Storm-Induced Slope Movements at East Brady, Northwestern Pennsylvania

U.S. GEOLOGICAL SURVEY BULLETIN 1618

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By John S. Pomeroy

Description of the August1980 debris avalanching and other slope movements and a discussion of the factors involved

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FIGURES

Storm-Induced Slope Movements at East Brady, Northwestern Pennsylvania

By John S. Pomeroy

"Every trip taken into the Appalachian Plateaus provides continuing education about the full scale and scope of mass movement of loose material. There is so much to learn from observing the signs of active slumping and mass wastage that one cannot but wonder why such phenomena are not better known and more widely publicized."

Byron N. Cooper (1969, p. 66)

Abstract

The East Brady, Pa., area was subjected to an intense rainfall during the night of August 14, 1980, resulting in debris avalanching and other slope movements. Prestorm rainfall was substantially above normal during the 1980 summer.

Almost all the debris avalanching took place along existing hillside depressions. In comparison with the geomorphic effects of the 1977 Johnstown storm, the greater concentration of slope movements at East Brady is a reflection of steeper slopes and a higher drainage density. Colluvium is minimal and bedrock is exposed in almost all scars.

The bedrock-colluvium interface served as the slippage surface for most of the 1980 storm slope movements. Head scarps revealed a concentration of water or seeps at contacts of permeable and impermeable horizons. About 90 percent of the slope movements originated at or below the Lower Kittanning coal bed, which lies below a thick sandstone section.

Slope movement involving both colluvium and bedrock has been continual throughout historic and prehistoric times. One historic bedrock slump measures 60 m wide at the head and 137 m at the toe. The 1980 storm reactivated 20 to 25 percent of the deposit, but all movement took place in colluvium where slippage was at or close to the bedrock-colluvium interface. Only one conspicuous hollow along the slope opposite East Brady showed no storm-induced movement from the 1980 storm; however, extensive hummocky material in that hollow attests to older slope movements.

Stress release along valley walls has contributed to an increase and widening of joints and an opening of bedding-plane fractures. Movement of separated blocks and slumping of rock masses all contributed to the formation of colluvium. Subsequent buildup of weathered rock and soil and infrequent flushing out of that material has led to colluvial slope movements such as those that occurred in August 1980.

Storm-induced movements in August 1980 affected about 2.5 percent of the slope surface in two areas adjacent to East Brady and ranged in density from 56 to 85 movements per square kilometer. A minimum of 50,000 tons of regolith is estimated to have been transported along the slopes opposite and east of East Brady. About one quarter of this amount is believed to have entered the Allegheny River.

INTRODUCTION

The area adjacent to East Brady and Bradys Bend, Pa., was subjected to more than 13 cm of rain on the evening of August 14, 1980 (fig. 1; Pomeroy, 1980a). Slope movements, chiefly debris avalanches of saturated colluvium, occurred during the storm along the steep sides of the Allegheny River valley (fig. 2).

A slope-stability reconnaissance study of western Pennsylvania based on aerial photographic interpretation and local field investigations (Pomeroy, 1978) delineated an extensive rock slump opposite East Brady as well as deposits of other slope movements. These other slope deposits, mostly prehistoric, do not necessarily represent single events but resulted from successive movements of saturated regolith. Limited radiocarbon dating of similar deposits from the Upper Ohio Valley indicate a Wisconsinan and post-Wisconsinan age (Gray and others, 1979).

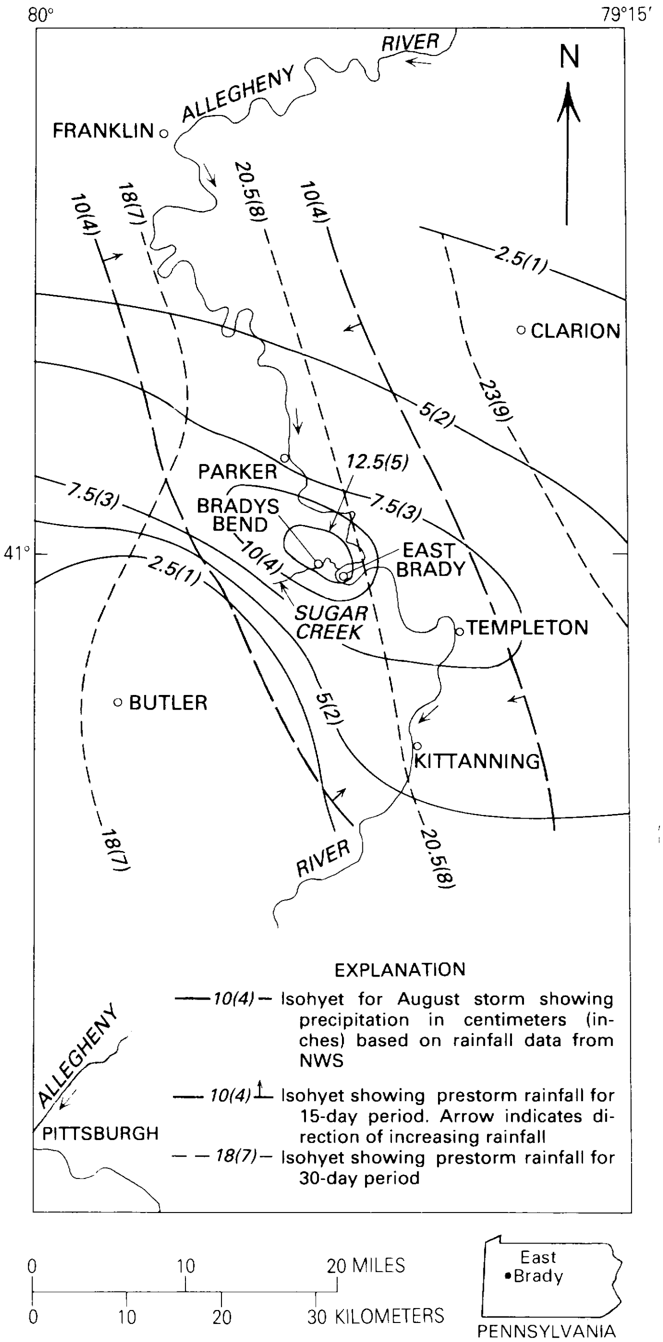


Figure 1. East Brady region, Pennsylvania, showing total rainfall for the August 14, 1980, storm, and prestorm rainfall for 15-day and 30-day periods.

The purpose of the current investigation was to describe the features of slope movements caused by this locally severe storm and to relate the geologic and other factors, including slope and rainfall, to the slope movement in the East Brady area. A few days were spent in the area on each of three occasions--immediately after the storm in August 1980, in mid-November 1980, and in early May 1981. During the earlier visits, slopes to the northeast along the Allegheny River and along Sugar Creek (figs. 1, 2) were also examined. Aerial photographs taken in 1938, 1972, and 1974 provided evidence of some recent slope movements.

In this report, I have adopted the term "slope movement" rather than "landslide" as a general, inclusive term. "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). The popular geomorphic term "mass movement" is synonymous with "slope movement" and is not used in this report.

The term "debris avalanche," the most common type of slope movement feature produced by the storm, was originally defined by Sharpe (1938). A debris avalanche "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). Varnes (1978, p. 18) continued to use the term and defined it as a variety of very rapid to extremely rapid debris flows. Both authors concluded that the transport mechanism for debris avalanches is chiefly flowage of the viscous soil-water matrix.

Although many workers in the Eastern United States have adopted the term "debris avalanche," other investigators have preferred the term "debris slide" to describe similar movements (Pomeroy, 1980b). The term "debris slide" is used herein to define only those movements that are commonly rapid and that involve translational or planar movement without flowage (Varnes, 1978). "Slumps" are regarded by all workers as rotational movement and are either rock slumps involving bedrock or earth slumps involving colluvium.

THE EAST BRADY STORM

An intense rainfall during the evening of Thursday, August 14, 1980, extending with diminishing force into early Friday morning, August 15, was centered over East Brady and affected parts of Armstrong, Butler, and Clarion Counties.

The town of Bradys Bend along Sugar Creek (fig. 1) was the most severely affected community because of the flash flooding. The thunderstorm began about 8 p.m. and became intense between 9 p.m. and 10 p.m. The rainfall was the heaviest ever experienced by several long-term residents. Flooding along Sugar Creek began at about 11:30 p.m. (August 14) and peaked $1\frac{1}{2}$ to $2\frac{1}{4}$ hours later. The creek was back within its banks by 9 a.m. (August 15). Nine people lost their lives in the

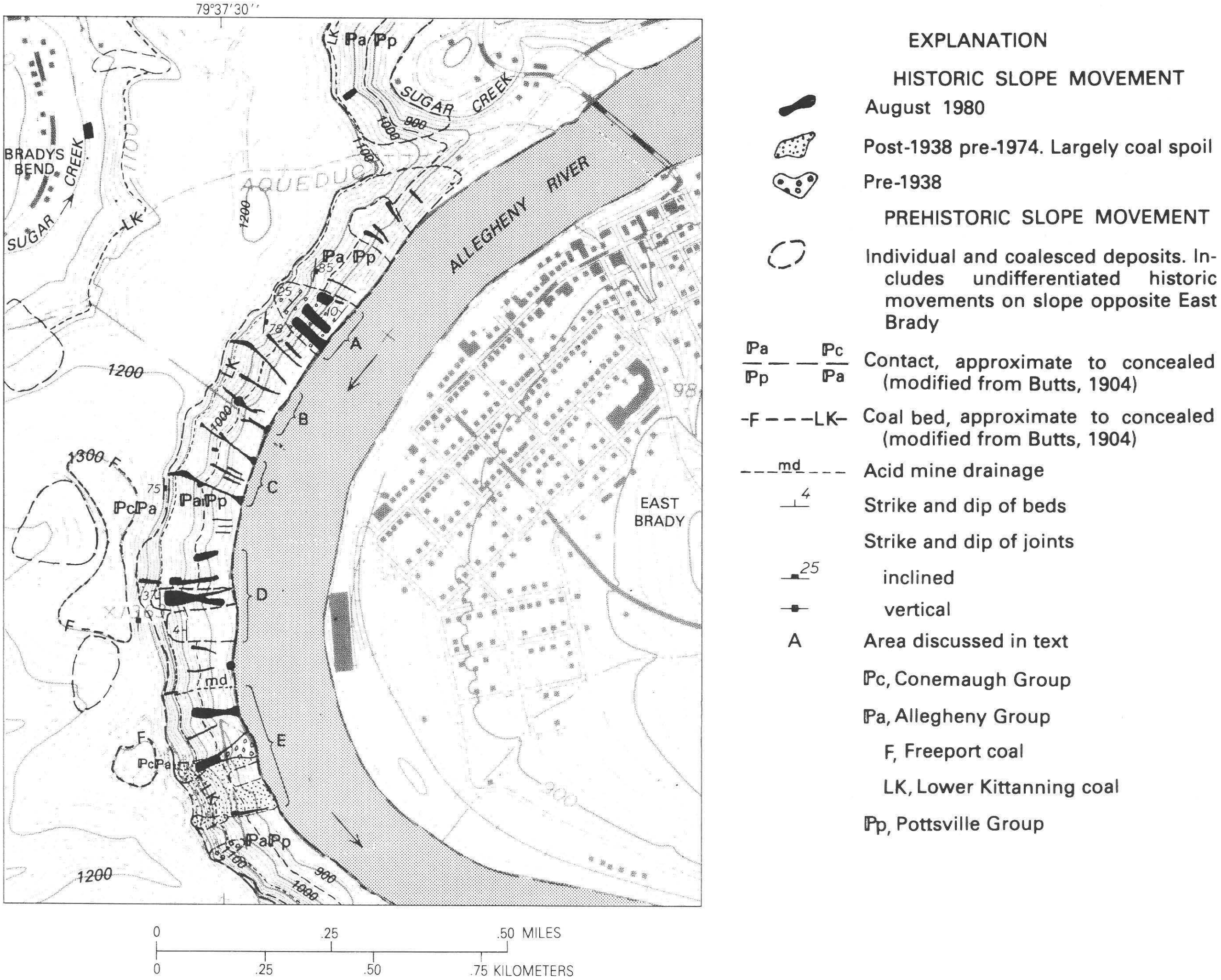


Figure 2. Slope opposite East Brady, Pa., showing slope movements and geologic features.

Bradys Bend area, and an estimated $50 million worth of property was damaged or destroyed (National Weather Service, 1980).

The heaviest recorded precipitation (14 cm) occurred at an unofficial rain gauge at Queenstown (Ralph Folino, National Weather Service, oral commun., 1981), which lies 1 km north of Bradys Bend. More rain probably fell at higher elevations. Because rain gauges are commonly sited in valley communities or on farmlands, rainfall measurements do not give a true indication of precipitation falling on hillside forestland. Lee (1980) stated that the annual amount of precipitation is about 4 to 8 cm greater for each 100 m of elevation. In addition to receiving more rain, upland forests lose less water by evaporation because of lower temperatures, and hence maintain wetter soils than do valley communities and farmlands (Eschner and Patric, 1982).

The National Weather Service (1980) reported that

> The locally heavy rain occurred at the intersection of two instability lines. One instability line had moved into Pennsylvania during the afternoon and then stalled east to west through central Pennsylvania. A second line in a north to south orientation, and, with associated thunderstorms, moved in from Ohio late in the afternoon. This second line intersected with the first line during the evening of the event. The net effect was to increase the intensity and duration of rainfall at the point these two lines intersected.

Rainfall data for western Pennsylvania for July and early August show that the ground was well saturated because of above-normal rainfall in the weeks preceding the event (fig. 1). Precipitation for the 2-week period ending August 14 ranged from 9 cm at Clarion to 11.5 cm at Kittanning. The 4-week prestorm rainfall ranged from 18 cm at Butler to 24 cm at Clarion. Total precipitation for the period June 1 to August 14 was 37 cm at Butler and 39 cm at Kittanning, much above average.

GEOLOGY OF THE EAST BRADY AREA

The region is underlain by cyclothemic sections of alternating beds of shale, siltstone and sandstone, and coal of Pennsylvanian age. Butts' bedrock geologic map (1904) shows the slope opposite East Brady to consist predominantly of beds of the Allegheny Group, which is approximately 106 m thick. A maximum of 18 m of beds of the Conemaugh Group caps the highest parts of the upland surface. The poorly exposed and less steep lower slope is underlain by the Pottsville Group. Most of the rock that crops out along the slope in enlarged drainages is shale and lesser amounts of siltstone and sandstone. Two coal beds, Freeport and Lower Kittanning, have been mined here in the past. Claystone forms an underclay beneath coal beds. Limestone is rare and occurs only in the lower part of the Allegheny Group. Outcrops, mostly resistant sandstone, are conspicuous only above the Lower Kittanning coal, which occurs two-thirds of the way up the slope.

The attitude of the rocks is subhorizontal with a regional dip of less than 1°.

The East Brady area lies 32 km southeast and downstream of the maximum extent of Pleistocene glacial ice (Illinoian and Wisconsinan stages). The Allegheny Valley was a major drainage leading from successive ice borders. In this periglacial environment, the Allegheny Valley was twice filled with glacial outwash deposits (Butts, 1904). Since glacial times the Allegheny River has been eroding its present channel in these deposits.

Soils along the East Brady slopes are classified as Weikert-Gilpin soils (USSCS, 1977) formed in colluvium and debris derived from interbedded shale, siltstone, and fine-grained sandstone. The soils are typically shallow and well drained, and rate of permeability is moderately rapid.

Incised drainages along the lower parts of slopes indicate that the maximum thickness of colluvium is about 5 to 6 m. The colluvium is most extensive on concave (sidewise) slopes below sandstone ledges.

X-ray diffraction analysis of light-gray clay from head areas of slope movements along the slope opposite East Brady shows illite to be 70 to 81 percent of the sample and kaolinite, 19 to 30 percent. Both illite and kaolinite are moderately well crystallized, and mixed layering (if any) is barely discernible (Virginia Gonzalez, written commun., 1982).

Clay from a 19-m-wide storm-induced earth slump at the Queenstown Road-Whiskey Run intersection, 2.5 km northwest of East Brady, was examined for its mineralogy. The dark-gray silty clayey colluvium from the Allegheny Group contained chiefly illite and subordinant kaolinite (Gloria Hunsberger, written commun., 1981). The illite is potassium-deficient, which is a condition prevalent elsewhere in shales and mudstones of Devonian to Permian age in western Pennsylvania. Fisher and others (1968) documented a similar potassium deficiency in the unstable illitic red shales and mudstones of Pennsylvanian and Permian age in southeastern Ohio.

SLOPE MOVEMENTS OPPOSITE EAST BRADY

A description of the slope movements opposite East Brady is keyed to figure 2 (A-E). Individual slope movements are discussed from north to south for areas A to E.

Area A

An inventory of slope stability features in western Pennsylvania revealed an apparent massive slope movement that had taken place opposite East Brady (figs. 2 and 3). Field inspection confirmed the presence of a rock slump. Slumped bedrock containing strata dipping moderately back toward the slope (fig. 4) could be differentiated among dislocated sandstone blocks on the very gently inclined bench (fig. 3, area A), in front of a bedrock-faced headwall. The width of the slump in the head area is approximately 60 m, increasing downslope to 137 m at the slump foot. Because the arcuate head scarp is easily recognized, the slope movement is probably historic. The movement probably occurred before 1920 because none of the older inhabitants of East Brady who were interviewed remembered the event. Furthermore, some trees as old as 60 years are rooted on the slump block. Slanted and curved tree trunks indicate that creep has occurred since the initial movement.

No evidence points to any recent deep-seated reactivation of the slump block. However, the 1980 storm reactivated parts of the deposit below the bench (fig. 5) affecting about one-fifth to one-fourth of the entire slump block. The most recent slope movement was shallow and took place in colluvium where slippage was at, or close to, the bedrock-

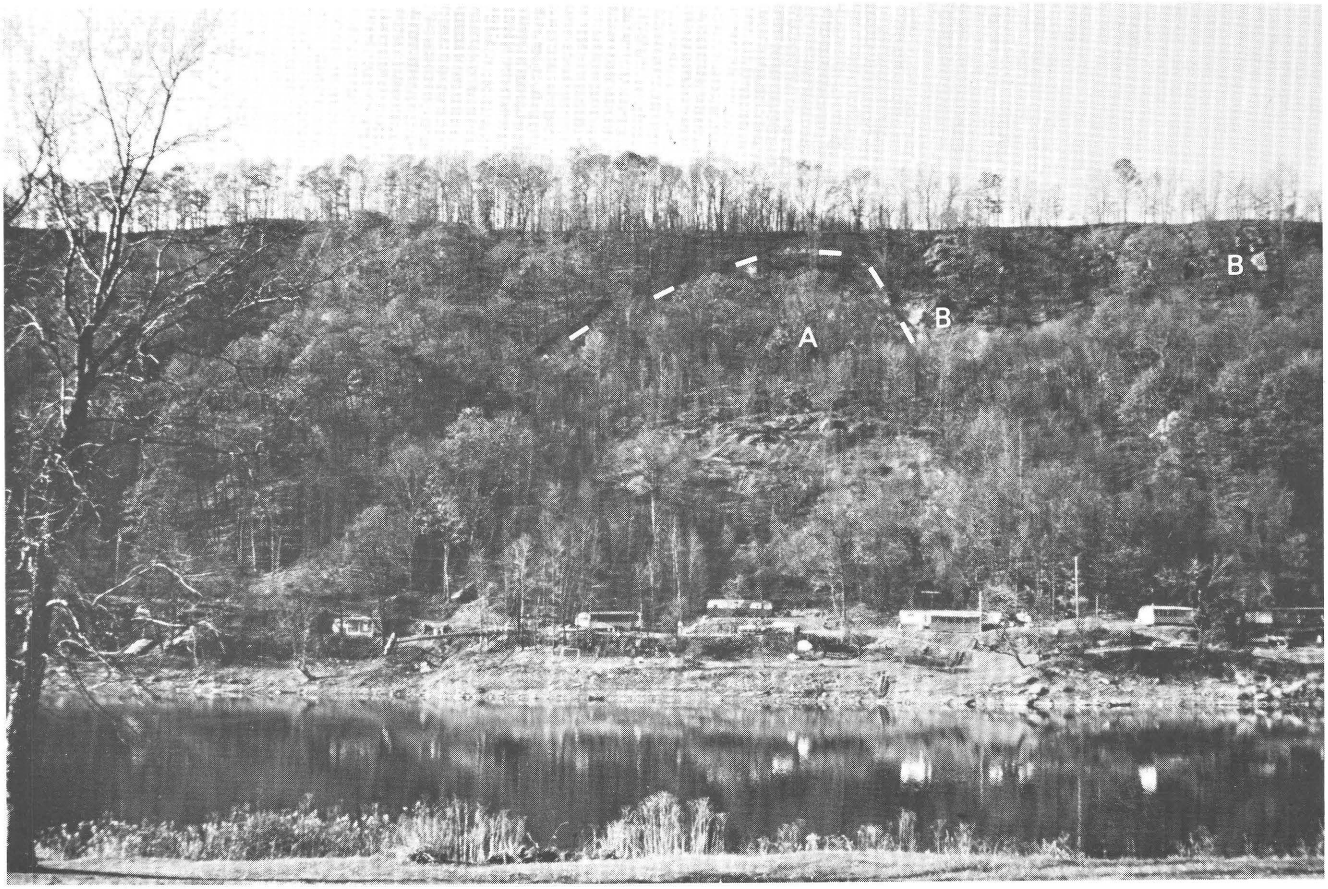


Figure 3. Large rock slump opposite East Brady, Pa., photographed in November 1976 (fig. 2, area A). Note indication of arcuate head scarp on pre-1938 rock slump. A is locale of figure 4. Subhorizontal bedrock adjacent to slump at B.

colluvium interface. Although outcrop was sparse along the fresh scars except in the head areas, weathered shale, carbonaceous shale, and sandstone float were abundant. Steep slopes above the sandstone headwall have been scarred by small debris slides. Small hollows a few meters wide above the old main scarp directed storm runoff water from the 13° (24 percent) sloping grassland on top. Scarring of the steeper slopes lying above the main scarp resulting in removal of thin soil and vegetative cover has made the head scarp more visible than before (fig. 5). Some precariously perched weathered bedrock along the nearly vertical headwall of the slump fell as a result of the 1980 storm.

The slope in the head areas of the two conspicuous movements ranged from 34° (68 percent) to 38° (78 percent). Each movement was approximately 21 m wide, and main scarps were 1.5 m high. No loss of life resulted from the reactivation of part of the older deposit. However, several mobile homes were extensively damaged, and at least two cars were destroyed.

A possible prehistoric rock slump was found 150 m northeast of this area (fig. 2, area A).

Figure 4. Slumped bedrock that lies within large historic rock slump (fig. 2, area A).

Area B

The highest debris avalanche originated about 12 m below the upland rim (fig. 2). The head was 6 m wide and developed in thin sandy colluvium along the steep south side of a southeast-trending hollow. Seeps lie 15 m below the head at about 1,070 feet altitude at the contact of a 0.5-m-thick bluish-gray claystone and an overlying sandstone bed. Incised drainage below the main spring revealed a 12-m section largely of shale but containing minor very thin beds of sandstone. The path of the debris avalanche widened to 12 m before it joined the main hollow but then narrowed considerably, confined to the preexisting drainage. The height of the movement was shown by dried clayey silt 2.5 m above the ground on the bark of an undisturbed tree along the avalanche path. The debris avalanche stopped before it reached the Allegheny River because of a gentle lower slope.

About 60 m to the south and along a 41° (85 percent) slope, an 8.0-m-wide debris avalanche head was located in very thin (less than 1 m) colluvium overlying splintery carbonaceous shale. The flow followed a gulch that is not reflected by the topographic contours. Transported debris included a large tree that battered a trailer.

The head of a 6-m-wide debris avalanche was found along a 100-percent- grade planar slope. Less than 1 m of soil covered very thinly bedded shale and sandstone in the uppermost 2 m of the head. Above the head, a 15-m-wide concave-shaped (sidewise) slope had concentrated the water feeding into the disturbed area. Thin-bedded sandstone ledges flank the more extensive head area of the older slope movement. The debris avalanche cascaded over a 6-m cliff composed of a 4.5-m-thick shale section capped by 1.5 m of sandstone and widened as it fell into a nearly 100 percent grade, 18-m-wide, bowl-shaped depression. This concave-shaped area is itself the head area of a former larger slope movement. Material from the 1980 debris avalanche here consisted of coarse shale and sandstone fragments surrounded by a clayey silt matrix. The debris avalanche narrowed downslope and terminated on a more gentle slope, except for a highly fluid clay-rich appendage that stopped within a few meters of a mobile home.

Along the lower slope to the south, two 7.5-m-wide (head area) movements occurred along a 37° (77

Figure 5. Large rock slump opposite East Brady, Pa., photographed in November 1980 (fig. 2, area A). Compare with figure 3. Scarring of headward margins at A. Slope movements (B) occurred during August storm. Site C (at foot of recent flow) is former location of trailer seen on figure 3.

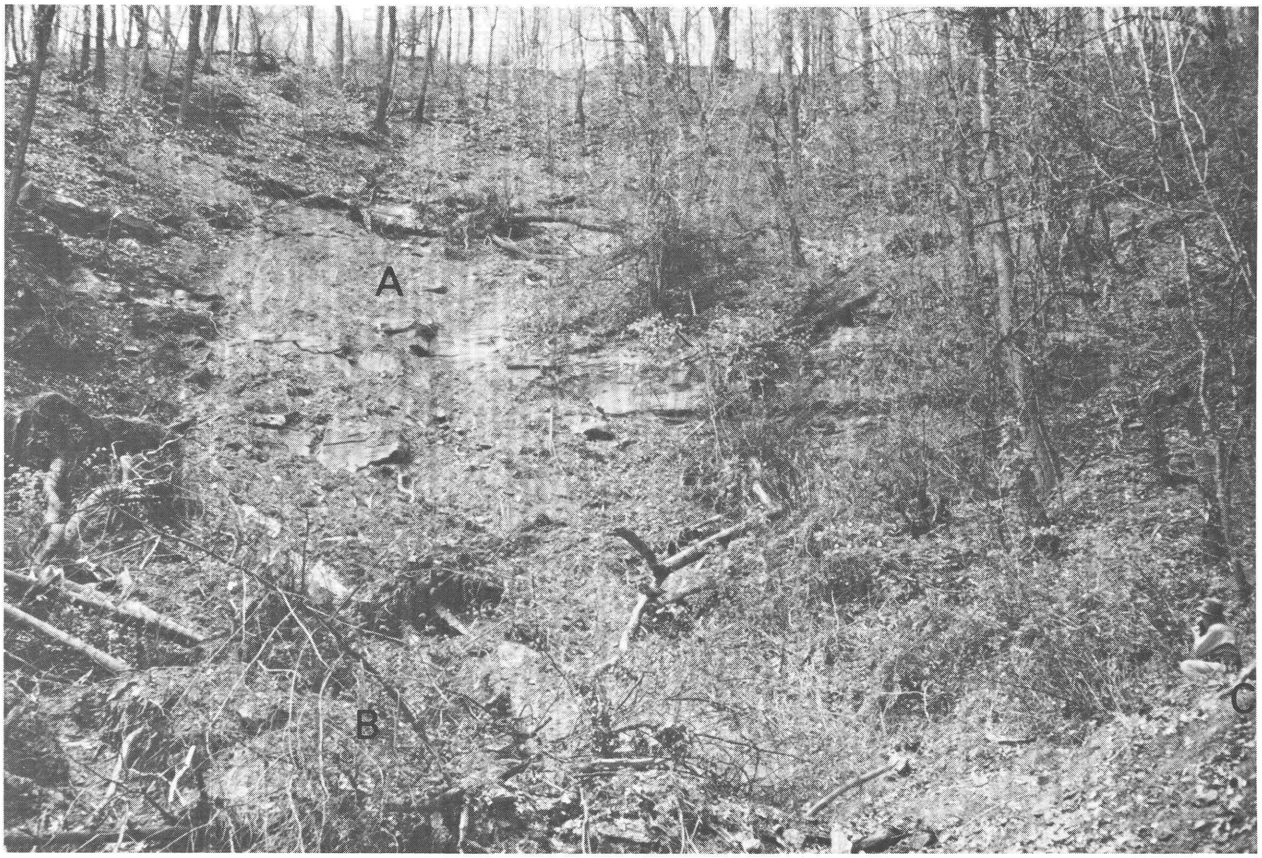


Figure 6. Head of longest debris avalanche (fig. 2, area C). Note thinness of removed regolith in head (A) and pileup of material at bench in foreground (B). The debris avalanche continued downslope from bench. Person (C) is at lateral margin of slope movement.

percent) planar slope. They narrowed downslope, converged, and flowed into the river. The foot of the combined movements later became part of a 15-m-wide, 4.5-m-long earth slump with a 1-m-high scarp at the river bank.

Hummocky terrain, which includes mounds 2.5 m high and 15 m wide along the lower slope, attests to prehistoric slope movement.

Area C

Two heads of debris avalanches (at 970 and 1,060 feet altitude) contributed colluvium to a conspicuous V-notched drainage (fig. 2). The 3-m-wide upper slope movement along the south side of the drainage took place in thin soil above interbedded sandstone and shale. Below the head scarp, debris was wrapped around the uphill side of a tree and extended 1 m above the ground surface. The lower head along the north side of the drainage showed carbonaceous shale and light-gray underclay. The combined detritus from the gulch formed an 18- to 24-m-wide fan at the edge of the river. A 30-m section of shale interbedded with thin sandstone crops out in the enlarged gulch.

In the midst of a larger old slope movement, where living trees are scarce among vines and briar, a 9.0-m-wide movement started at 980 ft altitude and extended downslope for only 15 m. The head scar lies within a shale sequence below a sandstone ledge (and within a laterally concave slope or shallow gully not discernible on the map).

A trio of narrow debris avalanches occurred in the same older slope movement area previously mentioned. All the movements originated in silty to clayey colluvium derived largely from shale. The debris avalanches, approximately 10 m wide at their heads, moved down a 40° (82 percent) slope.

The longest (180 m) debris avalanche originated on the south side of a wide, steep, concave (sidewise) slope 10 m below the rim (fig. 6). The debris avalanche was 4.5 m wide at the head; sandy fragmental colluvium, 0.3 to 1.0 m thick, was exposed along its margin. The unusually steep (64°) bedrock-colluvium interface and a conspicuous north-south trending joint dipping 75° to the east were noted at the head of the slope movement.

The debris avalanche broadened downhill over a very steep (greater than 100 percent) slope and reached a maximum width of 12 m in an area of abundant seeps slightly below a sandstone bench The slope movement followed the V-drainage, and the width narrowed to less than 6 m. The foot widened laterally to 24 m where the slope moderates immediately above the shoreline. A poststorm, 12-m-wide debris slide that formed at 980 feet altitude on the south side of the channel choked the path of the debris avalanche. Similar poststorm tensional features have formed near Johnstown (Pomeroy, 1982) and can be attributed to a lack of support along the slope bordering the deepened debris avalanche channel.

Area D

A 15-m-wide debris avalanche along the south side of a laterally concave slope (fig. 2) showed thin colluvium overlying shale at its head. The sandstone-ribbed cove steepens above the head scar.

The conspicuous drainage to the north appears to be the only one along the slope opposite East Brady without any evidence of recent storm-induced mass movement, probably because of the extreme thinness of colluvium. However, hummocky material from ancient slope movements covers the lower slope.

About 12 m below the highland rim, a head scar (fig. 7) of a debris avalanche exposed 4.5 m of interbedded shale and sandstone with the lowermost half in splintery brown shale. The 8-m long by 10-m wide amphitheater-shaped head revealed a 6-m-high main scarp cut at an angle greater than 50°. The adjacent slope measures 38° (78 percent). Although the debris avalanche commenced as an earth slump, it cascaded and flowed downslope over a 45°-50° (>100 percent) surface and maintained a width of 7.5-9.0 m. The debris avalanche stopped on the conspicuous bench below 1,100 feet.

A 13-m-wide debris avalanche started at the rim of the bench directly in line with the upper slope movement and continued downslope for about 100 m.

A large debris avalanche (fig. 8) originated at about 1,050 feet altitude at the edge of the bench south of the previously mentioned movement. The main part flowed downslope until it stopped along the more gentle slope about 30 m from the river. In its lower extremity the flow bifurcated, and a 4.5- to 6.0-m-wide segment flowed to the river. The fact that the main path was cut below the level of the intersection of the fork indicated that the appendage represented an earlier event during the storm.

The head (fig. 8), nearly 30 m at its widest dimension, is part of a slightly larger concave (sidewise) slope. The adjacent slope measures 39°

Figure 7. Amphitheater-shaped head scar of debris avalanche (fig. 2, area D) with outcrop (a) in left center of photograph. Shirt hanging on tree indicates scale.

(80 percent). Carbonaceous and noncarbonaceous shale and small amounts of sandstone form the face of the 45° (100 percent) scarp. Slippage occurred at the bedrock-colluvium interface, and, as a result, a thickness of about 1.5 m of colluvium was removed from the head area. Small seepages were observed along the head scarp where boulder colluvium overlies thin sandstone, coal, and claystone. This part of the slope has been subjected to previous historic slope movements as documented on aerial photographs.

The 4° to 5° westward dip of beds exposed in the present scarp (fig. 9*A*) indicates that the recent failure occurred in an older rock slump of probable prehistoric age. The carbonaceous shale and coal in the colluvium below the scarp are similar to the slope debris at locality A. The very gently sloping bench above the main scarp is hummocky with sandstone boulders to the base of the cliff and resembles the slope movement at locality A. Trees, at least 60 to 65 years old, are growing on massive sandstone blocks. The fact that they are not slanted nor do they show curved trunks indicates a lack of recent creep movement. One slump block dips 37° back toward the slope (fig. 9*B*).

A large prehistoric coarse rock debris deposit lies to the south. The bouldery surface containing large sandstone blocks is masked by a forest no younger than that on the adjacent slope to the south. The movement was 85 m wide at its base and caused the shoreline to bow out slightly in this area.

At the head, a sandstone cliff nearly 30 m high with closely spaced (1.0 to 1.5 m) joints trending north-south and dipping 70°-85° to the east supplied the rock debris.

Area E

An adit in the Lower Kittanning coal is found at about 1,085 feet altitude. Acid mine drainage is copious (fig. 2) and shows the influence of the underlying impermeable underclay. Though no slope movement occurs at this horizon, the position of the underclay indicates lithologic control for seepage. Also, the coal has closely spaced joints, which makes the coal an excellent aquifer.

The head scarp of a debris avalanche originating at the 1,000-ft contour was 25 m wide and occupied the north side of a larger older slope movement. Shale and coal were exposed in the headwall along a 36° (72 percent) slope. A few sandstone ledges lie immediately above the head. The debris avalanche continued to the river where a 20-m-wide earth slump took place about 15 m above the shoreline.

Small scars 4.5 to 6.0 m wide at the head of a small cove were observed just below a nearly vertical slope of sandstone. The highest scar shows 1.5 m of Lower Kittanning coal and underclay along a 39° (80 percent) slope. Seepage at the coal-underclay contact probably caused the colluvial slope movement.

Several episodes of historic slope movement have originated in the major gulch east and southeast of a prominent knob affected by strip mining (fig. 2). The most recent movement, part of a wider concave (sidewise) slope where sliding and flowage have occurred in the past, began a few

Figure 8. Part of 30-m-wide head of debris avalanche. Small seepages are common above person (center of photograph) where sandstone boulder colluvium and sandstone overlie thin coal and claystone. Gently sloping surface above scarp is part of head area of prehistoric rock slump (fig. 2, area D). Note person for scale.

meters below the level of the Lower Kittanning coal and underclay along a 36° (72 percent) slope. Shale, mostly fissile, crops out along the head scarp and path below. Tree growth of various ages surrounding the head area suggests that several historic episodes of slope movement have taken place. Seepage was noted at a sandstone-shale contact near the top of the head scarp. With the addition of water from the overlying seep at the Lower Kittanning coal-underclay contact, the pore-water pressure of the thin soil probably exceeded its shearing resistance, and the debris avalanche was triggered. Extensions, 6 to 9 m wide, have taken place post-dating the storm above both sides of the head scarp. The terminus of the August 1980 debris avalanche lies on top of an old (pre-1938) flow.

The debris avalanche at the south end of the area shown in figure 2 showed a head area containing shale along a 38° (78 percent) slope below a much steeper slope of sandstone and shale. The slope movement took place in the colluvial soil at or immediately below the contact of the permeable and impermeable horizons.

SLOPE MOVEMENTS EAST OF EAST BRADY

The August 1980 debris avalanches, debris slides, and slumps also took place elsewhere in the East Brady area, particularly along the north-facing slope 1.5 to 3.0 km east of East Brady (fig. 10). Lesser affected areas included the slopes 3.0 to 8.0 km up the river from East Brady, in the Templeton region (16 km southeast of East Brady along the Allegheny River), and the Sugar Creek valley and adjacent tributaries west of East Brady (fig. 1). Only the north-facing slope east of East Brady will be discussed.

In at least 10 locations, an unimproved dirt road at the base of the slope was blocked by soil, rock, and tree material from debris avalanche channels. Most of these toe deposits were 9 m in width or less, and average thickness was slightly more than 1.5 m.

Most of the debris avalanches east of East Brady occupied well-defined drainage channels showing nearly continuous bedrock exposure. Few were more than 120 m long; most involved less than 83 m relief and were confined to the lower half of the slope. Debris avalanches on 100 percent grade or steeper slopes were uncommon because of an extremely thin cover of colluvium. The lower slope is steeper than that opposite East Brady and shows only thin (0-5 m) colluvium. Much of the material along the chutes cascaded over a sandstone cliff above the unimproved dirt road and flowed into the

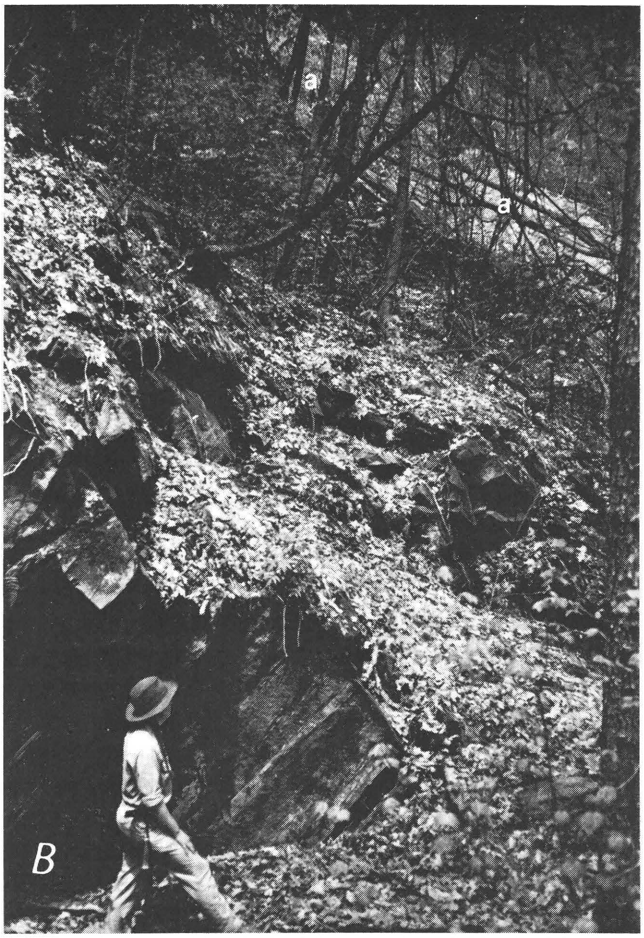
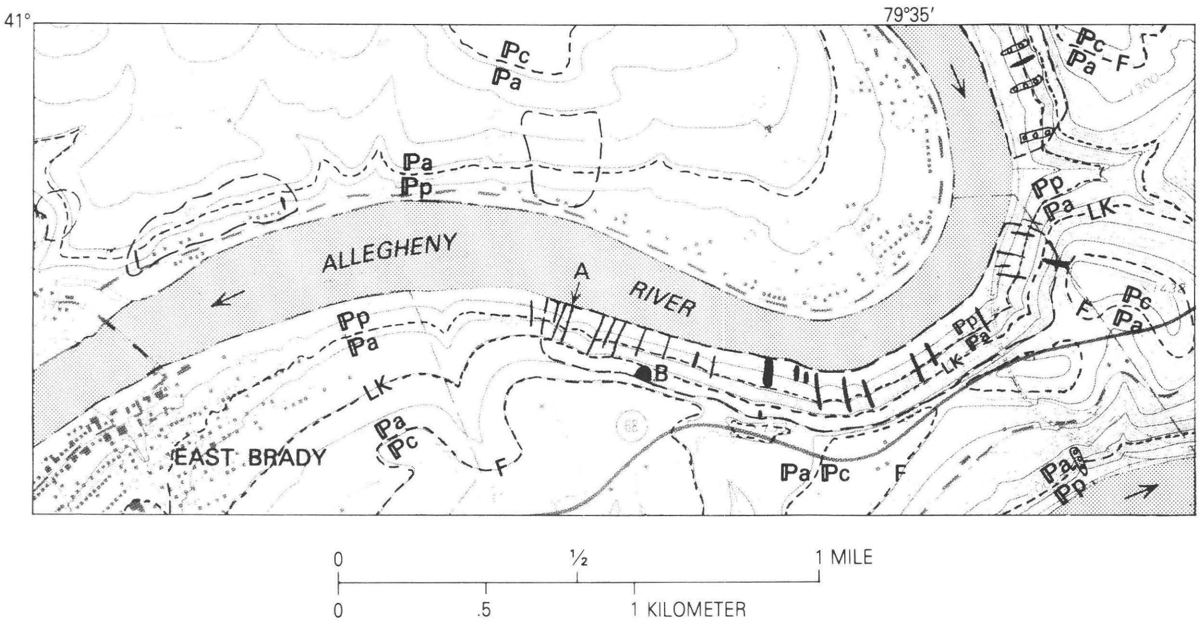


Figure 9. Slope movements in 1980. *A*. View across 1980 major slope movement (fig. 2, area D) in colluvium. Gently slumped bedrock is part of midsection of older (prehistoric) movement. *B*. Slumped bedrock in foreground dipping 39° back toward slope. Bedrock is in head area of same prehistoric rock slump as in 9*A*. 1980 slope movement (a) in background (fig. 2, area D).



EXPLANATION

HISTORIC SLOPE MOVEMENT

August 1980

Pre-1938

PREHISTORIC SLOPE MOVEMENT

Individual and coalesced deposits. Includes undifferentiated historic slides

A,B — Slope movements referred to in text

Pa/Pp — Pc/Pa — Contact, approximate (from Butts, 1904; Patterson and Van Lieu, 1972)

-F - - -LK- Coal bed, approximate to concealed (modified from Butts, 1904)

73 — Strike and dip of joints

Pc, Conemaugh Group

Pa, Allegheny Group

F, Freeport coal

LK, Lower Kittanning coal

Pp, Pottsville Group

Figure 10. Slope movements east of East Brady.

Allegheny River. A greater thickness (by about 9 m) of Pottsville Group rocks is exposed here than in the area opposite East Brady, and the steeper topography reflects less shale and more sandstone.

At locality A (figs. 10, 11*A*, *B*) the slope in the midsection of the debris avalanche averaged 40° (82 percent) but lessened to 33° (65 percent) at the head. The 3-m-high main scarp was within a concave (sidewise) slope. Almost 2 m of colluvium was estimated to have been removed at the head. The head (fig. 11*B*) was slightly wider than the chute below, which was 6 m wide and 2.5 to 3.0 m deep. The path of the debris avalanche measured 135 m. A minimum of 1,500 m^3 of colluvium was probably flushed out of the channel and entered the Allegheny River.

As the lower slope moderates slightly eastward toward the river bend, a thicker cover of colluvium shows a few wider and more irregularly shaped debris avalanches (fig. 10). Heads of some scars were as much as 25 m wide.

Along this north-facing slope, evidence of older but historic debris avalanches abounded. One old 30-m-long linear scar, covered with 1.2- to 1.8-m-high brush, was equal in width and continuous with the fresh debris avalanche immediately below it. Brushy slope areas, 20-25 m wide, devoid of forest growth represent obvious older historic movements.

Parts of a few of these areas showed reactivation.

An roughly equidimensional scar (B, fig. 10) is seen in the upper part of the slope. The width and length were 45 m and 48 m respectively along a 45° (100 percent) slope (fig. 11*C*). Thin soil and weathered rock, most not exceeding 0.3 m in thickness, were stripped off this large area, which is underlain by shale and sandstone. The terminus of the detritus was along a natural rock bench at the base of a 7.5-m-high sandstone cliff which was overridden by the debris. Well-developed joints, striking N. 80° W. and dipping 73° NE. paralleling the river, account for the loose, highly weathered regolith that contributed to the rock debris.

More than 90 percent of the historic slope movement along this side of the river has taken place beneath the position of the Lower Kittanning coal. Seepages along this horizon probably played a role in the initiation of slope movement.

DISCUSSION

Rainfall, slope, and geologic factors contributed to the occurrence of the debris avalanching and related movements in the East Brady area.

The intensity of the 1980 storm was a major factor; much of the rain fell within an hour or slightly longer period. By comparison, the Johnstown storm of 1977 (Pomeroy, 1980b, 1982) involved more rainfall (as much as 30 cm) over a longer period of time, but with concentrated rainfall during short intervals. Wolman and Gerson (1978,

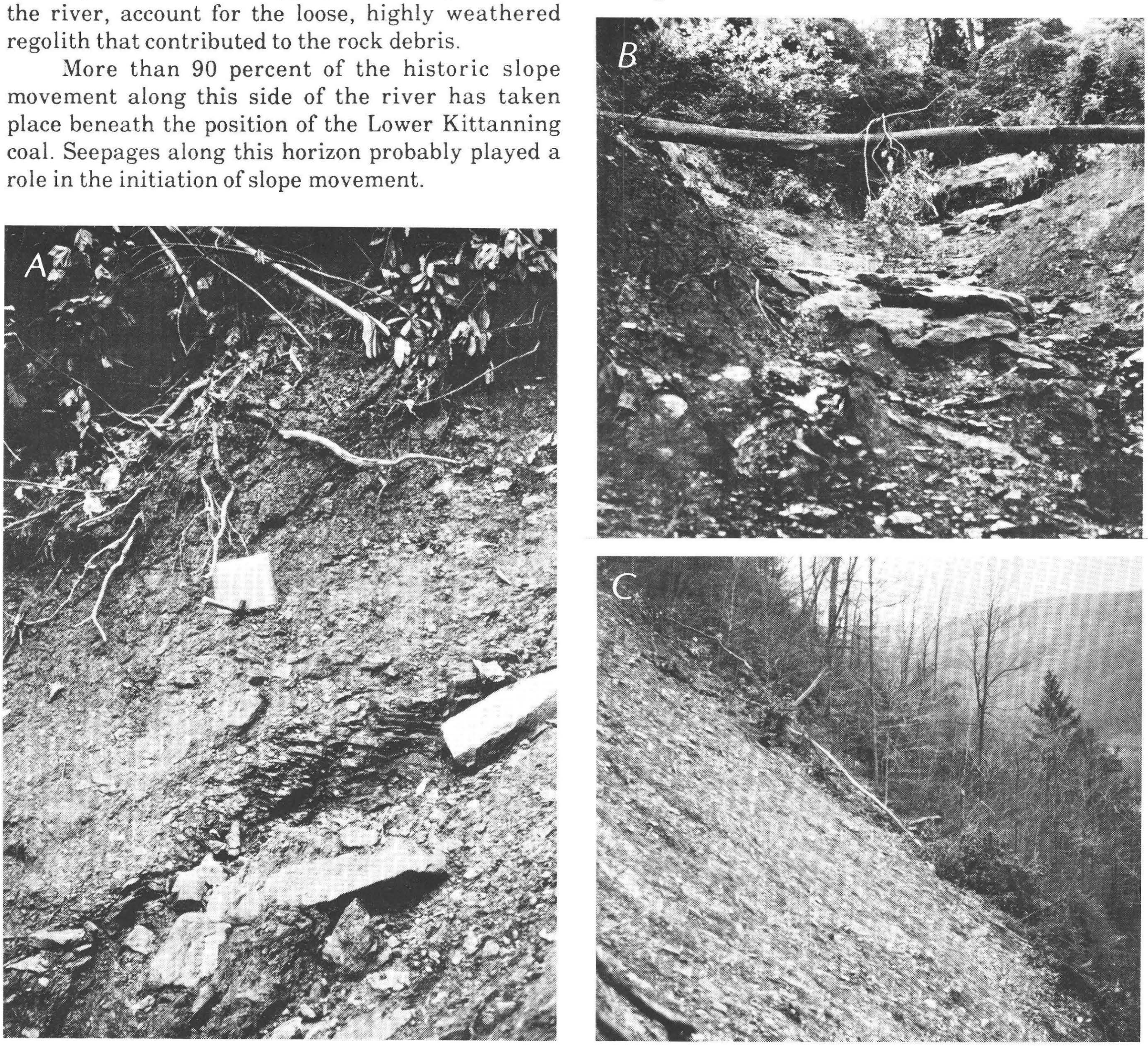


Figure 11. Slope movements east of East Brady. *A*, View across debris avalanche (A in fig. 10). Chute is about 2.6 m deep and 6.0 m wide. Slope is 35° (70 percent). Regolith is 1.5 m thick. *B*, Head of debris avalanche (A in fig. 10). Note break in slope between head and chute. Brush-covered linear depression (former debris avalanche site) lies above fresh scar. *C*, Slope movement scar (fig. 10, area B) along steep slope (45°, 100 percent) east of East Brady. Note extreme thinness of removed regolith. Distance from position of camera across slope to other lateral margin is 45 m.

p. 202) concluded that intensive rainfall is the most important prerequisite for extensive slope movements in humid montane environments. The author concurs with this assessment on the basis of both the East Brady and Johnstown investigations (Pomeroy, 1980b, 1982) but would add that an abnormally high total precipitation during the weeks preceding the catastrophic event is a significant factor in hillside failure.

Prestorm rainfall totals were substantially above normal for the 15-, 30-, 45-, 60-, and 75-day periods during the 1980 summer for a large part of western Pennsylvania. Only the 15-day prestorm total at Johnstown in 1977 was comparable, but below normal precipitation characterized the other periods at Johnstown. Thus, the prestorm soil moisture content in 1980 was significant, especially when coupled with the intensity of the August storm. I disagree with the conclusions of some workers (Eschner and Patric, 1982, p. 346), who suggest that about 13 cm (5 inches) of rain per day is the approximate threshold amount necessary to saturate soil and initiate debris avalanching or any other form of mass movement. The wetter the soil at the onset of the storm, the less rain is needed to start any type of slope movement. Thus, antecedent moisture is the determinant factor concerning how much rainfall in a single storm is required to initiate slope movement.

Orientation of the affected slopes was a factor in the density of the slope movements. East-facing slopes are exposed to the sun only in the morning when temperatures are lower. Thus, the slope opposite East Brady has an inherently high soil moisture content at all times. The north-facing slope east of East Brady is even slower to dry out.

More than 90 percent of the debris avalanching took place along existing hillside depressions in contrast to the siting of debris avalanches at Johnstown (Pomeroy, 1980) but similar to other storm-induced phenomena in Appalachia (Hack and Goodlett, 1960; Bogucki, 1976, 1977; Williams and Guy, 1973; Stringfield and Smith, 1956). The greater concentration of the slope movements at East Brady, as opposed to Johnstown, probably is a reflection of steeper slopes and a higher drainage density. Slopes in the head areas of debris avalanches at East Brady average 38° (79 percent) ranging from 32° (62 percent) to 50° (100 percent). Johnstown debris avalanche heads have an average slope of 33° (65 percent) and range from 27° (50 percent) to 38° (78 percent).

Most colluvium affected by slope movement has accumulated within hollows or laterally concave slope areas (fig. 12). Hollows develop where they do in part possibly because of an underlying density of tension joints in the bedrock greater there than in adjacent slopes, as suggested by Gray and Gardner (1977) and Woodruff (1971). At East Brady, outcrop is abundant only in the hollows where debris avalanche chutes have carved their paths, and it is difficult to compare fracture density there with that of either side. Nevertheless, intensive ground-water movement over a period of time in the hollows (or coves) has produced a deeper regolith than that along adjacent slopes. Unusually heavy precipitation occurs infrequently, at which time the loose rock and soil is flushed out, and drainages are further deepened by sliding and flowage of rock material from higher on the slope. Some movements of colluvium along planar slopes have caused accumulation on benches (fig. 12). Many slope movements involved materials from both types of accumulation (figs. 6, 12).

The stratigraphy, structure, and lithologic composition of the bedrock at East Brady are comparable to those at Johnstown except that considerably more sandstone occurs in the 30-m interval above the Lower Kittanning coal at East Brady. However, the extent and thickness of the colluvial cover is vastly different. At East Brady the colluvial thickness is minimal, and weathered bedrock is exposed in almost all the scars. In the Johnstown area, weathered bedrock seldom crops out in the scars; a minimum thickness of 5 m of colluvium exists at the heads of some debris avalanches near Johnstown (Pomeroy, 1982).

During the August 1980 storm, slope movements in the East Brady area took place chiefly on the bedrock-colluvium interface; less common were slippage surfaces within the colluvium. The base of the soil mantle overlying the weathered rock represents a weak plane on which creep has taken place. Surface water percolating through the thin soil (commonly less than 0.6-1.0 m thick) tends to accumulate on top of the rock surface (usually shale) or the thin soil above it. Observations indicate that shale or claystone is usually exposed along the head scarp of a slope movement where more permeable sandstone lies directly above and a concentration of water is present at the contact.

About 90 percent of the slope movements originated at or below the Lower Kittanning coal bed both east and west of East Brady (figs. 2, 10). Though seeps were seen at other horizons, the most pronounced springs emanated from the contact of the coal (densely jointed) and underclay below a dominantly sandstone section. In the absence of coal, seepages were common at the base of a

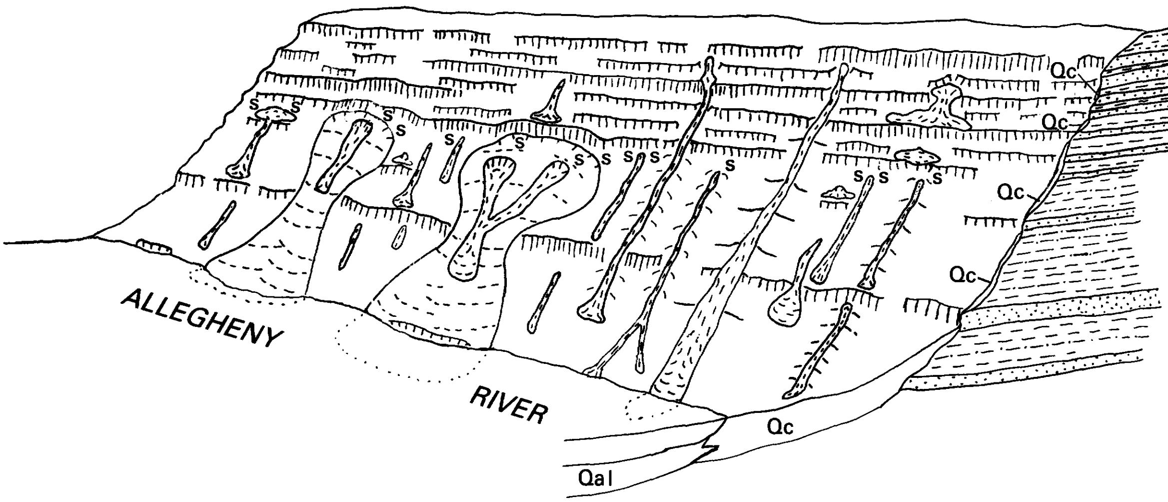


Figure 12. Schematic diagram showing colluvial slope movements along concave slopes or hollows and above benches. Relative distribution of lithologies is suggestive of those along slope opposite East Brady. Symbol S denotes horizon of abundant seeps; Qc, Quaternary colluvial deposits; Qal, Quaternary alluvial deposits. Diagram suggested by Gray and Gardner, 1977.

sandstone ledge or, where the slope was covered by colluvium, seeps were present in the soil beneath the inferred position of a sandstone ledge. High pore pressures probably originated at the colluvium-bedrock contact in such areas. In contrast, the head areas of the few debris avalanches above the Lower Kittanning coal bed were commonly dry.

As pore-water pressure increases and shearing resistance decreases in the thin colluvial cover because of an intense rainfall, a transformation process called spontaneous liquefaction (Terzaghi, 1950, p. 110) takes place. The change of state from a supersaturated soil to a thick viscous fluid follows.

The slope movement of colluvium was of two types. One type consisted of downhill rotational or planar sliding for a short distance (4.5 to 9.0 m) from the head scarp followed by flowage, such as that at the highest debris avalanche in area D (figs. 2 and 7). More commonly, the rotational or planar sliding is not evident and, instead, the flowing action begins at the head scar as it did at the highest debris avalanches at areas B and C (figs. 2 and 6).

Various amounts of large sandstone, siltstone, and shale clasts dominate the 1980 planar slide movements as at area A (fig. 2) and in the rotated head areas of several debris avalanches. A clay- to silt-rich matrix is dominant over the sandstone and siltstone clasts downslope along the flowage part (and the toe) of the debris avalanches.

The amount of regolith removed from slope areas in the 1980 event is difficult to estimate because prestorm configurations of drainages cannot be determined. Scott (1972) believed that the average thickness of colluvium removed along several Blue Ridge debris avalanche paths was approximately 1.2 m during an intense storm. On the basis of measurements at selected debris avalanche paths, I conclude that the average depth might have been slightly less at East Brady, or about 1.0 m. Assuming a density of 1 ton per cubic yard for the weight of the saturated regolith, a minimum of 50,000 tons of hillside material is estimated to have been removed from the slopes opposite and east of East Brady in August 1980.

The east-facing slope opposite East Brady (fig. 2) and that part of the slope 1 to 3 km east of East Brady (fig. 10) show a somewhat similar number of movements, 34 and 28 respectively, but with a higher density of movements opposite East Brady, 85 versus 56 movements per square kilometer. The density of the 1977 movements along three slopes at Johnstown ranged from 65 to 93 movements per square kilometer. Similar data from storm-induced slope movement areas elsewhere in Appalachia is lacking or is based on maps of a smaller scale, which would invalidate a comparison.

About 2.5 percent of the slope surface from the two East Brady areas was affected by slope movements during the 1980 storm.

Origin of slope movements.--Observations confirmed the presence of many episodes of continuous slope movements involving both colluvium and bedrock throughout historic and prehistoric times. Stream undercutting has been a dominant geomorphic process because the slope opposite East Brady (fig. 2) (and that east of East Brady, fig. 10) is on the outside bend of a meander.

Probably more significant to the origin of slope movements has been valley stress relief phenomena as described by Ferguson (1967), Ferguson and Hamel (1981), and Gray and others (1979) in several sites in western Pennsylvania and northern West Virginia. Wyrick and Borchers (1981) have applied the concept in a hydrologic study in southern West Virginia. Valley stress phenomena are independent of tectonic processes. Stream erosion has removed horizontal support from valley walls and vertical support from the valley floor in the subhorizontal cyclothemic rocks of the Appalachian Plateau (Ferguson and Hamel, 1981). Because of the unequal stress distribution in the walls and floor, weathering, erosion, and slope movements are intensified.

Observations in the East Brady area revealed that nearly vertical to vertical tension joints are closer spaced and wider toward the valley wall. Blocks have separated along joints and moved downhill; some rock masses slumped or failed along subsurface planar surfaces. Seasonal thawing contributed to an accumulation of water in the upper colluvial layers and bedrock that produced a water-logged condition and reduced shear strength of the soil and rock material. Slope movement then resulted from the additional weight of the unstable regolith surcharged with moisture and from the reduction in the internal friction and cohesion of the regolith.

Stress relief has intensified secondary permeability (through fractures or joints), which is believed to be more significant to ground-water movement than primary permeability in the Appalachian Plateaus (Wyrick and Borchers, 1981). The role of secondary permeability in the origin of debris avalanches has been speculated for an area affected by an August 1972 heavy rainfall in southwestern West Virginia (Everett, 1979). Enlargement of a joint near the top of a hill and the eventual buildup of water pressure in the slope caused a rock slump at Brilliant Cut, Pittsburgh, in 1941 (Gray and others, 1979). The failure surface was concave upward with its lowest position in a claystone at the base of the cut as determined by borings. Deep-seated rock slope movements probably underlie extensive colluvial movements at several localities along I-79 north of the Ohio River west of Pittsburgh. Since the site was first studied in 1969 (Gray and others, 1979), large tension cracks parallel to the valley axis farther up the slope and in bedrock have opened and are widening. Both of the Pittsburgh slope movements probably originated

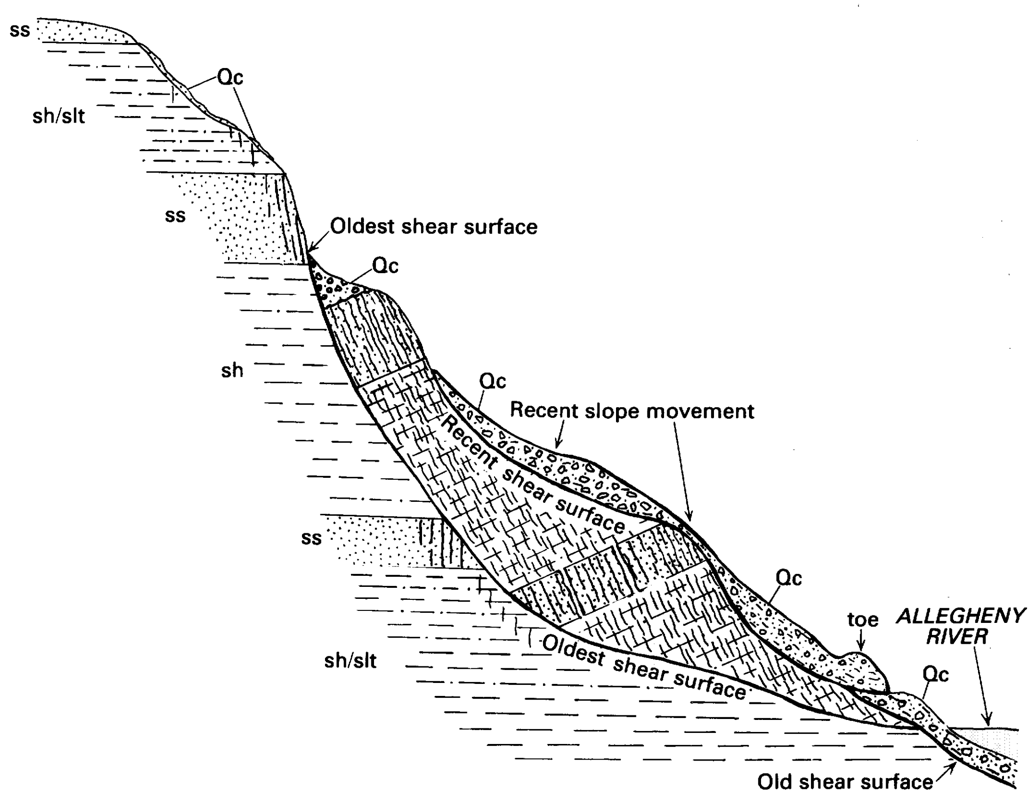


Figure 13. Schematic diagram showing rock slump and subsequent colluvial movement along the slope opposite East Brady. Note that the recent shear surface is probably the site of an older colluvial movement. Qc, Quaternary colluvial deposits.

from valley stress relief.

A number of claystone layers, any one of which could serve as a failure surface, are found throughout the rock section at East Brady. The steeply dipping to vertical joint faces in sandstone above the colluvium-draped benches at several sites opposite East Brady are believed to have served as a point of origin for rock slump movement (fig. 13). Subsequent buildup of weathered rock and soil and infrequent flushing out of the material has followed in the form of colluvial slope movements (fig. 12) such as those that occurred in August 1980. Colluvium is thickest and most extensive on concave slopes called hollows or coves. Reactivation of rock slumps is a possibility whenever the optimum set of conditions is present.

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