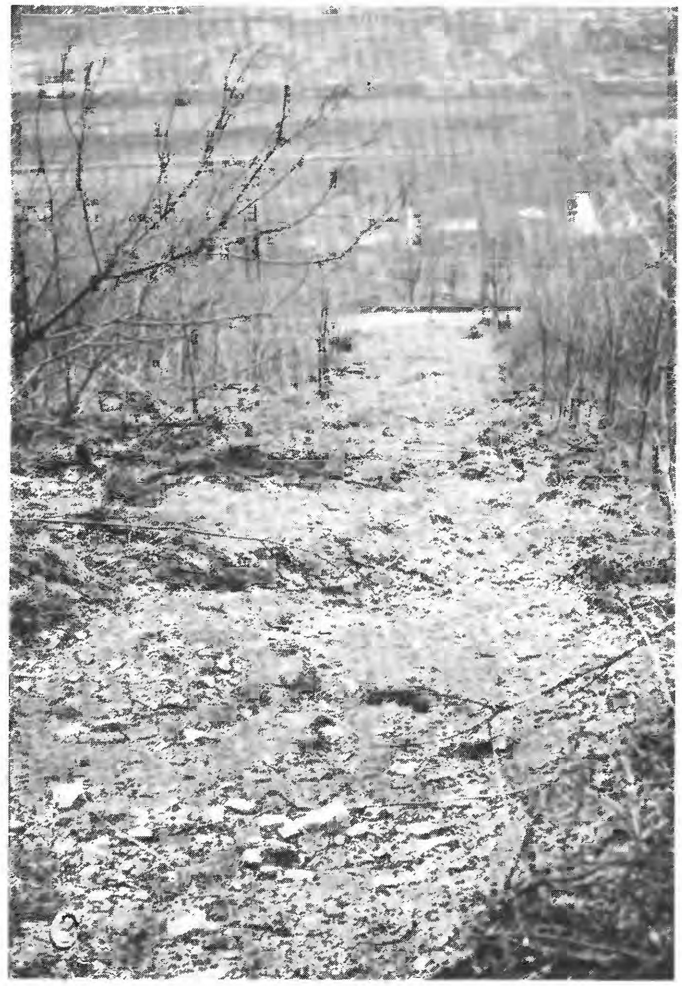


FIGURE 5.—Debris avalanches A-1 and A-2 (see fig. 4), Woodvale. *A*, View of debris avalanches A-1 and A-2 from the southeast. *B*, Debris avalanche A-1 from road above foot. Roadcut in foreground is covered by slide debris. *C*. Debris avalanche A-1 from head.

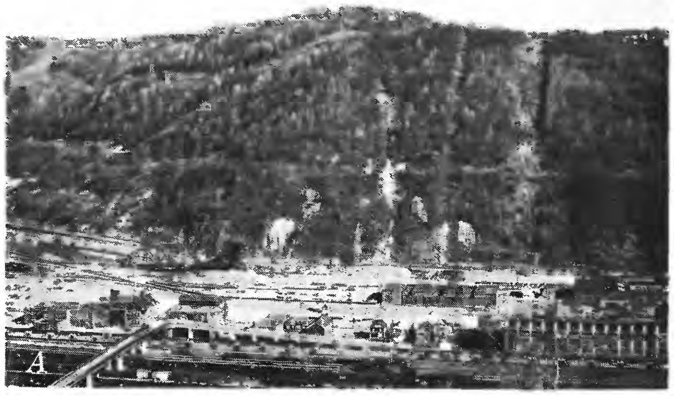
was restricted to a zone of a few meters length in the head area.

On the south side of the valley, a nearly 200-m-long and 3- to 10-m wide debris avalanche (B, figs. 4 and 6) followed a preexisting gulch along an 85-percent-grade (40°) forested slope. As much as 2 m from the edge of the path of the debris avalanche, rock fragments (projectiles) were lodged in shrubs as high as 0.6 m above the ground surface.

The head scarp, 25 m wide and 3 to 3.5 m high, of a 300-m-long debris avalanche (C, figs. 4 and 7), was along a planar 60-percent-grade (30°) forested slope. The initial slippage appears to have been planar, additional water being responsible for the flow downward from the head area. The rupture surface was possibly along the bedrock-colluvium interface as shale was seen in place in the lowermost part of the head area. The slope gradient is considerably less downward from the head area (fig. 7*A*). The flow was diverted from its previous course and followed the steep decline along a cleared stretch beneath a transmission line; it then followed an even steeper drainage notch leading to the bottom of the slope.

The slope above Franklin supports a scrub forest of mostly brush and a few scattered groves of stunted trees. Slump D-1 (figs. 4, 8*A*, 15*C*) was nearly 20 m wide, 20 m long, and clearly showed rotational movement (sliding) in sandy to silty colluvium. The slope configuration is slightly concave, and the gradient is only 30–35 percent (17°–20°). The slumped mass overlies a spring.

Debris avalanche D-2 (figs. 4, 8*B*, 15*C*) was 220 m long and 15 m wide at its head and occurred along a 35-percent-grade (20°) slope; its path was extremely variable in width. The flow terminated in a house but did no structural damage to it. Above the street, young trees and shrubs were flattened along the path. Although no springs were found in the head area, one major seep 15 m downslope from the scarp was observed. A long-standing drainage ditch 40 m upslope from the street and roughly parallel to it was filled in by the flow. The debris avalanche clearly lies within a slope showing moderate lateral concavity. Except for a few gullied segments in its lower part, the flow track showed a minimum removal of regolith (fig. 8*B*).



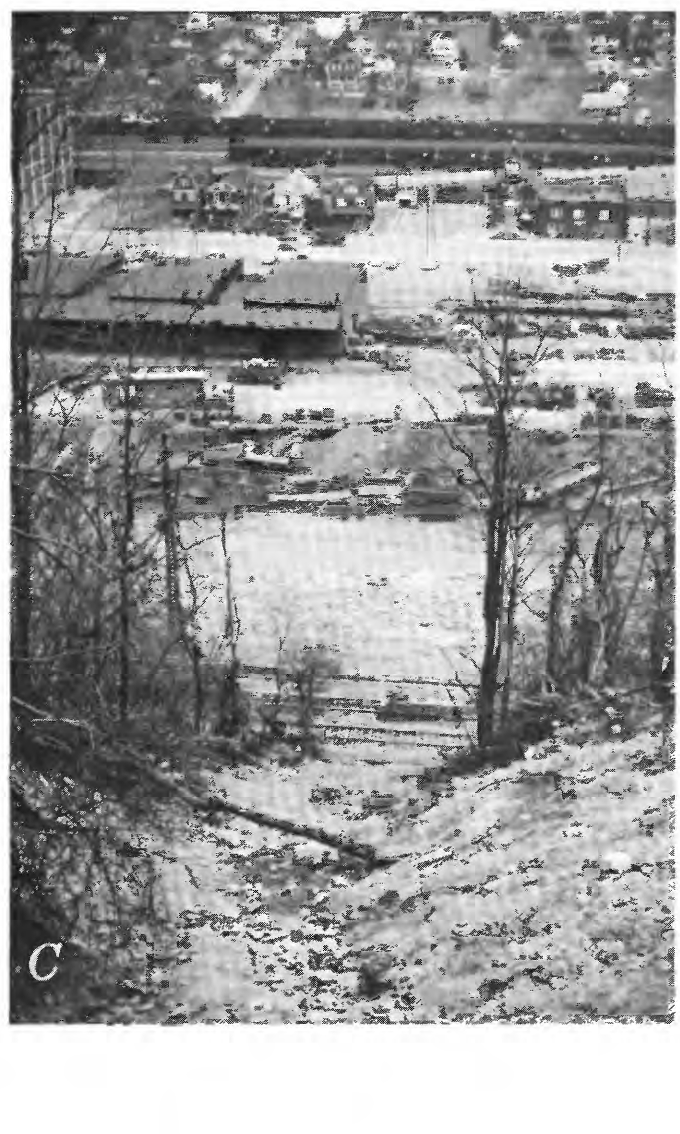


FIGURE 6.—Debris avalanche B (see fig. 4) south of Woodvale. *A*, Position 1 is camera location for photographs *B* and *C*. Debris avalanche follows pre-existing drainage. *B*, Upper part. Note suggestion of imbrication in sandstone colluvium. *C*, Lower part. Deposit removed from base of slope.

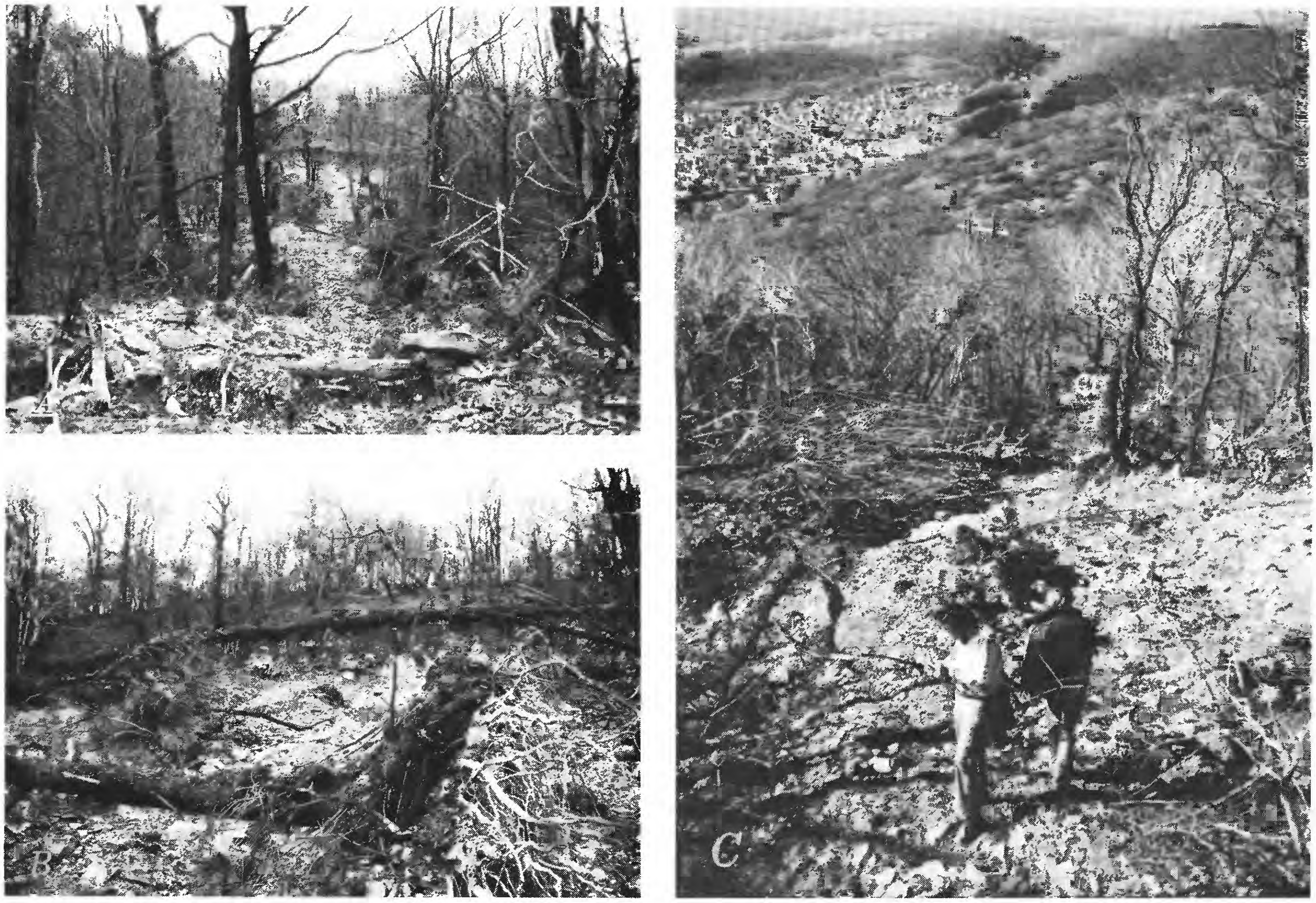


FIGURE 7.—Debris avalanche C (see fig. 4) south of Franklin. *A*, Debris avalanche along planar slope. Note moderate gradient (fig. 4) below head area. In foreground, the debris avalanche alters its course to the left. *B*, Sandstone colluvium in headwall. *C*, Northward, down from rim of head scar. Position a corresponds to foreground in photograph *A*.

A 27-m-wide complex slump-earthflow (E, figs. 4, 8*C*–*D*) that had a head scarp ranging in height from 4 m on the west side to less than 2 m on the east side occurred beneath a transmission line. The slope movement was restricted to the nonforested area. Slumped areas were found in front of the toe of the earthflow and extended downslope. Though the slope is greater than 60-percent grade (30°) above the head scarp and is slightly concave to the crest, the slope averages 35 to 55 percent (20° to 30°) and is planar in the slump-earthflow area itself.

FRANKLIN TO MINERAL POINT AREA

Several debris avalanches and minor slumps were found within two north to northwest-facing concave slope areas, each approximately 1 km wide along the south slope above the Little Conemaugh River northeast of Franklin (fig. 4). Nearly continuous hummocky colluvial deposits along the lower slope indicate episodes of ancient landsliding.

The largest debris avalanches took place along 80–85-percent-grade (40°) slopes; they had head scarps as wide as 25 m and as high as 4 m (figs. 4, 9*A*, *B*, *D*). The alinement of a trio of debris avalanches at F (figs. 4, 9*E*, 10*B*) suggests a common origin; indeed, seeps were noticed in these head-scarp areas. The bedrock dips to the west-northwest along an overdip slope.[1] Several coals and their underclays in the Allegheny Group underlie the slope, and springs would be expected above either the impermeable coal or underclay. A copious flow of acid mine drainage (figs. 9*B*, 10*B*) emanates from an abandoned adit at one site but has not contributed to any mass movement in that area. Slumps too small to map were present near an abandoned mine-access road along the upper part of the slope as well as near the jeep road along the lower part of both sides of the drainage (fig. 9*C*). These slumps were commonly 6 m wide and 8 m

[1] An overdip slope is defined as a land surface sloping in approximately the same direction as, but more steeply than, the dip of the strata (Briggs, 1974).

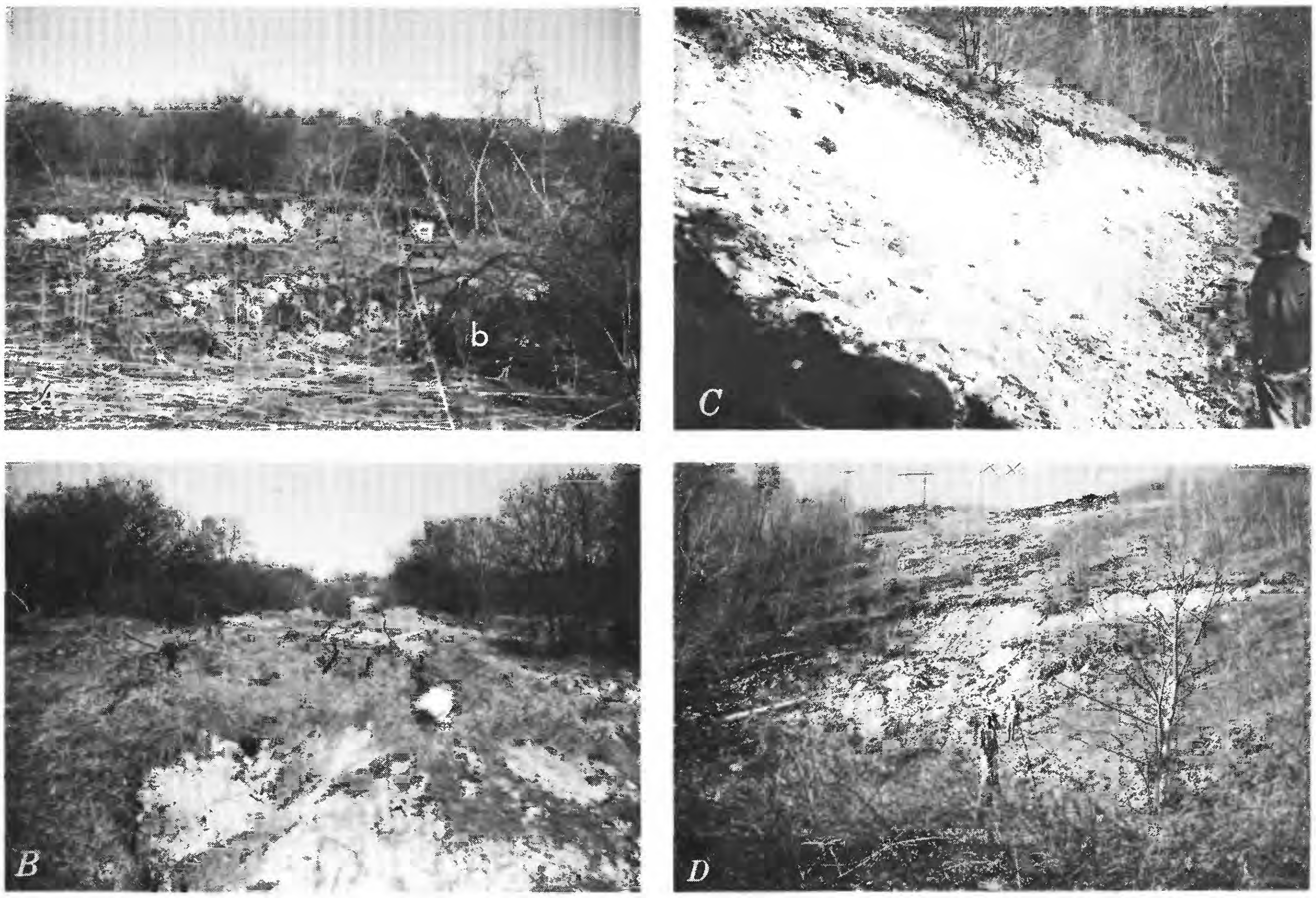


FIGURE 8.—Mass movement D-1 and D-2 at Franklin, and E, south of Woodvale (see fig. 4). *A*, Slump (D-1). a, head scarp; b, toe. Note moderate slope. *B*, Debris avalanche (D-2) above Sycamore Street. *C*, Head scarp in colluvium of slump-earthflow (E) south of Woodvale. *D*, Note restriction of width of slump-earthflow (E) to transmission line. Note fallen pole on left side of picture.

long and had a 1- to 1.5-m high scarp on a slope rarely exceeding 60 percent (30°).

Movement resulting in a massive slump-earthflow (fig. 10*A*), which measured 60 m wide at its head and 90 m at its foot at the slag dump west of the river, may have taken place along the slag fill-colluvial interface. More than 30,000 m^3 of material was displaced.

MINERAL POINT TO SOUTH FORK AREA

The impact of high water forcefully undercutting (scouring) the 15-m-high slope below the railroad caused a nearly continuous 0.5 km stretch of slumping at Mineral Point. Cracking of the fill along the embankment was noted in April 1978 and indicates continuing mass movement. Small debris slides above the railroad tracks, resulting in the displacement of at least one utility pole, took place along nearly 80- to 100-percent-grade (40°–45°) slopes. Debris avalanches along planar to concave slopes are not as common in this segment as they are in the downstream sections, probably because of gentler slopes and less relief. The most conspicuous debris avalanche (fig. 9*F*) was approximately 120 m long; the head scarp was only 6 m wide but widened downslope (70 percent grade or 35°) to 20 m at river level. Two massive boulders, remnants from strip-mine operations higher along the slope and precariously perched above the head scarp, controlled the headward extent of the debris avalanche.

Strip-mine areas had no large-scale movements except for a 35-m-wide failure of a spoil bank at the head of a tributary valley nearly 3 km south-southeast of Mineral Point. A few small debris slides and slumps (commonly unmappable at a scale of 1:24,000) were above and near the base of high walls.

HINCKSTON RUN AREA

Slides and flows are especially pronounced along the west side of the drainage in the 5-km stretch between the mouth of Hinckston Run and the Hinckston Run reservoir. Most of the east side has been draped by extensive slag deposits, and because the material was porous and well drained, no extensive mass movement took place in the slag although the deep rills of the surface were intensified. The apparent overloading or surcharging of the natural slope by the additional weight of the slag and precipitation failed to produce any large-scale mass movement, although small debris slides were noted in areas of mixed slag and earth fill. The veneer of slag along most of the east side of the drainage apparently has served as a protective mantle for the underlying slope.

Large-scale aerial photographs (1:6,000) of Hinckston Run taken in May 1977 were examined for any indications of recent slope movement. Only one large slide in earthen fill superposed on a colluvial slope (c, fig. 11) was detected in this prestorm documentation.

Several debris slides and debris avalanches occupy the south-facing grassy slope in the lower part of Hinckston Run near the coke works (fig. 14*B*). Twin debris avalanches (A, figs. 11, 12*A*–*C*, 14*B*), each 14 to 23 m wide at the head scarp, had as much as 4 m of colluvium and occurred along a 55-percent-grade (30°), planar-to-convex slope that steepens downhill. Both head scarps were arcuate and were either near or under utility lines; the location is probably not a significant factor inasmuch as the bareness of the entire south-facing slope was apparent. A small 50 m^2 grove of young trees between the two debris avalanches remained largely intact because the tree roots anchored the soil, promoting stability. No seeps were seen anywhere in the area of the slope movement.

Upstream, debris slides and debris avalanches occupy the forested west side of the drainage. The southern part of the east slope, which was not altered by slag emplacement, also has been subjected to debris avalanching (fig. 13*A*). The mass movement seldom exceeded 100 m in length and 12 m in width and took place along planar to concave slopes that have 55–80-percent grade (30°–40°).

An irregularly shaped debris avalanche (B, fig. 11), the head of which lies beneath a utility line, was found downslope from a spring and within a much larger ancient landslide form. A 50-m-wide slag fill slump-earthflow (C, fig. 11) was not induced by the storm; it appears on the prestorm 1977 aerial photographs. I do not know whether a recent 18-m-wide bedrock slump (D, figs. 11, 12*D*) above the road was induced by the storm or by road construction. Inclined trees and a 15° dip of the strata back toward the slope reflected some rotational movement along joint planes. A 35-m-long and 20-m-wide earthflow (E, fig. 11) occupies the left center section of a 35–45-percent-grade (20°–25°), concave grassland slope east of Hinckston Run.

UPLAND AREA WEST OF HINCKSTON RUN

Clusters of debris slides are present along two east-facing mostly grassy amphitheater-shaped slopes 1.2 km west of Hinckston Run reservoir. At area *F* shown on figures 11, 13*B*, *C*, and 14*A*, three of the four slides consist of shallow zones of soil that slid out for a very short distance, not exceeding a few meters, from the head scar. After sliding, the soil rapidly disintegrated into clods, which rolled and (or) flowed downslope. The slides were 45 to 50 m long, and their headward margins formed along 50–55-percent-grade (27°–30°) slopes. A scattering of debris was seen where the slope moderates. Kesseli (1943) referred to this form of mass movement as "disintegrating soil slips" and believed that these forms were probably indigenous only to the West Coast because they had not been mentioned in the literature from the eastern part of the country. Varnes (1958, p. 32) cited Kesseli's "disintegrating soil slips" as a variety of debris slide. In the same cove, but lower on the slope, was a 6-m-wide by 8-m-long earthflow. This mass remained coherent and flowed as a unit during the storm. A gentler slope and a thicker accumulation of soil lower on the slope were factors in the formation of the earthflow. The landowner, Paul Klim (oral commun., April 1978), verified that all four slides formed during the night of the storm. A few small earthflows were identified elsewhere in the upland area west of Hinckston Run on slopes of less than 50-percent grade (27°).

At area G, shown in figures 11 and 15*A*, a 100-m long debris avalanche along a 35-percent-grade (20°) slope measured 1 to 8 m in width. The affected regolith was less than 1 m thick in the upper part and thinned to extinction close to the base of the slope. Part of the foot of a 25-m-long by 20-m-wide earthflow (H, figs. 11 and 15*A*) served as a head for a small debris slide.

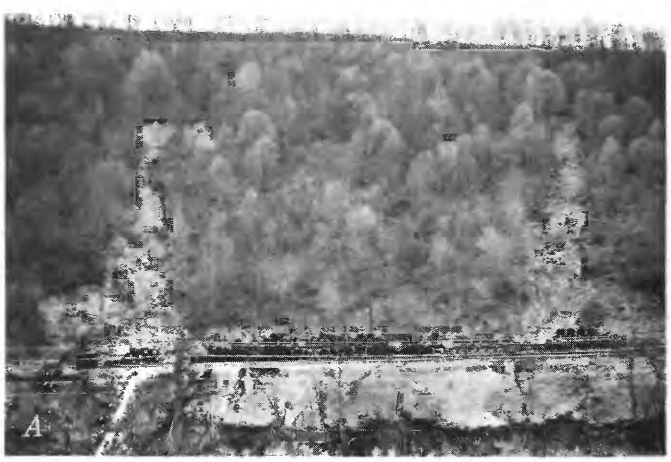
FACTORS IN DEBRIS-AVALANCHE FORMATION

RAINFALL

Because rainfall data are relatively scant, considering the size of the affected area, only a generalized isohyetal map has been made (fig. 2). According to the National Weather Service office at Pittsburgh, the greatest amounts of rain (slightly more than 30 cm) fell at Nanty Glo, Laurel Run Dam reservoir, and an area approximately 6 km southeast of the Johnstown airport. The map shows that the area of greatest rainfall covered an oval area approximately 60 to 70 km^2 east and northeast of downtown Johnstown. That all areas within the 30-cm (12-inch) isohyet received the same amount of rainfall is highly unlikely considering the erratic nature of thunderstorms. In downtown Johnstown, readings of nearly 23 cm were well documented. Rainfall totals were much less to the southwest, at the fringe area of Johnstown, where less than 13 cm fell. No rain fell at Ligonier, 28 km to the southwest.

Rain was nearly continuous for approximately a 9-hour period from 7 p.m. on July 19th to 4 a.m. on July 20th. Residents reported that the lightning also was nearly continuous. Approximately 5.5 cm of rain fell on a part of Johnstown in the 40-minute period from 2:50 a.m. to 3:30 a.m. (U.S. National Oceanic and Atmospheric Administration, 1977b).

One of the coldest winters on record preceded the July storm. The intense cold was followed by mean temperatures that were slightly above the 40-year norm for the months of March, April, May, and July. Monthly precipitation totals for January, February, May, and June were below the 40-year norm, but monthly precipitation was higher than the norm in March and April and significantly higher during the first 18 days of July when 11.4 cm had fallen (fig. 16). The ground was well saturated as records indicate that more than 11 cm



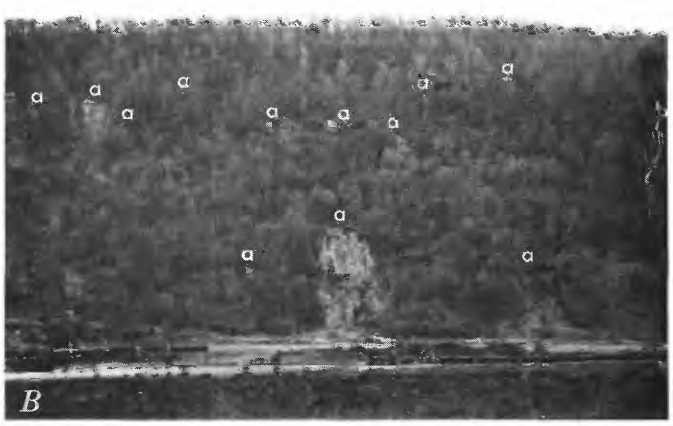
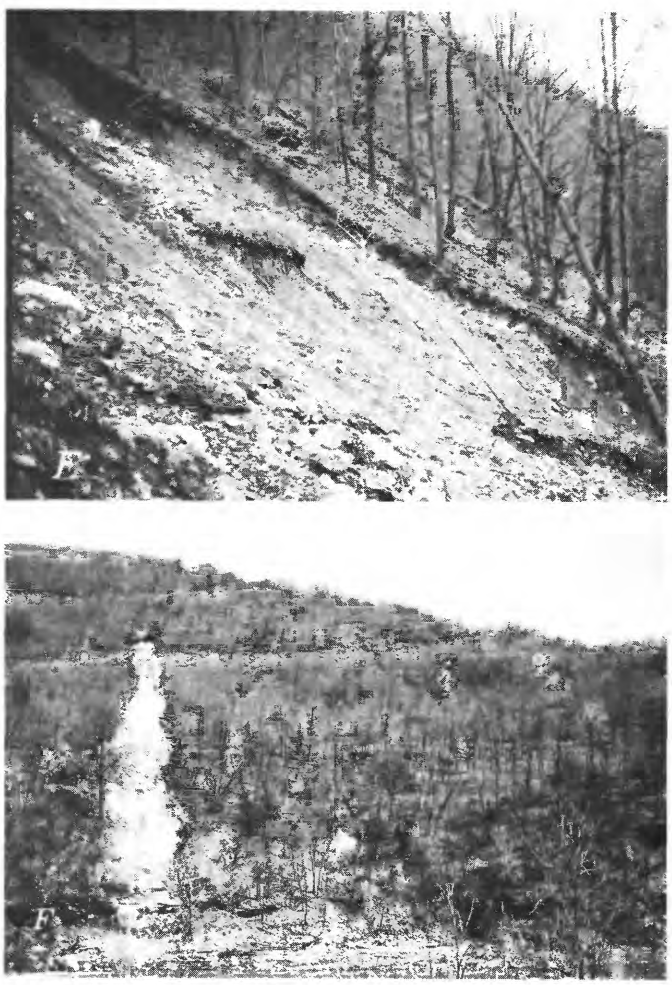


FIGURE 9.—Mass movement northeast of Franklin (see figs. 3 and 4). *A*, Debris avalanches within large relict landslide area. *B*, Symbol *a* denotes debris avalanche or debris slide. Acid mine drainage occurs at abandoned adit *b*. *C*, Typical slump above jeep road; *a*, head scarp. *D*, Looking northwestward, across Little Conemaugh Valley from slide complex (*F*, fig. 4). Note debris slides above railroad track. Edge of head area of debris avalanche in foreground (a). *E*, Profile of head areas of debris-avalanche complex (F, fig. 4).

of rain had fallen during the 14-day period preceding the storm.

Heavy precipitation originates from tropical cyclonic storms or hurricanes, from weak continental low-pressure systems, and from localized severe thunderstorms sometimes called cloudbursts. The last group has the potential of becoming especially severe when preceding the passage of a front, and the Johnstown deluge apparently resulted from a combination of these factors.

Debris avalanches correlate with periods of intense rainstorms, which are most common in June, July, August, and September. Bogucki (1970, p. 143) determined that all storms that are known to have produced mass movement in the southern Appalachians from Virginia and West Virginia to Georgia took place during these 4 months, as documented by Stringfield and Smith (1956), Hack and Goodlett (1960), King (1931), Moneymaker (1939), Bogucki (1976), and U.S. Geological Survey (1949). To this list can be added the effects of Hurricane Camille in Virginia and West Virginia in August 1969 (Williams and Guy, 1971, 1973; Woodruff, 1971; Virginia Division of Mineral Resources, 1969; Webb and others, 1970; Scott, 1972; Schneider, 1973).



Flowage is the main mechanism of regolith movement shown in all three pictures. *F*, Debris avalanches (a) between Mineral Point and South Fork. Note perched boulders at head of conspicuous debris avalanche.

Flaccus (1958, p. 180) concluded that all 127 White Mountain debris avalanches (New Hampshire) that could be dated by month took place between June and November. The storm of July 18, 1942, in north-central Pennsylvania that produced as much as 89 cm (35 in.) of rainfall at some points (Eisenlohr, 1952) caused several debris avalanches (Stewart, 1952, p. 78). My reconnaissance in Cameron and McKean Counties, Pa., in early 1978 indicated that two debris avalanches were caused by the heavy rainfall—more than 38 cm (15 inches)—associated with Hurricane Agnes in June 1972 (Bailey and Patterson, 1975, p. 46). Bogucki (1977, p. 322) cited slope movement in the Adirondacks of New York from storms of June 1963 and September 1971. Two hurricanes in mid-August 1955 were responsible for intense rainfall in several areas of the northern States (U.S. Geological Survey, 1956). Hack (Hack and Goodlett, 1960, p. 55) visited the Pocono Mountains of northeastern Pennsylvania in September 1960 to examine the effects of the 1955 storms and observed four debris avalanches on the face of the Pocono Escarpment in the Skytop area. Extrapolation of total rainfall for each storm (U.S. Geological Survey, 1956, p. 3-4) indicates that as much as 48 cm (19 inches) fell in the Pocono Mountains. Hack (oral commun., 1978) believed that the Skytop debris avalanches formed as a direct result of the later considerably more intense storm.

A list of slope movements triggered by heavy precipitation in different climatic zones by Temple and Rapp (1972, p. 164) indicates that, in the Northern Hemisphere, heavy rainstorm-induced mass movement takes place between mid-June and early October.

SLOPE CHARACTERISTICS

GRADIENT

A reconnaissance of the entire Johnstown area indicated that debris avalanches are not necessarily related to the steepest slopes. For example, the slopes along the Conemaugh River Gorge northwest of Johnstown (fig. 2), which have a steeper gradient than do those in the area north and northeast of Johnstown, did not show a large amount of mass movement. Thinner and narrower deposits of colluvium derived from predominantly pre-Allegheny Group sandstones and a lesser but still heavy total rainfall reduced the likelihood of slope movements despite the steeper slopes. Williams and Guy (1973, p. 29–30) showed that no apparent cor-

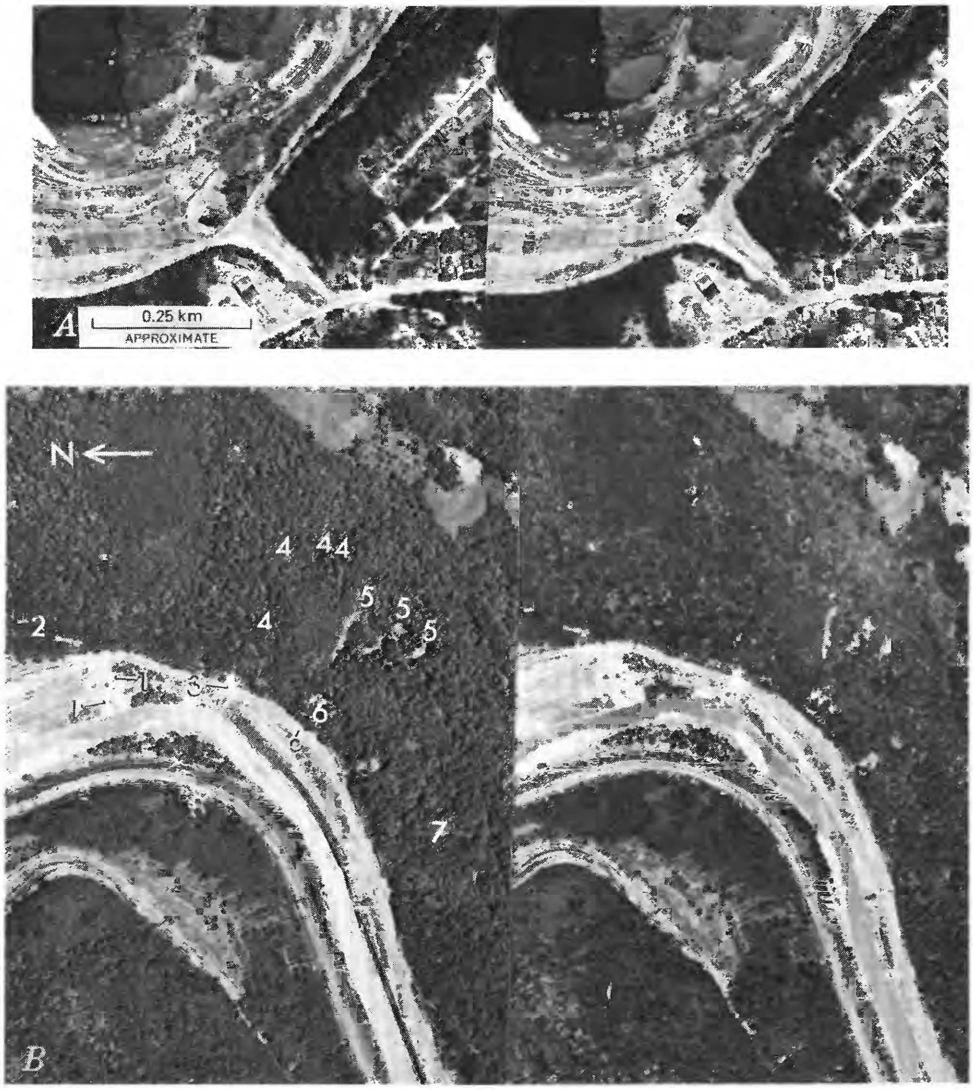


FIGURE 10.—Stereoscopic pairs of aerial photographs. *A*, Slag dump northeast of Franklin. Massive slump-earthflow disrupted railroad tracks (1). Failure probably took place at the contact of slag and fill material. Area had been renovated when field checked. *B*, Little Conemaugh River area between Franklin and Mineral Point. Area 1 represents coarse stream deposits emanating from drainage (2). Depositional area (3) likewise covered railroad tracks and resulted from incisement of long narrow drainages (4). Debris from three debris avalanches (5) (fig. 9*E*) at area 6. Feature 7 is not debris avalanche but represents acid-mine-drainage path (fig. 9*B*). Small debris slides above tracks (8) are seen in background of figure 9*D*. Photography by L. Robert Kimball and Associates.

relation existed between slope angle and debris-avalanche frequency during Hurricane Camille in Virginia.

Slope length is not significant in the formation of mass movements. Even in the area of highest rainfall intensity, mass movement is not related to the length of the slope.

Debris avalanching in the study area took place on slopes in the head area that have grades as low as 20° (35 percent) and as steep as 40° (85 percent); the average grade was slightly more than 30° (60 percent). Slumps and earthflows took place on gentler slopes (as low as 16° or 28 percent).

Other investigators have observed slope gradients in areas of debris avalanching. Flaccus (1958, p. 185) indicated that in the White Mountains, upper slope gradients range from 25° to 35° (45–70 percent) and average about 32° (62 percent). Bogucki (1976, p. 188)

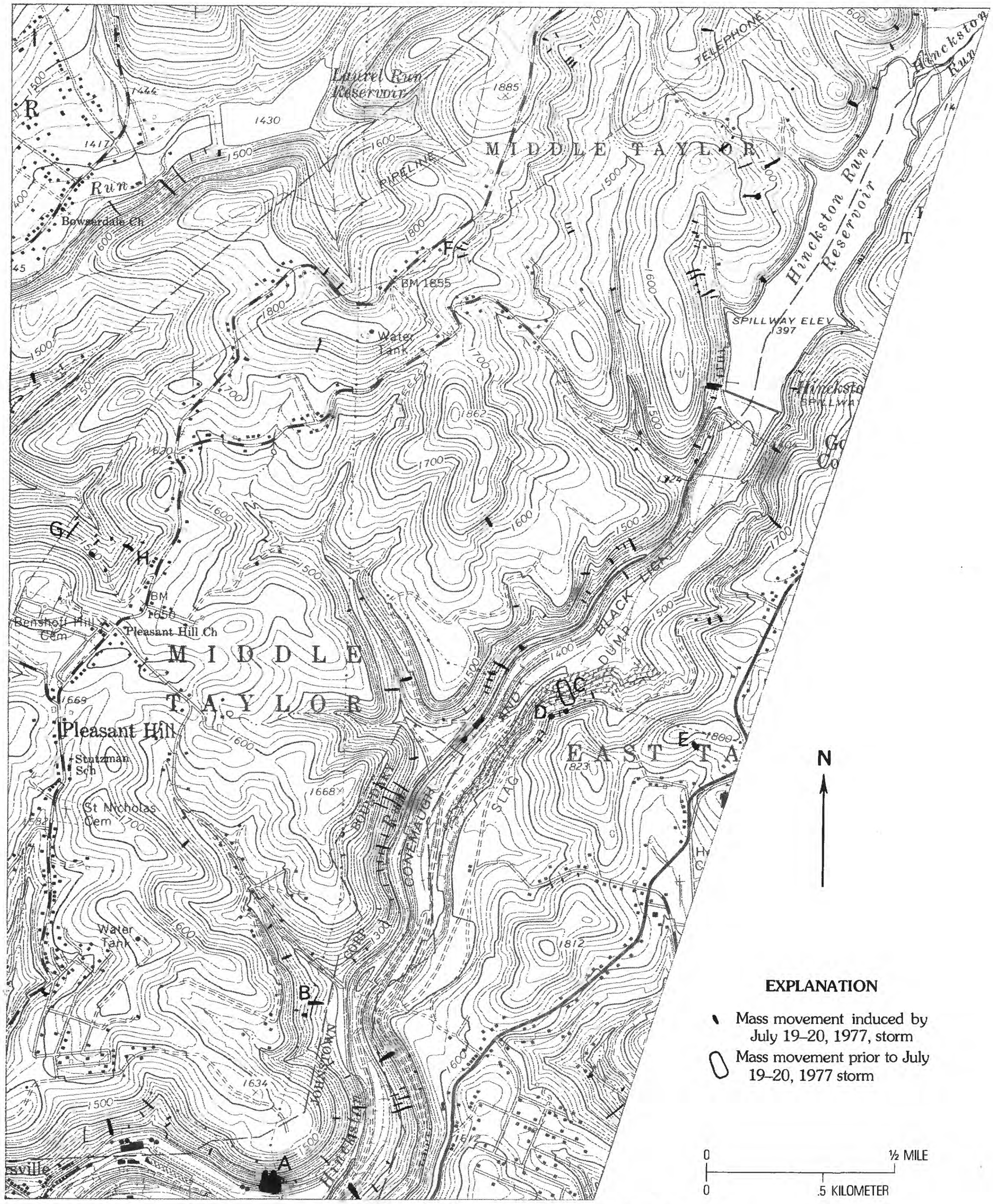


FIGURE 11.—Localities of recent mass movement in Hinckston Run area.

determined that slopes in the head areas in the Great Smoky Mountains average 40° (85 percent), with a range of 35° to 44° (70 to 100 percent). In the Blue Ridge Mountains area of Virginia that was affected by Hurricane Camille, Scott (1972, p. 130–131) found that the average inclination in the upper part of the slopes was 32° (62 percent). Schneider (1973, p. 51) concluded that in West Virginia the slope at which the greatest amount of slope movement took place is 29°-31° (56 to 60 percent).

The average slope inclination of headward parts of debris avalanches in the Johnstown area, despite the fact that this area has less relief than the other four Appalachian areas, is approximately 30°, the same as that in three of the areas.

The heads of most debris avalanches in the Johnstown area are on or near the steepest part of the slope, but few are at or near the crest of the hill because of the limited catchment area.

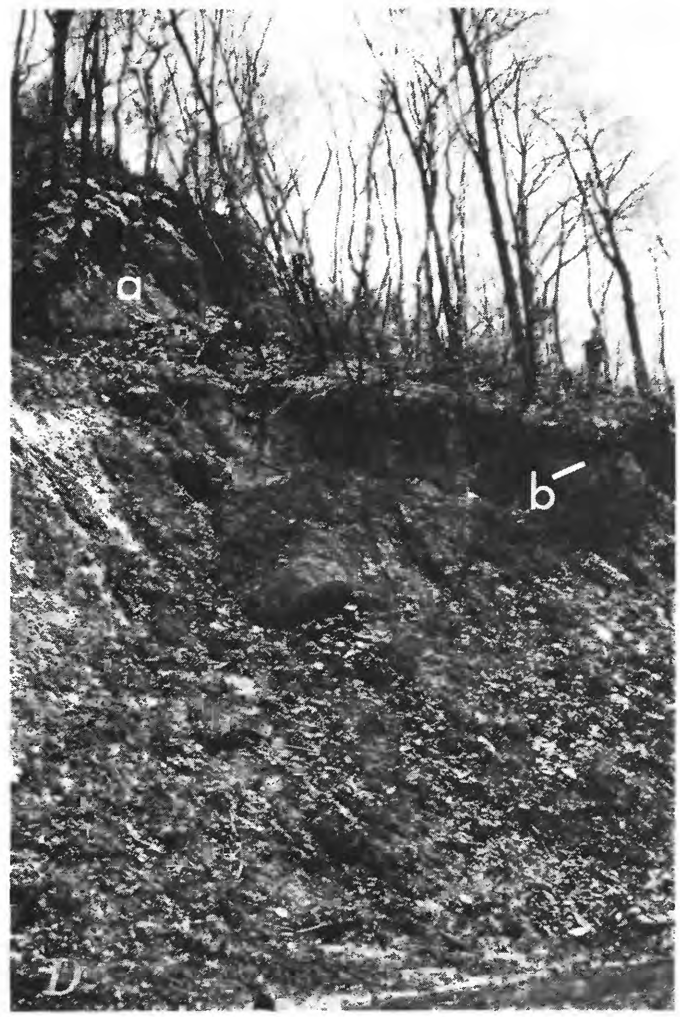


FIGURE 12.—Mass movement along Hinckston Run (figs. 3 and 11). *A*, Conspicuous debris avalanches (1) along west side of drainage. Twin debris avalanches (fig. 11, A) are at right side of picture. Subject of figure 12*B* and *C* are indicated at b and c. Road above drainage was still closed as of early 1979. Laurel Hill in distance (Conemaugh River gorge at notch). *B*, Transported tree (on road in distance) and coarse colluvial debris. *C*, Colluvium in head area of the more conspicuous debris avalanche (fig. 12*A*). *D*, Bedrock slump (fig. 11, D). Note scarp at a and inclination of bedding (b). Relative scale is indicated by man above b.

FORM

Williams and Guy (1971, p. 36) found that at least 85 percent of the debris avalanches originating during Hurricane Camille took place along a previously existing depression on the hillside. Bartholomew (1977) showed this relationship in the northern fringe of the area devastated by Camille. Hack and Goodlett (1960, p. 43) noted that, in a nearby area in Virginia, the scars or chutes are most numerous in the hollows. Bogucki (1976, p. 188; 1977, p. 321) revealed that major slide scars in both the Mt. LeConte area (Great Smoky Mountains) and the Adirondacks originated at valley heads or were associated with small or incipient hollows on side slopes.

The Johnstown region and other debris-avalanche areas in the Appalachians are in different physiographic provinces. Accordingly, differences in relief, landforms, and drainage patterns are caused by the evolution of the landscape as well as by lithologic dissimilarities. In the Johnstown area, both forested and nonforested slopes contain probably fewer well-defined stream channels than do other areas in the Appalachians. Only a small percentage of debris avalanches has taken place along well-defined hollows, such as those along the northwest- to north-facing slope between Johnstown and Franklin. Most of the mass movement is along planar to gently concave slopes, which may or may not be part of a wider, in some places 1 km or greater, laterally concave slope. Unlike debris avalanches forming a chute, and consequently widening and deepening the channel and forming a larger drainage, movement of debris from nonchanneled debris avalanches ceases downslope wherever a lessening of grade reduces the velocity of movement and causes a pileup of the material.

Temple and Rapp (1972, p. 172) showed that almost 60 percent of the slope movement in an area of Tanzania was along straight valley sides. The Johnstown area is another locality where most debris avalanches do not follow drainage lines, possibly because well-defined ancient debris avalanche paths are relatively sparse.

ORIENTATION

Wherever one or more linear orientations (topography, drainage, strike of bedding) exist, a slide or flow obviously tends to face the same direction as do most of the slopes. In the Johnstown area, Hinckston Run and the Johnstown to Mineral Point segment of the Little Conemaugh River parallel the faintly expressed linear elements.

Any meaningful statistical study along Hinckston Run is precluded by the slag-bank emplacement along most of the east side of the drainage (see "Hinckston Run area"). However, mass-movement forms show a strongly preferred orientation in the highland area west of Hinckston Run where slightly more than 75 percent fit into the north to east quadrant (fig. 11).

A preferred orientation does exist along the slopes of the Little Conemaugh River between Johnstown and

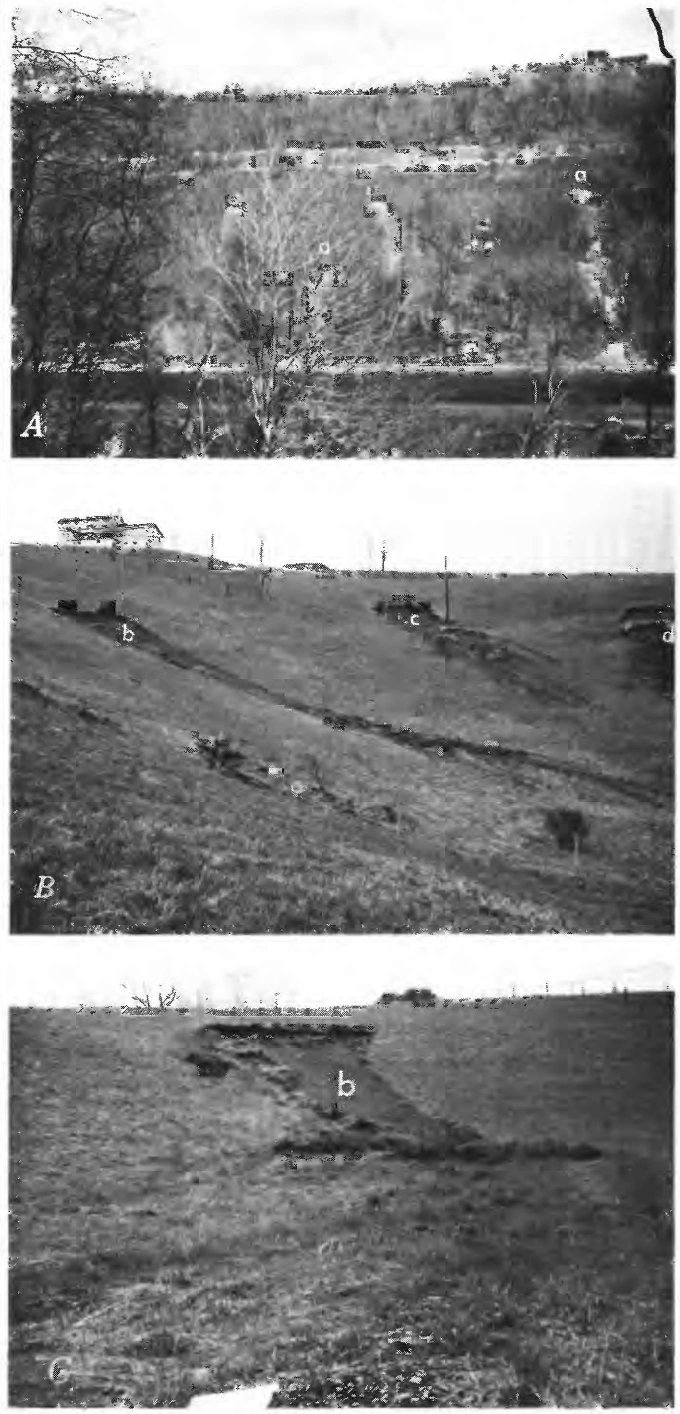


FIGURE 13.—Mass movement along Hinckston Run and upland area west of Hinckston Run (see figs. 3 and 11). *A*, Debris avalanches (a) along east side of drainage. *B*, Area F (fig. 11) showing one earthflow (a) and three debris slides (b, c, d). White object (map) within earthflow serves as a relative scale. *C*, Debris slide (b) terminus consists of small fragmental debris. Clods appear behind clastic remnants.

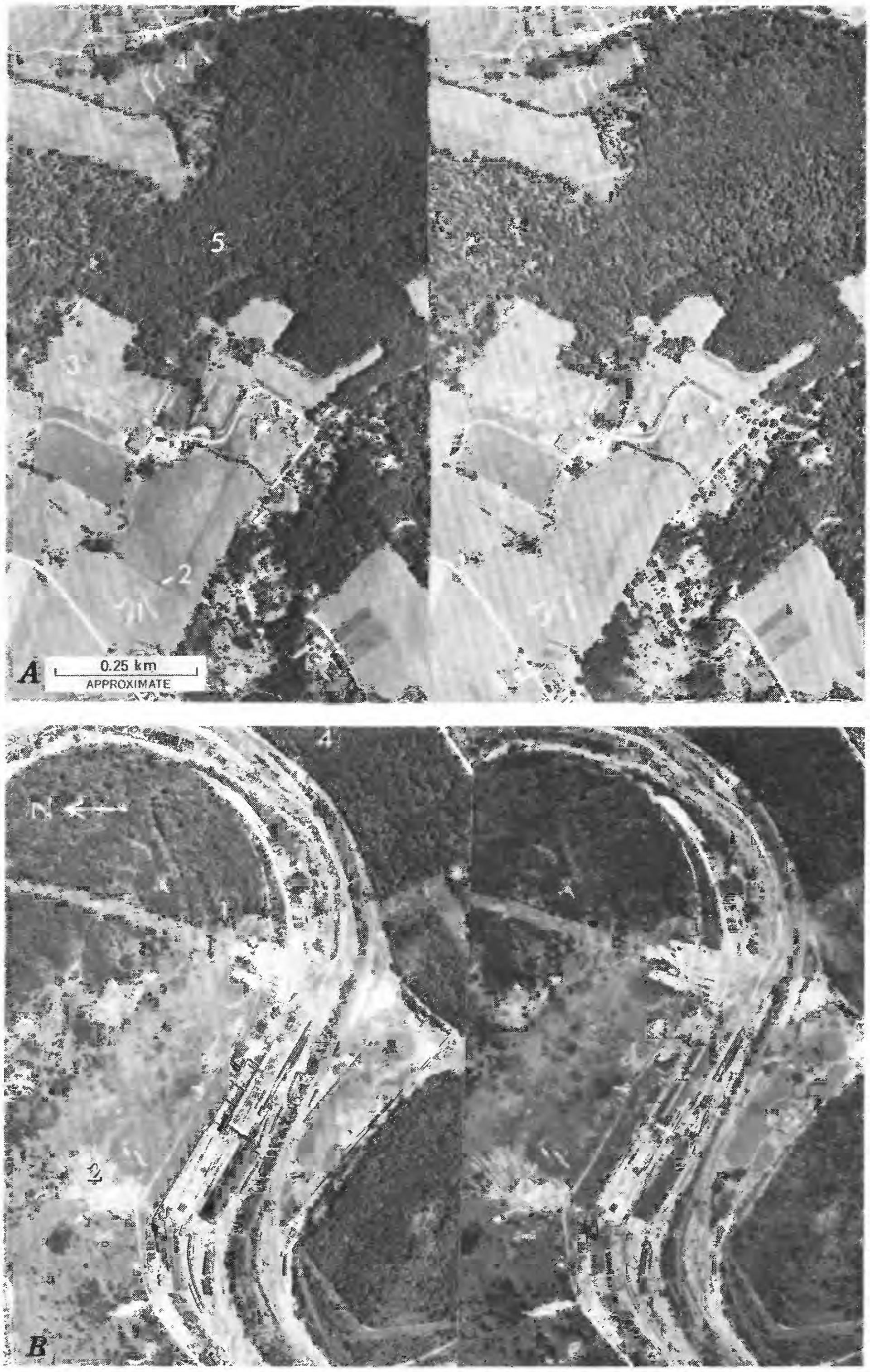


FIGURE 14.—Stereoscopic pairs of aerial photographs. *A*, Highland area west of Hinckston Run. Debris slides (1) and earthflow (2) seen in figure 13*B*. Earthflow (2) moved virtually intact. Debris slides at 3 and 4. Note affinity of slides and flows to east-facing concave to planar slopes. Cleared area south of 5 is debris slide along steep slope undercut by stream. *B*, Hinckston Run (lower section). Grassland planar-convex-concave slopes with debris avalanches and slides (fig. 12 *A–C*). Debris avalanche (1) is shown in figure 12 *A–C*. Note influence of small tree grove. Area 2 is man-modified slope and not a mass-movement area. Debris fan (3) from poorly discerned minor drainage in forested area (4). Photography by L. Robert Kimball and Associates.

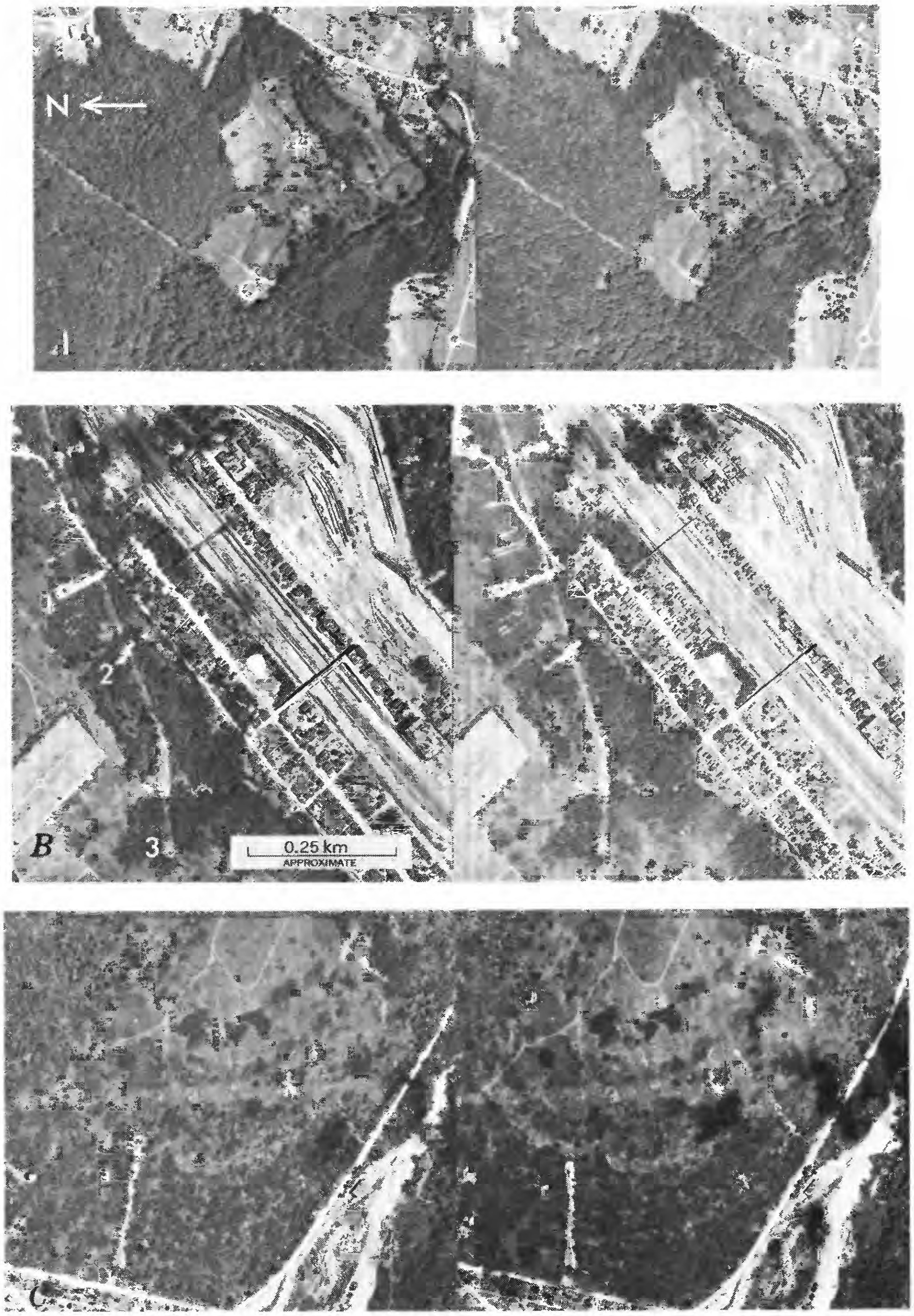


FIGURE 15.—Stereoscopic pairs of aerial photographs. *A*, Highland area west of Hinckston Run. Note lack of slides and flows in forested area compared with brush-grassland section (fig. 11, G and H). *B*, Woodvale area. Debris avalanches 1 and 2 (figs. 4 and 5, A-1 and A-2) along planar to gently concave slope. Note relationship of slump-earthflow (3) to utility line. *C*, Franklin area. Slump and debris avalanche (D-1 and D-2 on fig. 4) on largely nonforested slope above Franklin. Slump (1) shows sliding rather than flowage as demonstrated at 2 (see fig. 8*A*, *B*). Photography by L. Robert Kimball and Associates.

Mineral Point in that 60 percent of the mass movement takes place on slopes facing northwest, north, northeast, and east. However, the Little Conemaugh valley along this stretch (except for the northernmost section) is asymmetric, the slopes southeast of the drainage being slightly steeper and longer than those on the opposite side. The dense pattern of debris avalanches along one segment could be related to geologic factors, discussed in "Geology and soils". In the northernmost part, the decidedly steeper southeast-facing slopes bear a larger number of slides and flows. Slope gradient, at least locally, and geologic factors might be more significant elements affecting landsliding location than orientation is.

In southern Washington County, I found that more than 75 percent of earthflows occurred on slopes facing northwest, north, northeast, and east, and that the most predominant orientations were north and northeast. Slopes facing north receive less exposure to the sun, and soils there will remain wet longer after rain than will soils on southfacing slopes. Snow on the slopes facing northwest to east is the slowest to melt.

Williams and Guy (1973, p. 29) concluded that slopes facing north, northeast, and east had the greatest number of debris avalanches induced by Hurricane Camille in Nelson County, Va., although Scott (1972, p. 157) claimed that the storm-induced slope movement showed no apparent preferred orientation. Bogucki (1977, p. 321) found that mass-movement distribution showed a preferred orientation over a broad area in the Adirondacks, but in the most intensely affected sector of that highland area the distribution seemed to be independent of orientation. Rapp and Stromquist (1976, p. 194) noted that scars were preferentially oriented toward the strong winds of a violent rainstorm in Scandinavia. Flaccus (1958, p. 184) believed that slope exposure was not a factor in debris-avalanche distribution in the White Mountains.

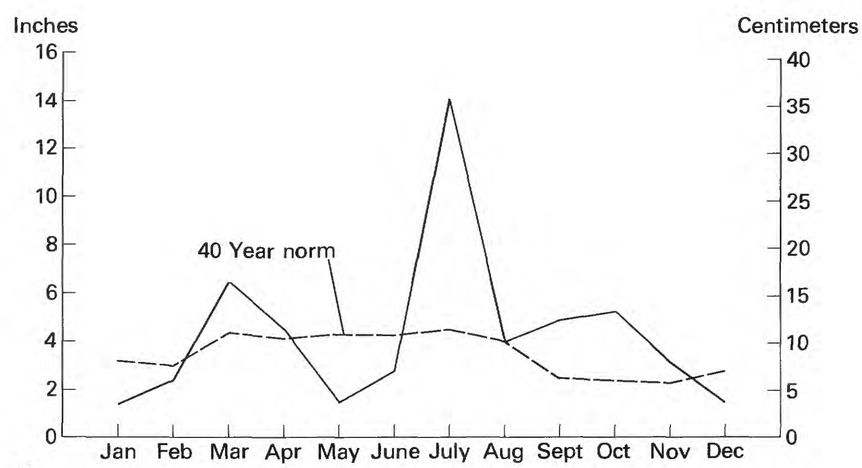
GEOLOGY AND SOILS

The Allegheny and Conemaugh Groups and their derivative soils are lithologically similar. The distribution of mass movement is about the same in each group. The soils along the slopes that have the greatest tendency to slide are classified for the most part as belonging to the Summerhill-Gilpin very stony silt loam (U.S. Soil Conservation Service, 1974a,b). These soils have developed in largely silty colluvium, which has been transported from higher elevations or has formed in place (U.S. Soil Conservation Service, 1974a, p. 13). The Summerhill soils are, in part, considered to be plastic but are given a low shrink-swell potential rating despite an A-7 AASHO (American Association of State Highway Officials) classification, which would indicate at least a moderate tendency to swelling and shrinking (U.S.S.C.S. 1974a, p. 31).

Between Franklin and South Fork (fig. 3), most of the

	DAY OF MONTH																				TOTAL
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Inches	.02	.02				.10	.51	1.54	.03			.43	.53				.26	1.02	.06	8.75	13.27
Centimeters	.05	.05				.25	1.30	3.90	.08			1.09	1.35				.66	2.59	.15	22.22	33.69

A



B

FIGURE 16.—Precipitation data. *A*, Precipitation at Johnstown, July 1–20, 1977. Source of data U.S. National Oceanic and Atmospheric Administration (1977b, p. A-2). *B*, Monthly precipitation during 1977 at Johnstown. Source of data Johnstown Tribune-Democrat, January 8, 1978, from U.S. National Oceanic and Atmospheric Administration records.

lower slopes are underlain by thickly bedded nearly monolithologic units of mostly sandstone (Pottsville Group), red and green shale (Mauch Chunk Shale), and arenaceous limestone (top of Pocono Sandstone). Small debris slides and slumps in colluvium above the railroad tracks and on an access road between Mineral Point and South Fork are controlled mainly by the steepness of the cut slopes. The head of the only conspicuous debris avalanche in the Mineral Point-South Fork area is approximately 12 to 15 m below the inferred position of an economically important flint clay and associated plastic clay within a thin shale sequence in the Pottsville Group (Phalen, 1910, p. 12).

One of the major reasons for the relatively dense pattern of debris avalanches along the southeast side of the Little Conemaugh River northeast of Franklin (fig. 9*A*, *B*) might be related to geologic factors. That part of the stratigraphic section that has abundant coal beds and accompanying underclays as well as shales, siltstones, and sandstones (Allegheny Group) underlies the midslope section. Head scars of debris avalanches occur at, or slightly downslope from, the plastic clays at various levels throughout the section. Coupled with this lithologic control is an overdip slope where the dip of the strata is inclined approximately 4° to the northwest and where springs are particularly abundant at the contact of impermeable and more permeable beds. However, not only are slopes slightly steeper here than are those along most slopes above the Little Conemaugh River, but the configuration of the slope within two 1-km-wide hollows north of Clapboard Run (fig. 4) are conducive to maximum water accumulation. A possibility exists that the intensity of the rainfall might have been greater in this area because the opposite more planar to convex side of the ridge above the Clapboard Run road (fig. 4) had many debris slides. Therefore, although geologic factors such as lithology and structure are important, the rainfall intensity and slope factors cannot be ignored.

The western part of the study area (west of Franklin) is dotted with debris avalanches and debris slides at various levels, mostly within the Conemaugh Group.

Hack and Goodlett (1960, p. 44) noted that debris avalanches in a Virginia area were generally confined to a stratigraphic unit of alternating shale and sandstone in preference to a massive sandstone unit. The slope movement distribution in other areas (Bogucki, 1970, p. 118; 1977, p. 320; Flaccus, 1958, p. 186; Williams and Guy, 1971, p. 35) suggests that lithologic types in crystalline rock terrains had little effect.

Terrain underlain by shale and clay is inherently weak in resistance to weathering and mass movement. However, considerable thickness of shale alone does not appear to promote instability. In fact, the more diverse the lithology is within any group or formation, the more varied is the permeability, resulting in a higher susceptibility of the weathered slope material to slide or flow. The textural heterogeneity of the upper part of the stratigraphic section in the Johnstown area is conducive to mass movement. Although catastrophic rains can induce slope movement on any moderately steep terrain regardless of underlying rock type, those colluvial slopes consisting of admixtures of sand, silt, and clay are most vulnerable. Generally, Allegheny- and Conemaugh-derived colluvial soils are more susceptible to mass movement than are those derived from the older stratigraphic units because the younger rocks contain more clay.

VEGETATION

Both debris avalanches and debris slides occur along forested and brushy to grassy slopes. Along the Little Conemaugh River and Hinckston Run (and excluding the slag-dump section), forested slopes predominate, and the density of mass movement forms per square kilometer is slightly less than that along the nonforested slopes. In the highland area west of Hinckston Run (fig. 11) more than 90 percent of the debris slides are in the conspicuous nonforested terrain. More specifically, in the area just north of Pleasant Hill, only a small section of the slope has been cleared, but all the debris slides took place in this brushy to grassy area (fig. 11, 15*A*).

The head scars of many mass-movement types are found in brushy areas beneath utility lines throughout the study area; commonly, the width of the head scar is controlled by the width of the cleared area (figs. 8*D*, 15*B*).

Schneider (1973, p. 92) found that forest cover reduces frequency of slope movement, and Scott (1972, p. 157) determined that a healthy forest decreases the susceptibility of slopes to debris avalanching. In eastern Africa, Temple and Rapp, (1972, p. 175) observed that less than 1 percent of the slope movement took place along the forested and steeper slopes. In New Zealand, Pain (1971, p. 83) noted that rapid mass movement is more frequent (ratio 5 to 1) under grass than under forest; Selby (1967, p. 155; 1976, p. 132) made a similar observation. In the U.S. Pacific Northwest, the destruction of forest cover by timber-harvesting operations has accelerated debris avalanching (Swanston and Swanson, 1976).

Flaccus (1958, p. 188), however, stated that maturing forests tend to increase susceptibility to mass movement, in part owing to the weight of the forest itself, but he admitted that these theories were not adequately tested.

Flaccus (1958) is not alone in his beliefs. So (1971) wrote that the distribution of the disastrous mass movements associated with a 1966 rainstorm in Hong Kong suggested that vegetation played only a limited part in stabilizing slopes. So (1971, p. 62) determined that the greatest number of slope movements took place in woodlands, the next greatest number were on bare surfaces and scrubland, and by far the fewest were on grasslands.

However, the author believes that the stabilizing effect of tree roots in the soil-binding process cannot be overlooked. Much of the tiny grove of trees adjacent to the debris avalanche labeled as 1 in figure 14*B* resisted the regolith movement. Furthermore, a few dense laurel thickets along slopes bordering Laurel Run Reservoir, where 30 cm of precipitation was recorded (fig. 11), evidently reduced the impact of the deluge and contributed to sparse mass movement in that area. Locally, high concentrations of sliding and flowage in forested areas might be due to higher concentrations of rainfall.

VIBRATIONS

The vibrations of heavy thunder might be a contributing agent in initiating some slides and flows. Residents of Johnstown and environs remarked about the seemingly continuous lightning and thunder during the night of the July 1977 storm. Flaccus (1958, p. 188–189) cited evidence of a large debris avalanche in the White Mountains immediately after thunder. Then, too, any slope movement at one location could conceivably generate enough noise and vibration to trigger slides and flows along the same slope; these forces might account for the group clustering of debris avalanches in some areas. Because all the mass movement in the Johnstown area occurred during darkness and intense rain, there was little chance for an eyewitness account.

MECHANISM OF DEBRIS AVALANCHING

The actual movement of regolith involved in the debris avalanching generally consisted of limited planar or rotational sliding extending downhill a short distance from the head scarp, followed by flowage caused by spontaneous liquefaction.

The change from sliding to flowage is believed to be caused primarily by the intrusion of water into colluvium; this intrusion increases the pore-water pressure and decreases the shearing resistance of the colluvium (Terzaghi, 1950, p. 91). Other changes include the additional weight of the regolith itself imposed by the water and the role of water in eliminating the surface tension and cohesion in silty to clayey soils.

As the pore-water pressure increases, soil particles lose their coherency, and the colluvial soil becomes a thick viscous liquid in a transformation process called spontaneous liquefaction (Terzaghi, 1950, p. 110). This change accounts for the transition from the initial sliding movement to the more profound consequent flowing action. With regard to the Johnstown phenomena, the author concurs with Scott's ideas about the debris avalanches in the Blue Ridge. Scott (1972, p. 163–165) concluded that debris-avalanche initiation is best explained by the application of Terzaghi's (1950) theories.

Computations of regolith removal from selected major slides indicate that 1,500–4,000 tons of material was removed for each of the slides.

SUMMARY

Most of the mass movement took place within the area of the 25-cm and 30-cm isohyets, the greatest amount being on slopes above the Little Conemaugh River and Hinckston Run, northeast and north of Johnstown.

Rainfall, slope characteristics (including gradient, form, and orientation), geologic and derived soil factors, vegetation, and vibrations play a role in the origin of the mass-movement features; however, precipitation intensity is the most important factor.

Slope steepness alone is not necessarily a critical factor nor did most slides and flows induced by the Johnstown storm occur along previously existing depressions or hollows along hillsides as they did in other parts of Appalachia. Overall, I saw a slight tendency for most mass movement to be preferentially oriented along slopes facing northwest, north, northeast, and east. The exact role of lithology and structure is difficult to assess, but, at least locally, these factors might be significant. The density of slides and flows is slightly greater along nonforested slopes than along forested slopes. Thunder vibrations might have triggered some slides and flows.

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