Slope Movements in the Warren-Allegheny Reservoir Area, Northwestern Pennsylvania

U.S. GEOLOGICAL SURVEY BULLETIN 1650

U.S. DEPARTMENT OF THE INTERIOR

March 3, 1849

Slope Movements in the Warren-Allegheny Reservoir Area, Northwestern Pennsylvania

By JOHN S. POMEROY

Discussion of slope movements along the Allegheny River valley from the area southwest of Warren to the Allegheny Reservoir at the New York State line

U.S. GEOLOGICAL SURVEY BULLETIN 1650

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1986

For sale by the Books and Open-File Reports Section, U.S. Geological Survey,
Federal Center, Box 25425, Denver, CO 80225

Library of Congress Cataloging-in-Publication Data

Pomeroy, John S., 1929-
Slope movements in the Warren-Allegheny Reservoir area, Northwestern Pennsylvania.
(U.S. Geological Survey bulletin ; 1650)
Bibliography: p. 14
Supt. of Docs. no.: I 19.3:1650
1. Earth movements—Pennsylvania—Warren Region. 2. Earth movements—Allegheny River Valley (Pa. and N.Y.) 3. Slopes (Physical geography)—Pennsylvania—Warren Region. 4. Slopes (Physical geography)—Allegheny River Valley (Pa. and N.Y.) I. Title. II. Series.
QE75.B9 no. 1650 557.3 s [551.3] 84-600412
[QE598.3.U6]

CONTENTS

Abstract **1**
Introduction and scope of present investigation **1**
Acknowledgments **1**
Geologic setting **2**
Slope-movement terminology **2**
Clay mineralogy of colluvial slope-movement material **3**
Description of recent slope movements **4**
  Warren area **4**
  Allegheny Reservoir area **7**
    Kinzua Bay **7**
    Allegheny Reservoir **8**
Prehistoric debris flows **8**
Discussion **9**
References cited **14**

PLATE

1. Distribution of slope movements along the Allegheny River valley in northwestern Pennsylvania **In pocket**

FIGURES

1. Index map showing location of study area **2**
2. Generalized geologic map of Warren-Allegheny Reservoir area **3**
3. Diagrammatic representation of a slump earthflow **5**
4. Photographs showing slope movements in the Warren area **6**
5. Photographs showing slope movements in the Allegheny Reservoir area **11**
6. Maps showing selected prehistoric slope movements **12**
7. Photographs showing lateral margins of relict debris flows **13**

Slope Movements in the Warren-Allegheny Reservoir Area, Northwestern Pennsylvania

By John S. Pomeroy

Abstract

Extensive slope movements occur along the Allegheny River valley between the area south of Youngsville and the Allegheny Reservoir to the New York State line. All the observed slope movements took place in soils and colluvium derived from subhorizontal nonmarine and marine clastic rocks of Devonian age. Regolith overlying the Venango Formation, which consists predominantly of shale, is particularly prone to movement and occurs along the lower slopes throughout the region. Shear surfaces in blue-gray clay are found in shallow-seated earth slumps and translational (planar) slides. The principal clay minerals in the slippage zones of recent slope movements include illite and lesser amounts of kaolinite. The illite is potassium-deficient and comparable to the illitic clays from slide-prone areas in the Pennsylvanian and Permian terrain of southwestern Pennsylvania and southeastern Ohio.

The lower one-fourth to one-third part of most slopes in the Warren area is particularly sensitive to movement wherever roadcuts or other excavations have been made. Filling of the Allegheny Reservoir and subsequent fluctuations of its pool elevation are not the major factors in slope movements above the reservoir. Before the filling, slope failures occurred at the dam and at highway and railroad relocations. Present-day slope movements extend as high as 43 m above the pool level. Uppermost scarps of these slope movements are discontinuous and do not show evidence of movement within the past 10 years. The fact that the freshest scarps are near the waterline suggests that pool-level fluctuations do cause some lower slope movements. Foot areas of well-defined ancient debris flows along Allegheny Reservoir have not been reactivated by the reservoir filling.

Oil and gas exploration has increased in the Warren-Allegheny Reservoir region in recent years. Because of the necessity of constructing and maintaining new access roads, the incidence of slope movements can be expected to increase until slopes are restabilized.

INTRODUCTION AND SCOPE OF PRESENT INVESTIGATION

The Warren-Allegheny Reservoir area in northwestern Pennsylvania (fig. 1) was investigated for slope movements and related features in 1978 (Pomeroy, 1981) as part of a comprehensive reconnaissance study of mass movements of the Appalachian Plateaus region. Traverses along the shoreline of Allegheny Reservoir in 1980 and 1981 documented slope-movement activity.

Neither soil reports (U.S. Soil Conservation Service, 1971, 1974) nor the geologic map and report (Butts, 1910) suggested any slope-stability problems in the Warren area. Slope failures were observed east of Warren in the area encompassing Allegheny Reservoir by Philbrick (1976), who mentioned slope movements as an engineering problem during the construction of Kinzua Dam.

This paper describes the present and past slope movements along the Allegheny valley between the area south of Youngsville, Pa., and the Allegheny Reservoir to the New York State line, and discusses the nature and causes of the failures. This report is part of a series of studies that can serve as benchmarks for future comparative studies of occurrences, frequencies, and rates of slope movements.

ACKNOWLEDGMENTS

Field trips with J.P. Wilshusen (Pennsylvania Geological Survey) and William Parrish (Soil Conservation Service, Warren, Pa.) in May 1979 and with L.R. Auchmoody, Thomas Collins (National Forest Service, Warren), Helen Delano (Pennsylvania Geological Survey), and Wesley Ramsey (Soil Conservation Service, Warren) in May 1982 allowed for an exchange of ideas.

Gloria Hunsberger, U.S. Geological Survey, determined clay mineralogy by X-ray diffraction methods. Jeffrey W. Popp, U.S. Geological Survey, accompanied me on ground and shoreline traverses in 1981.

L.W. Petulla, District Engineer, and R.T. Fox, District Soils Engineer (Pennsylvania Department of Transportation, Franklin, Pa.), kindly furnished copies of subsurface data (auger boring logs) obtained in several slope-movement areas along the Allegheny River.

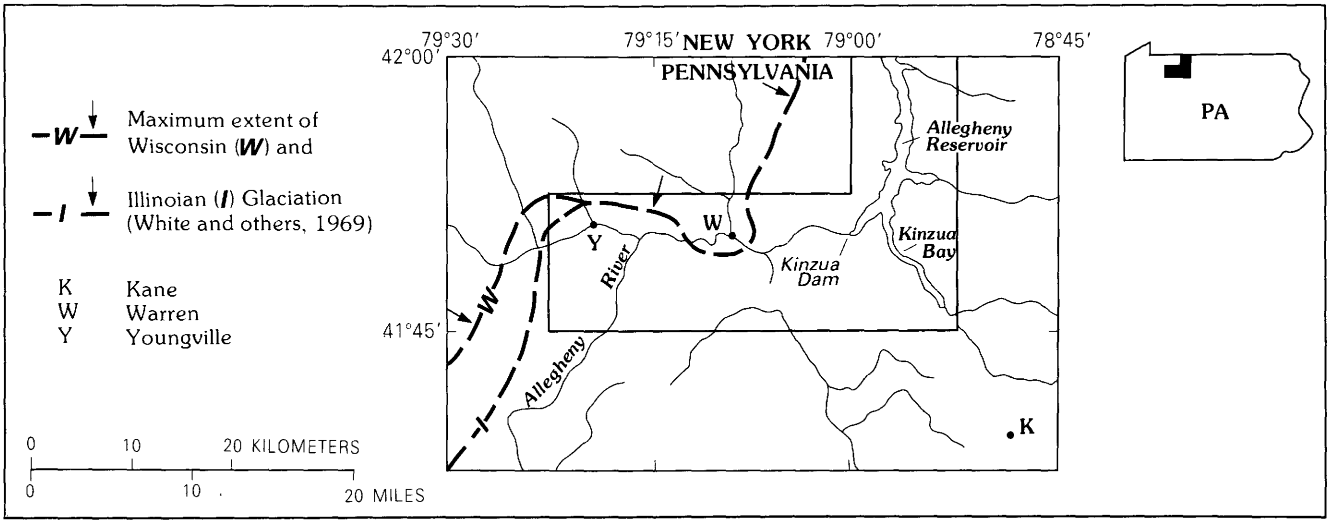


Figure 1. Index map showing location of study area.

GEOLOGIC SETTING

Nearly flat to very gently dipping (less than 2°) marine and nonmarine clastic rocks, typically interbedded shale, siltstone, and sandstone, underlie the region. The rocks range in age from Devonian to Pennsylvanian. Bedrock is only locally exposed because of an extensive cover of colluvium.

Butts' (1910) geologic map of the Warren 15-minute quadrangle showed that slopes along the Allegheny River valley are underlain by the Conewango Formation of Devonian-Mississippian age. These rocks were interpreted as belonging to the Conneaut and Conewango Groups of Devonian age; the latter group includes the Cattaraugus and Oswayo Formations (Gray and others, 1960; Lytle, 1965; Lytle and Goth, 1970).

Greenish-gray to dark-gray shales and subordinate red shales interbedded with siltstone, sandstone, and less common conglomerate underlie the slopes along the Allegheny River valley. The columnar section at Kinzua Dam (Lytle and Goth, 1970, p. 9) indicates that shale is the predominant lithologic type between elevations of 1,250 and 1,500 feet. This interval in the stratigraphic section, presently called the Venango Formation, is the least competent unit in the section and is poorly exposed except at Kinzua Dam. Exposures along a new access road on the south-facing slope above Ludlow St. (Warren) showed in 1983 a few layers of 10- to 13-cm-thick blue plastic claystone between shale beds. Claystone has not been mentioned in the geologic literature of this area. The recent State geologic map (Berg and others, 1980) shows the oldest rocks (Chadakoin and Venango Formations) to be overlain by the slightly to moderately coarser grained Oswayo, Riceville, and Shenango Formations, the Corry Sandstone, and the Cuyahoga Group (fig. 2). This interval can be recognized on the Clarendon 7 1/2-minute quadrangle map by the abundance of steep slopes above the 1,500-foot contour. The Pottsville Group caps the highest elevations.

No geologic map exists of the area encompassing Allegheny Reservoir. Red clastic rocks of the Catskill Formation intertongue with a predominantly gray clastic sequence east and southeast of Allegheny Reservoir (Berg and others, 1980).

Most of the study area is within the nonglaciated section of the Appalachian Plateaus province. A small part of the area (fig. 1) is covered by local deposits of drift (Wisconsinan Stage) transported by a continental ice sheet that moved into the area from the Erie Basin and Ontario (White and others, 1969). One effect of a periglacial climate was increased rock weathering, which produced a cover of colluvium thicker than that found in other areas of western Pennsylvania southwest of Warren. Subsurface data (Pennsylvania Department of Transportation, written commun., 1981) indicate thicknesses of colluvium exceeding 11 m at several slope-movement localities in the Warren area. Most of the colluvium is gray to brown silty clay and contains sandstone, siltstone, or shale fragments.

SLOPE-MOVEMENT TERMINOLOGY

The 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). In this report, I have used the general term "slope movement" rather than "landslide" except for movements that involve only sliding.

Four types of slope movements (Varnes, 1978, fig. 2.1) are evident in the Warren-Allegheny Reservoir area.

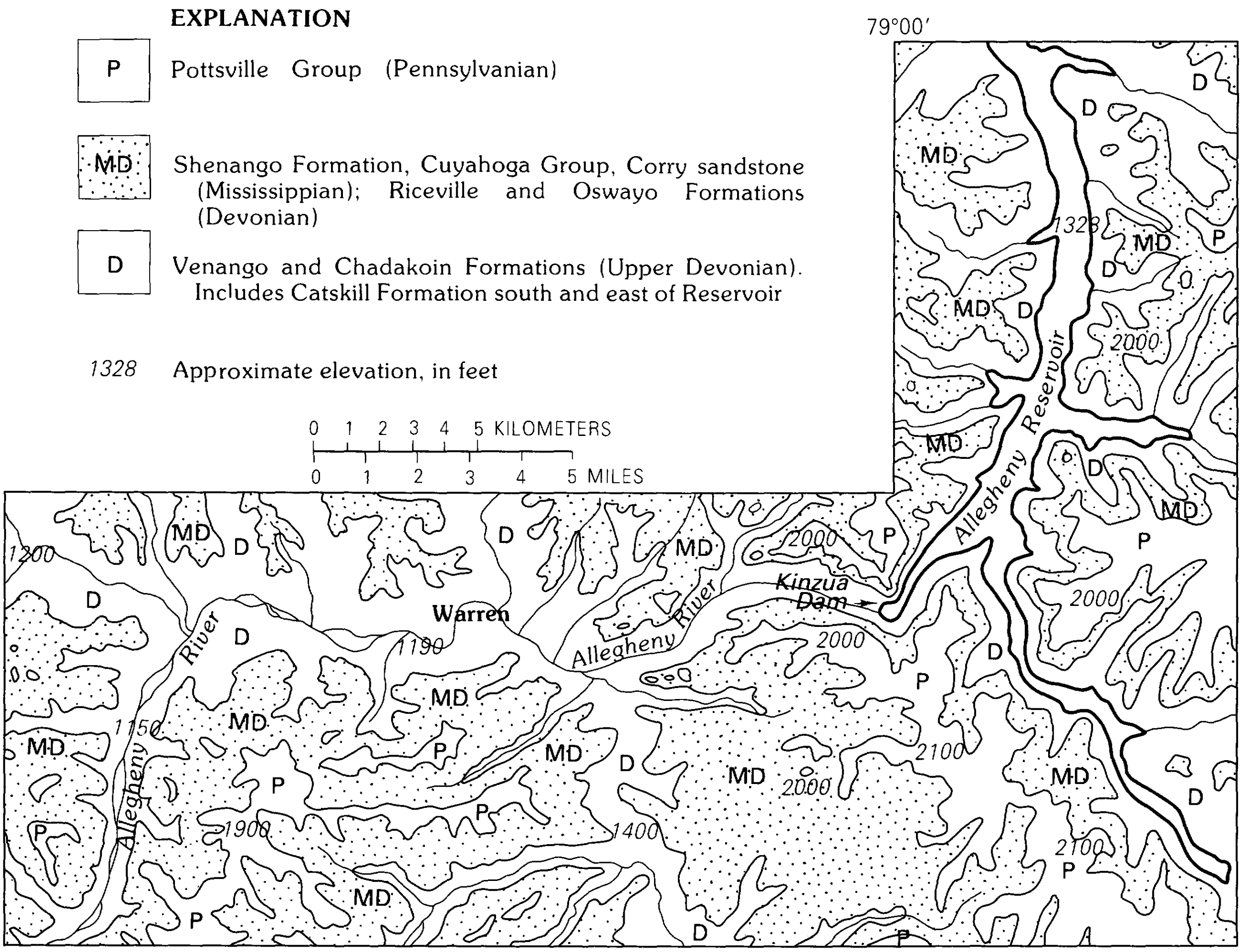


Figure 2. Generalized geologic map of Warren-Allegheny Reservoir area. (Modified from Berg and others, 1980.)

They include falls (rock falls), slides (earth slumps and debris slides), flows (debris flows, earthflows, and debris avalanches), and complex movements (slump-earthflows).

Rock falls are extremely rapid free falls of bedrock. Alternating competent and incompetent lithologies, in addition to closely spaced vertical joints parallel to the major drainages, are contributing factors to the process, especially in the Warren-Allegheny Reservoir area. Slides are either earth slumps involving rotational movement with an upward curving rupture (shear) surface or debris slides, which take place along planar or mildly undulatory shear surfaces and are translational movements. Both slide movements can be very slow to rapid. Flows in the Warren-Allegheny Reservoir area are of three types that range in movement rate from extremely rapid (debris avalanche) to very rapid (debris flow) to extremely slow (as in some earthflows). Flows in surficial materials show movement resembling those of viscous fluids. Most slope movements are complex in that features of two or more basic slope movements are represented, as in the slump-earthflows (fig. 3). Also, most earthflows are complex in that shear occurs along the lateral edges and basal surface even though plastic flow is evident within the displaced material (Varnes, 1978, fig. 2.1). All slides, flows, and complex movements take place in both soil and colluvium.

CLAY MINERALOGY OF COLLUVIAL SLOPE-MOVEMENT MATERIAL

Clay mineral analyses of 12 samples of colluvial slope-movement material were determined by means of X-ray diffraction techniques.

The principal minerals in all samples were potassium-deficient illite, which was dominant, and kaolinite. Vermiculite and chlorite were found in trace amounts in a few samples.

Potassium-deficient illites are prevalent elsewhere in colluvial deposits in the unstable terrain underlain by Pennsylvanian and Permian rocks in western Pennsylvania and southeastern Ohio (Pomeroy, 1982a; Fisher and others, 1968). The presence of potassium-deficient illite in these rocks and in Devonian rocks of the Warren-Allegheny Reservoir area points to a common association of this clay with slope movements. Fisher and others (1968) concluded that the leaching of potassium ions in the illite has contributed to the instability of the host material.

DESCRIPTION OF RECENT SLOPE MOVEMENTS

Warren Area (See pl. 1.)

Locality A. (pl. 1)—The largest slope movement at this locality is along both sides of the road 1.0 km south of Youngsville on a northwest-facing slope. A 20-m-wide earth slump along the road shoulder is at the base of a larger unstable area above the road. A 45- to 60-m-wide zone of recent movement extends upslope for nearly 70 m along a 17°–20° (30 to 35 percent) slope. The 1-m-high main scarp of the upper slump-earthflow is complexly scalloped. Blue-gray clay forms the slippage plane and lies less than 1 m below the surface in the head area. Seeps are numerous in the main body and foot of the slope movement. The slump-earthflow has been moving slowly, which has necessitated almost constant clearing of the road gutter. In 1980, a higher 30-m-wide slump along a 29° (57 percent) slope above a new unimproved dirt road was noted.

Near the base of the same northwest-facing slope is a series of discontinuous older scarps and tilted surfaces where trees are slanted. The heads of these slumps are above another unimproved dirt road. Slumping also occurs above the road intersection at the base of the slope.

A 15-m-wide, 9-m-long earthflow is evident along an 18° (33 percent) modified grassy slope at the east side of a ski run about 0.35 km southeast of the previously mentioned road intersection. The movement involved less than a 0.6-m thickness of soil and clearly postdated the slope modification.

Locality B. (pl. 1)—Earthflows at locality B_1 lie above the Youngsville Bypass (U.S. 6), which traverses 1.5 km of the lower slope west of the U.S. 6–U.S. 62 intersection. The cleared slope above the road is a 60 to 70 percent grade and is not benched. Earthflow movements took place during and after construction. Most of the slope movements were along the lowermost part of the slope at the east end.

A fresh 20-m-wide slump at locality B_2 along a 22° (44 percent) forested slope above a recent oil-field access road was noted in 1979 about 2.5 km west of the U.S. 6–U.S. 62 intersection. The 1.5-m-high main scarp was almost perfectly arcuate, and both flanks extended to the access road. The rotational shear movement took place within wet silty to clayey colluvium. Reinspection in 1981 revealed a seepage-prone area in front of the main scarp where much of the colluvium and trees had been removed. No crown cracks had formed above the main scarp; consequently, no upslope retrogressive failure was indicated.

Locality C. (pl. 1)—This area is the man-modified slope above U.S. 6–62, 7.0 km west of Warren. Ubiquitous vestigial and newer recent slope movements, induced largely by road widening and a lack of benching, have taken place along a 0.7-km-wide, 55–60 percent slope. The forested margin has been affected locally by several small earth slumps and two small older debris avalanches. The debris avalanches, which predate 1939 aerial photography, did not reach the base of the then completely wooded slope. Field inspection revealed that each avalanche was still faintly discernible and measures 3.0 to 6.0 m wide at the top of a roughly cup-shaped depression, which widens to 9 m where the present man-modified slope begins.

Locality D. (pl. 1)—The type of slope movement (D_1) north of Starbrick is a 20-m-wide earth slump above both a small drainage and a road. Several minor scarps separate the toe from the main scarp. Blue-gray clay serves as the sole of the slide.

An area of extensive but barely discernible small slumps and earthflows (D_2) along a forested slope lies north of U.S. 6–62 east of Starbrick. Discontinuous surface cracks no longer than 10 m have resulted from ground disturbance by construction of access roads and installation of oil pumps (after 1971) along the slope. Individual slope-movement features are too small to show on plate 1, but when combined with other similar features are indicative of the sensitivity of the colluvial material to minimal surface modification.

Locality E. (pl. 1)—Several different forms of slope movement are obvious along this mostly deforested 1-km-wide, 60 percent slope above U.S. 62 north of downtown Warren. Road widening unaccompanied by benching has caused this steep colluvial slope to be sensitive to movement. The 1939 aerial photographs do not suggest any obvious slope-stability problems when the road was narrower and the forest extended to the road.

Locality F. (pl. 1)—An approximately 35-m-wide post-1939 scar in colluvium (F_1) is visible along a steeper than 60 percent slope below a road paralleling the south side of the river. The toe of the displaced material has been removed by river erosion during high-water stages. Curved mature tree trunks suggest creep above the road. The colluvium-bedrock contact in the head area is 5.4 m below the surface where brown silty clay colluvium containing rock fragments overlies a 1-m-thick soft (weathered) brown claystone (Pennsylvania Department

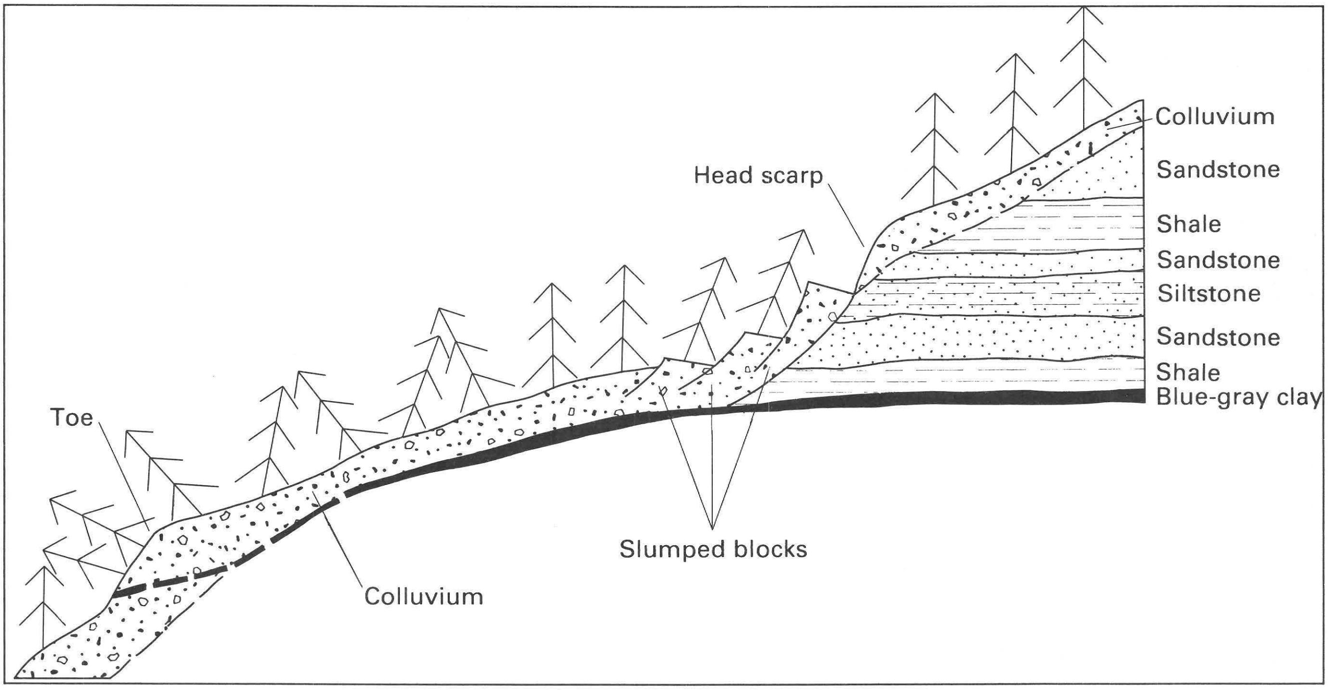


Figure 3. Diagrammatic representation of a slump earthflow. Note slant of trees.

of Transportation, unpub. data). The colluvium-bedrock surface is inferred to have been the plane of separation.

Along the slope southwest of Warren, small slope movements (F_2) less than 10 m in width and in length are evident above access roads to oil-gas pumps and above the pumps where slope cutting has taken place. Both debris sliding (along planar surfaces) and earth slumping are very shallow (less than 1.0 m) along moderate (25 percent) slopes.

Locality G. (pl. 1)—Many slope movements occur both above and below the road opposite Warren along the south side of the Allegheny River. An extensive 200-m-wide regraded area between the road and the railroad tracks next to the river showed renewed slumping in addition to surface cracks along the road surface. Shallow slumping, where an oil pump is located on the main scarp 20 to 25 m above the road, resulted in the bowing of horizontal pipes installed on the surface across the slope (fig. 4*A*). Crown cracks and smaller discontinuous scarps occur above the main scarp. Bluish-gray clay, which serves as the sliding plane, forms an impermeable surface in the head area where seeps are common. At least 12 m of clayey silt and silty clay containing rock fragments (colluvium) underlie the land surface (Pennsylvania Department of Transportation, unpub. data), and there is no indication of bedrock.

A younger slope movement, across the road from locality G, is planar (translational) along a 27° (50 percent) slope, and the head scarp is less than 1.0 m high. Blue-gray clay showing downslope striations is shallow (less than 1 m below the surface) and acted as the shear surface. The debris slide is 24 m long and 6 to 9 m wide at the head but widens to nearly 20 m at the base. An unimproved dirt access road above the head of the slope movement has diverted the drainage downslope along a channel that cuts through the road berm and into the slope-movement area. A new scarp has formed above a widened section of the same road.

Locality H. (pl. 1)—A 35-m-wide zone of slumping below a rough road paralleling the north side of the Allegheny River (H_1) just east of Warren was examined in the spring of 1978. Recent accelerated creep above the road was at least partially responsible for the poor condition of the road. In the fall of 1978, a 200-m-long section of freshly repaved road above the repaired lower slope showed cracking and sagging along the outer part of the road (fig. 4*B*). Colluvium, nearly 10 m thick and consisting of brown silty clay containing rock fragments, overlies gray shale (Pennsylvania Department of Transportation, unpub. data).

A 30-m-wide zone of recent shallow rotational and translational (planar) movement (H_2) (fig. 4*C*) along a 22° (44 percent) slope was noted in 1978 above a man-made bench about 1.5 km east of locality H_1. Blue-gray clay, less than 1 m below the surface in front of the main scarp, probably served as the shear plane. Excavating for house sites along the lower part of the slope triggered the slope movement. In 1981, retrogressive movement

A

B

C

D

upslope from the former head scarp had affected the forested area as far as 25 m above the road.

Locality I. (pl. 1)—Pennsylvania Rte. 59 has been subject to accelerated creep and sliding in recent years. Movement has been particularly obvious along a 1-km-long section of the road where it has resulted in riverside cottages being destroyed. The larger of the two major problem areas is 60 m wide (fig. 4*D*). A naturally caused debris avalanche above the road shows evidence of flowage but does not extend to the highway. About 11 m of brown to gray silty clay containing rock fragments overlies gray siltstone bedrock at this westernmost location. Nearly 14 m of colluvium overlies a 1.5-m-thick gray claystone at the larger slope movement to the east (Pennsylvania Department Of Transportation, unpub. data). The slippage surface was within the colluvium (R.T. Fox, oral commun., 1982). The extremely hummocky terrain above the road eastward to Kinzua Dam attests to the instability of the colluvium.

Locality J. (pl. 1)—Several slope movements wherein head scarps range in width from 7.5 to 24 m occur along the east-facing slope above Hemlock Run. Equal numbers either "head" on the outer side of an unimproved dirt road or "toe in" to the inner side of the unimproved access road from above. Though most recent slope movements have taken place along the more moderate lower slope, occasional small slope movements occur along upper parts of slopes bordering on sites of slight surface modification, such as access roads.

Locality K. (pl. 1)—Several long and narrow slope movements of the debris avalanche type took place northwest of Allegheny Reservoir. An access road to a quarry traverses the heads of the movements and, indirectly at least, triggered movement.

Allegheny Reservoir Area (See pl. 1.)

The Allegheny River valley was flooded behind Kinzua Dam in a U.S. Army Corps of Engineers project that commenced in 1936 and was completed by 1967. The maximum slope inundation is about 35 m behind the dam and decreases to about 24 m at the New York State line.

◄ **Figure 4.** Slope movements in the Warren area. *A*, Slope opposite Warren along south side of Allegheny River. Scarps (A) and movement in head area have affected oil pipeline installation (locality G, pl. 1). *B*, Recently renovated road with renewed displacement at A and cracks in the foreground along north side of Allegheny River east of Warren (locality H_1, pl. 1). Reconstructed slope is below road. Accelerated creep occurs above road, indicated by leaning trees. *C*, Slump, predominantly with head scarp (A) above cut bench 2.5 km east of Warren (locality H_2, pl. 1). *D*, Slow slope movement has necessitated costly road reconstruction on Pennsylvania Rte. 59 east of Warren (locality I, pl. 1).

Kinzua Bay

Most of the slope problems indigenous to the west side of Kinzua Bay involved cut and fill operations used in construction of Pennsylvania Rte. 262 above the present shoreline. Most failures occurred along the outside of the highway rather than above the road, but not all problems were related to fill failure. Existing scarps at several sites below the road shoulder point to the failure of the colluvium. Extensive slope movements of colluvium above the roadcuts were less of a problem.

Locality L. (pl. 1)—Pronounced creep and hummocky ground, but without any discernible surface cracking, lie above the highway, and a 40-m-wide lower slope movement is evident below the road.

The largest slope movements along the west side of Kinzua Bay are 60 m to 75 m wide, at least 8 years old, and extend to the shoreline. Scarps are commonly not well exposed because of slope grading, but hummocky ground is commonly present in the main body and foot areas.

Locality M. (pl. 1)—A series of slope movements have taken place both above and below a 0.6-km length of the road above Dutchman Run. Part of the head area of one slide shows reactivation.

Locality N. (pl. 1)—A major slope movement took place above a relocated major road (Pennsylvania Rte. 321) along the east side of Kinzua Bay. A 35-m-wide slump-earthflow that has a 1-m-high arcuate head scarp has occasionally blocked the highway. The road was cut in bedrock, and the overlying colluvium-bedrock contact is roughly parallel to the slope. Slippage is occurring at this contact. Several small surface cracks upslope from the main scarp attest to probable future (retrogressive) enlargement of the slump-earthflow, which could result in a continual cascading of colluvial material over the rockcut below.

Locality O. (pl. 1)—A wide zone of recent activity appears related to a surface culvert from the highway above. Excessive pore-water pressure in the colluvium probably has contributed to the instability of the slope.

Locality P. (pl. 1)—Two active landslide zones measure 76 m and 400 m in width. The main scarp is 16 m above the pool elevation at the smaller slump. The larger slide originates much higher (nearly 30 m above the reservoir level). The largely discontinuous main scarp does not appear as fresh as the more extensive downslope scarps.

Locality Q. (pl. 1)—A 140-m-wide movement that contains a discontinuous main scarp is present along a 28° (53 percent) slope 8 m above the pool elevation, but the most recent slope movement has been within 2.5 m of the shoreline. Pipeline remnants litter the slope and indicate past oil-production activity (Lytle and Goth, 1970).

Smaller slope movement areas to the south (14 to 18 m wide and 0.6 m-high main scarps) extend uphill only 6 m along a 19° (35 percent) slope. Movement is translational (planar) rather than rotational and is fresh.

Allegheny Reservoir

Locality R. (pl. 1)—Nowhere in the study area does a greater rockfall hazard exist than along Pennsylvania Rte. 59 in the Kinzua Dam area. The most dangerous rockfall zone is behind Kinzua Dam (fig. 5*A*), but a nearly continuous 5-km-long hazardous zone lies to the northeast. During the reservoir construction, Pennsylvania Rte. 59 had to be raised because of the pool elevation, and new highway cuts were made. Weathering and erosion in a sequence of closely spaced open joints in competent sandstones and siltstones and incompetent shales have produced a serious problem along the steep rock cut. Blocks of rock, weakened by undercutting of the softer lithologies and by joint widening, have fallen onto the road. Because of its northeast to northwest orientation, the cut retains moisture for long periods.

Locality S_1. (pl. 1)—A 140-m-wide slope movement has been triggered at least in part by a road (now closed) that led to a recreational area. The scarred area is grass covered and has been stabilized. The slope above the road has been cut back to siltstone-sandstone ledges. Vestiges of an unstable slope and its tilted trees are still apparent to the north. Northward along the shoreline are several small, very thin (less than 0.3 m) earthflows (fig. 5*B*) along a 12° (22 percent) seep-prone slope that were seen in May 1980 when the pool elevation was 2 m below normal. Blue clay forms the basal shear surface.

Locality S_2. (pl. 1)—A 450-m-wide laterally concave slope to the south, which appears to be an old slope-movement site, contains many recent planar slides and very shallow seated earth slumps (fig. 5*C*). A thin clay horizon was found within 0.5 m of the surface in the head area of one slope movement. Some main scarps are 60 m wide and as much as 1 m high. The slope surface is extremely hummocky and averages 20° (36 percent) (fig. 5*C*). The highest recent head scarp is at 1,470 feet altitude or about 43 m above the pool elevation. The bench surface in front of the highest scarp shows a 4° reverse dip, which implies rotational slippage.

Beyond the nose or convex part of the same slope to the southeast, similar but older slope movement at the same elevation appears as a bench with a reverse slope occurring in an area 18 m wide by 6 m long.

Locality T. (pl. 1)—Dead trees on hummocky ground immersed in the reservoir indicate slope movement (fig. 5*D*) along the north side of Sugar Bay. The main scarp is 4.5 to 6.0 m above the water, and the width of the movement is 134 m along a 21° (39 percent) slope. The fact that hummocky terrain is evident as high as 42 m above the reservoir indicates that the recent activity is part of an old slope movement. The slope steepens above the highest part of the hummocky surface as at previous localities.

Locality U. (pl. 1)—Two slumps, 18 m and 26 m wide, occur above Pennsylvania Rte. 321. The smaller slide took place along a 70 to 80 percent cut slope where bluish-gray clay, exposed in the head area, forms the slippage surface. The slumping occurred where the cut was too steep for the thin colluvium to remain in place. At the other slump, a break in the drainage ditch above the road contributed to the slippage in very thin colluvium.

Locality V. (pl. 1)—Slope movements include an 18-m-wide planar (translational) movement that shows a 1.5-m-high main scarp 2.5 m above the reservoir (fig. 5*E*), an estimated 120-m-wide slump-earthflow 4.5 m above the shoreline, and a very fresh bell- (or pear-) shaped translational or planar movement that measures 18 m across its midsection. A light bluish-gray clay slippage plane occurs 0.3–0.6 m below the surface in the head area of the planar movement. Ponding in the head area, which is 7.0 m above the reservoir, is caused by the impermeable clay barrier. The slope steepens significantly at about 12 m above the head of the movement.

Locality W. (pl. 1)—A 250-m-wide zone of recent slope movements, both planar and rotational, lies along a mixed grassland-forested slope. The topmost recent scarp lies about 11 m below a significant slope break (1,500-foot contour) or as high as 41 m above the reservoir level. The rotational types have scarps as high as nearly 2.0 m, and the translational (planar) forms have less conspicuous scarps. Scarps occur as low as 9.0 m above the water surface.

Locality X. (pl. 1)—Two active, mostly rotational, slope movements along a 32° (64 percent) slope occur on the west side of Allegheny Reservoir. The main scarps are 10 m to 18 m above the pool elevation and range in width from 27 to 42 m.

PREHISTORIC DEBRIS FLOWS

Evidence of prehistoric slope movements is abundant throughout the area. Individual and undifferentiated coalesced deposits are present along all major drainages.

Particularly striking are the colluvial slope movements, which are probably best described as debris flows (Pomeroy, 1983). Abundant examples exist southwest, south, and southeast of Warren (fig. 6) and both east and west of the northern part of Allegheny Reservoir.

These movements are common along drainages where few slopes exceed 60 percent. Generally siltstone, sandstone, and shale of Devonian age occupy the lower slopes, and conglomeratic sandstone from either the Shenango Formation or the Pottsville Group caps the highland area. The slope movements are probably Pleistocene to early post-Pleistocene in age. The soil developed on one of the debris flows (fig. 6*C*) is regarded as Wisconsinan in age according to Richard Cronce (Pennsylvania State University, Soil Genesis and Morphology Laboratory, oral commun., 1983).

Typical relict debris flows are on slopes of 20 to 50 percent in terrain having a relief of about 150 m. The flows are commonly 0.6 to 1.2 km long, rarely 2 km long, and 0.2 to 0.5 km wide. Most flows are probably less than 10 m thick, but locally may be as much as 30 m thick, on the basis of reconstruction of former valley profiles. Most debris flows show a laterally concave profile in the upper half to two-thirds of the slope and a convex profile in the lower part of the slope.

The surface of these prehistoric flows is mantled by a dense to sparse covering of subangular weathered boulders of conglomeratic sandstone from the Shenango Formation and (or) the Pottsville Groups. More coarser grained rocks appear to be in the surface layer rather than beneath. Either rain has washed out the finer material and left the coarser remnants on top or the larger boulders have naturally "floated" to the top in transport. Roadcuts in the toe on lower areas of these relict flows reveal sparse to abundant coarse clasts, as much as 3 m long, within a poorly sorted silty to clayey sand matrix. Small debris slides (less than 3 m wide) are commonly present along the cuts.

The large conglomeratic sandstone boulders of the lower extremities of the debris flows help in identifying these prehistoric flows. The landforms commonly have sharply defined boundaries except near their upper ends. In many places, the headward margins are discernible at the base of a steep slope where benching has occurred. The toes may have spread laterally as a single lobe with a steep front 1 to 3 m high. The flows have gentler surface slopes than those of the adjacent hillsides where bedrock crops out locally (fig. 7*A*). The lateral edges of a flow are bordered by an intermittent drainage channel (fig. 7*A*,*B*). The flanks of the lower end of some flows are bordered by laterally continuous, commonly 1.0- to 1.5-m high, levees or ridges.

Surface drainage is lacking on the flows except for gullies dissecting the lower parts. Despite the bouldery surface in many places, tree growth on a flow is comparable with that on the adjacent slopes.

The flows appear to occupy old drainageways, and, thus, they buried what were formerly V-notched tributaries. Because weathered rock was transported from near the tops of hillsides and redeposited at a lower level, the landscape has been smoothed.

An orientation analyses was made of nearly 2,000 relict slope-movement landforms from Warren County and adjacent counties to the south and east. Although a strongly preferred orientation is lacking, a slight majority of the slope movements took place along northward- or eastward-facing slopes. Slopes having a northerly component receive less exposure to the sun, which results in soils remaining wet longer than on south-facing slopes. East-facing slopes receive early morning sunlight, but the drying effect on these soils is ineffective because of the low temperatures at that time of day. Snow cover obviously lingers longest on slopes facing northwest to east. Thus, slopes that remained moist the longest showed slightly more slope movement than did others—a situation, of course, that holds true for the present time as well.

DISCUSSION

The lower one-fourth to one-third part of most slopes in the Warren area (pl. 1) is moderately to highly susceptible to slope movement. Road construction in the regolith has caused most movements.

A question arises as to whether reservoir filling and periodic fluctuations of the pool level have played a major role in the initiation of slope movement in the Allegheny Reservoir area.[1] In other areas, such as the Grand Coulee Dam impoundment (Schuster, 1979), movements along reservoir slopes have taken place after reservoir filling because of increased pore-water pressure and resultant shear-strength reduction or drawdown of a reservoir because of the removal of lateral support.

Historically, reservoir-related rockslides such as those at Vaiont in northern Italy (Schuster, 1979) are more destructive than slides in surficial materials. A reconnaissance survey did not reveal any areas above the Allegheny Reservoir shoreline indicative of bedrock slumping as at East Brady, Pennsylvania (Pomeroy, 1980a, 1984), and in the Greater Pittsburgh region (Pomeroy, 1982a). Because of the subhorizontal attitude of the bedding, movement of large volumes of rock along the bedding plane (block glides) is unlikely. Falls of large masses of rock that would generate large waves are not likely. Where a rockfall hazard exists, such as directly behind the dam, the highway would take the brunt of the fall rather than the reservoir itself (fig. 5*A*).

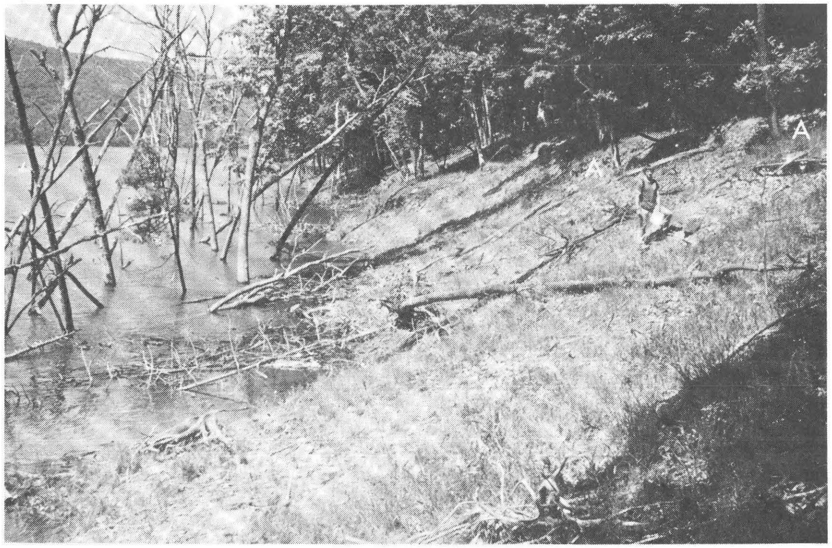
Locally, slope movements in colluvium along the reservoir shoreline have caused extensive damage to the forestland. Surges in water level are not a major consequence, but a continually active flow or slide will produce siltation, such as the muddying of the offshore water at locality T (pl. 1).

[1]Normal pool elevation at the reservoir is 1,328 feet. Although the maximum pool elevation of 1,365 feet has never been attained, the 1972 Agnes rainfall caused the water level to rise to 1,363 feet. Low pool levels of 1,267 feet were reached during drought periods in the late 1970's (Charles Dachtler, U.S. Army Corps of Engineers, Pittsburgh; Tom Fleeger, U.S. Army Corps of Engineers, Warren, oral commun., 1982). Pool levels were 1,321 feet and 1,332 feet at the time of the May 4, 1980, and June 16–19, 1981, shoreline traverses, respectively.

A

B

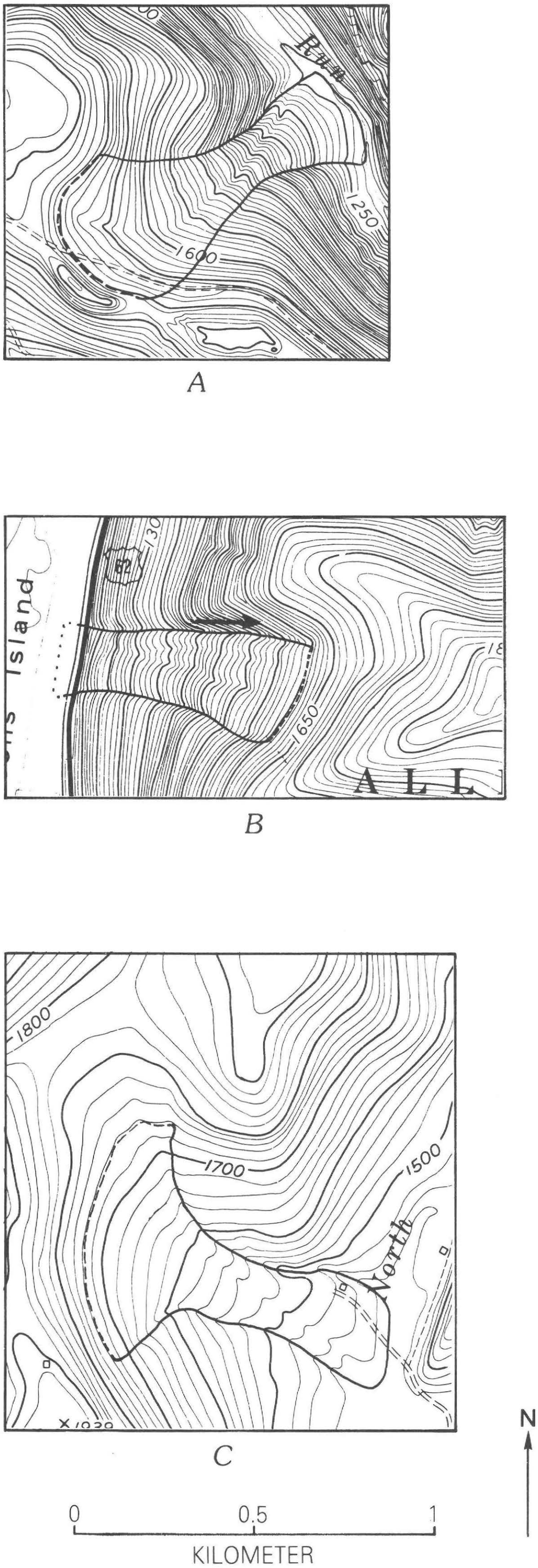
C



D

E

Figure 5. Slope movements in the Allegheny Reservoir area. *A*, Rockfall area above Pennsylvania Rte. 59 at Kinzua Dam (locality R, pl. 1). Note alternation of competent and incompetent lithologies and influence of jointing. *B*, Small planar (less than 0.3-m-thick) earthflow with head scarp (A) and toe (B) at locality S_1, plate 1. Pool elevation (Allegheny Reservoir) at time of investigation was 2 m below normal pool elevation. *C*, Hummocky terrain along concave slope (locality S_2, pl. 1) above reservoir. Ground cracking and scarps are numerous. *D*, Toe of recent slide in reservoir (locality T, pl. 1). Reservoir level was slightly more than 1 m above normal pool elevation. A is part of head scarp. *E*, Recent planar (translational) movement near Tracy Run (locality V, pl. 1). A is head scarp. Allegheny Reservoir in background. Blue-gray clay in head area.



◄ **Figure 6.** Selected prehistoric slope movements (includes head area and deposit. Localities are shown in plate 1). Note concavity in upper part, convexity (protuberance) in lower part, and a more moderate slope in contrast to adjacent areas. *A*, Slope above Thompson Run, 10 km south of Youngsville. *B*, Slope above Allegheny River 7 km southeast of Youngsville. Arrow indicates location of figure 7*A*. *C*, Slope above North Fork, Sixmile Run, 8 km southeast of Warren.

Schuster (1979, p. 15) reported a lack of comprehensive studies of reservoir-induced landsliding throughout the United States, but noted that Federal agencies involved in building dams have either formal or informal programs of landslide surveillance. The U.S. Army Corps of Engineers informally monitors landslide areas at Allegheny Reservoir and seeks the advice of the National Forest Service in reforesting affected areas (Charles Dachtler and Tom Fleeger, U.S. Army Corps of Engineers, oral commun., 1981).

Road construction, as suggested earlier in this report, has been a contributing factor to the colluvial slope movements above the southern part of Allegheny Reservoir. At localities P, S_2, and X (pl. 1), the 1939 aerial photographs and a 1949 edition of the Kinzua 15-minute quadrangle show a road at the base of the currently flooded lower slope. In fact, a bare scar on the 1939 aerial photographs above the road at locality P suggests slope movement.

Former oil-field exploration is evident at locality Q (pl. 1) as shown by field inspection and by Lytle and Goth (1970). On the basis of present-day observations in the Warren area, slope movement must have been prevalent in this area in 1939 because of the slope modification necessitated by road access.

Recent slope movements extend as high as 41–43 m above the reservoir at two localities (S_2, W). These high slope movements probably have not been caused by the initial filling and (or) subsequent fluctuations of the reservoir in view of the evidence that scarps appear freshest near the waterline. Upper slope scarps are largely discontinuous and do not show very recent movement. Hence, the idea of retrogressive mass movement (upslope) does not seem likely.

►
Figure 7. Lateral margins of relict debris flows. *A*, Lateral margin of ancient debris flow 8 km southeast of Youngsville (fig. 1). Bouldery flow of Pottsville Group conglomerate (A) separated by drainage from siltstone outcrop (Devonian) at B. See figure 6*B*. *B*, Lateral margin of debris flow 10 km southeast of Youngsville (fig. 1). Hammer at A for scale. Note conglomeratic sandstone boulders (B) on flow surface and adjacent boulder-free slope on left (C). Dashed line is approximate boundary of flow.

A

B

However, reservoir filling and subsequent fluctuations may account for slope movements as much as about 10 m above the water level. Certainly small fresh earthflows seen at locality S_1 suggest that movement along the low gradient slope has occurred because of water-level fluctuations. Fresh head scarps of slope movements at localities Q and V suggest that water level fluctuations probably caused the movements.

One of the reasons for a shoreline traverse in 1981 was to determine whether the lower or foot areas of ancient slope movements considered to be debris flows had been reactivated at least in part by the filling of the reservoir and whether any renewed lower slope movement would produce tensional features in head areas. Twelve such landforms were carefully examined, but no evidence (such as minor scarps or transverse cracks) was found to indicate any renewal of movement. These lower slope areas appear to have been stabilized after the initial movement.

Probably the most compelling reason for discounting reservoir filling and subsequent fluctuations as major factors in slope movement is the frequency of recent active movements along the Allegheny River valley in the Warren area downstream from the dam. The rock units and clay mineralogy of mass-movement material is similar to those in the vicinity of the Allegheny Reservoir. The lower one-fourth to one-third part of most slopes in the Warren area is particularly sensitive to movement wherever roads have been built or other man-induced activity has taken place.

Philbrick (1976) mentioned slope movements that occurred before reservoir filling at the dam site and at railroad and highway relocations in New York at the upper end of the reservoir. On the basis of all available data and descriptions, the slopes in the region have always been sensitive to modification irrespective of Allegheny Reservoir.

Slope movements will probably increase in future years in the Warren-Allegheny Reservoir region because of road construction related to increasing oil and gas development. Exploratory drilling at Chappel Bay has begun, according to U.S. Army Corps of Engineers officials, since the June 1980 shoreline reconnaissance. Recent exploration, as at localities B_2 and D_2 west of Warren (pl. 1), attest to further activity.

Late winter and early spring precipitation, in combination with the thawing of partially frozen ground, creates unstable slope conditions in slide-prone areas. Consequently, more slope movement takes place at this time of the year because of the high water content of the regolith. However, the importance of a single intense storm, most commonly a summer storm, in initiating mass movement cannot be overstated and has been documented elsewhere in Pennsylvania by Pomeroy (1980a, b, 1982b) and Pomeroy and Popp (1982). A 10-cm rainfall on June 29, 1982, at Warren caused partial failure of the slope and road blockage at locality G (pl. 1) according to L.R. Auchmoody, Research Forester, U.S. Forest Service (oral commun., 1982).

Blue-gray clay, at depths of 0.3 to 1.0 m, forms the slippage surface in many observed head areas of recent slope movements. Exposures along new access roads at the northwest edge of Warren show thin interbeds of blue-gray plastic claystone between shale at various horizons in the Venango Formation. Multiple shear surfaces probably exist at depth in the colluvium on the basis of the author's observations in back-hoe generated trenches in southwestern Pennsylvania. Subsurface data (Pennsylvania Department of Transportation, unpub. data, 1982) at one locality indicate that the plane of separation occurred along the colluvium-bedrock contact. Shallow rotational and translational (planar) movements are common. The rotational forms (slumps) have higher scarps and appear to be more prevalent where soil is thicker.

REFERENCES CITED

Berg, T.M., and others, 1980, Geologic map of Pennsylvania: Harrisburg, Pennsylvania Geological Survey, 3 plates, scale 1:250,000.

Butts, Charles, 1910, Description of the Warren quadrangle, Pennsylvania-New York: U.S. Geological Survey Geologic Atlas Folio 172, 11 p., scale 1:62,500.

Fisher, S.P., Fanaff, A.S., and Picking, L.W., 1968, Landslides of southeastern Ohio: Ohio Journal of Science, v. 68, no. 2, p. 67-80.

Gray, Carlyle, and others, 1960, Geologic map of Pennsylvania: Harrisburg, Pennsylvania Geological Survey, 4th ser., scale 1:250,000.

Lytle, W.S., 1965, Oil and gas geology of the Warren quadrangle [Pa.]: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report M52, 84 p.

Lytle, W.S., and Goth, J.H., 1970, Oil and gas geology of the Kinzua quadrangle, Warren and McKean Counties, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report M62, 99 p.

Philbrick, S.S., 1976, Kinzua Dam and the glacial foreland, *in* Coates, D.R., ed., Geomorphology and engineering: Strondsburg, Pa., Dowden, Hutchinson, and Ross, p. 175-197.

Pomeroy, J.S., 1980a, Recent storm-induced landslides, East Brady area, Pennsylvania: Pennsylvania Geology, v. 11, no. 5, p. 2-4.

______1980b, Storm-induced debris avalanching and related phenomena in the Johnstown area, Pennsylvania, with references to other studies in the Appalachians: U.S. Geological Survey Professional Paper 1191, 24 p.

______1981, Landslides and related features Pennsylvania—Warren 1° × 2° sheet: U.S. Geological Survey Open-File Report 81-238, 112 plates, scale 1:24,000.

______1982a, Landslides in the Greater Pittsburgh region, Pennsylvania: U.S. Geological Survey Professional Paper 1229, 48 p., 12 pls.

______1982b, Geomorphic effects of the July 19–20, 1977, storm in a part of the Little Conemaugh River area northeast of Johnstown, Pennsylvania: Northeastern Geology, v. 4, no. 1, p. 1–9.

______1983, Relict debris flows in northwestern Pennsylvania: Northeastern Geology, v. 5, no. 1, p. 1–7.

______1984, Storm-induced slope movements at East Brady, northwestern Pennsylvania: U.S. Geological Survey Bulletin 1618, 16 p.

Pomeroy, J.S., and Popp, J.W., 1982, Storm-induced landsliding, June 1981, in southwestern Pennsylvania: Pennsylvania Geology, v. 13, no. 2, p. 12–15.

Schuster, R.L., 1979, Reservoir-induced landslides: International Association of Engineering Geology Bulletin, no. 20, p. 8–15.

U.S. Soil Conservation Service, 1971, Warren County, Pennsylvania—interim soil survey report. Volume 1, Soil interpretations, 131 p.

______1974, Warren County, Pennsylvania—interim soil survey report. Volume 2, Soil maps, 330 p.

Varnes, D.J., 1978, Slope movement types and processes, Chapter 2 of Schuster, R.L., and Krizek, R.J., eds., Landslides—analysis and control: National Research Council, Highway Research Board Special Report 176, p. 11–33.

White, G.W., Totten, S.M., and Gross, D.L., 1969, Pleistocene stratigraphy of northwestern Pennsylvania: Pennsylvania Geological Survey, 4th ser., Bulletin G55, 88 p.