Slope Stability in the Marietta Area, Washington County, Southeastern Ohio

U.S. GEOLOGICAL SURVEY BULLETIN 1695

Slope Stability in the Marietta Area, Washington County, Southeastern Ohio

Frontispiece: Earth flows and creep along the northeast-facing slope 2 kilometers northwest of Stanleyville.

Slope Stability in the Marietta Area, Washington County, Southeastern Ohio

By JOHN S. POMEROY

An investigation of the distribution of slope movements
in a part of southeastern Ohio—a discussion of
geologic and other factors involved in their genesis

U.S. GEOLOGICAL SURVEY BULLETIN 1695

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

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

UNITED STATES GOVERNMENT PRINTING OFFICE: 1987

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 stability in the Marietta area, Washington County,
southeastern Ohio.
(U.S. Geological Survey bulletin ; 1695)
Bibliography: p.
Supt. of Docs. no.: I 19.3:1695
1. Slopes (Physical geography)—Ohio—Marietta Region.
2. Earth movements—Ohio—Marietta Region.
I. Title. II. Series
QE75.B9 no. 1695 557.3 s [551.4'36] 86-600274
[GB448]

CONTENTS

FIGURES

FIGURES—Continued

TABLES

Metric Conversion Factors

Multiply metric units	By	To obtain U.S. customary units
millimeter (mm)	0.0394	inch (in.)
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.621	mile (mi)
square kilometer (km^2)	0.386	square mile (mi^2)
cubic meter (m^3)	35.311	cubic foot (ft^3)

Slope Stability In the Marietta Area, Washington County, Southeastern Ohio

By John S. Pomeroy

Abstract

Geologic materials and slopes conducive to naturally occurring slope failure abound in the Marietta, Ohio, area. About 1,150 recently active earth flows, slumps, debris slides, and complex forms of slope failure were mapped within a mantle of weathered rock and soil. Earth-flow-type movements are the most prominent slope failure forms. Beneath this mantle is a thick sequence comprised of the Monongahela Group of Pennsylvanian age and the Dunkard Group of Pennsylvanian and Permian age. Both of these units contain subhorizontal red shale and mudstone interbedded with intermittent thin to thick sandstone beds. The area was investigated in 1983 and 1984 to obtain data related to the topographic and geologic setting of slope movements. Field data were obtained over a period of 75 to 80 days along closely spaced traverses in an area of about 180 square kilometers.

One large slope movement (approximately 54,000 square meters) within Marietta has forced the removal of 18 houses. Another actively moving slope involves a 1.4-kilometer-wide area above the Ohio River. A 4.5-square-kilometer forested area southeast of Marietta contains nearly 90 mappable recent slope failures ranging in size from 100 to 50,000 square meters.

Lithologic, geomorphic, and microclimatic factors play an important role in the origin and distribution of slope failures. Movements in the regolith originate below seeps on slopes of low permeability. The slopes most susceptible to movement are those overlying relatively thick intervals of shale and mudstone interbedded with thinner intervals of coarser grained clastic rock. Slope configuration and angle, aspect, existing surface drainage, and the effect of stress release along valley walls influence slope failure distribution.

Beginning in 1970, the Marietta area has been subjected to generally greater than normal precipitation resulting in high ground-water levels. Long-time residents report an increase in slope movements in recent years. The field investigation has confirmed the presence of fresh scars above hummocky ground along slopes. Most recent movements (about 90 percent) in this largely rural area are initiated by precipitation rather than by construction and other slope modifications.

INTRODUCTION

The Marietta area (fig. 1), Washington County, southeastern Ohio, was investigated during spring 1983 and 1984 and late fall 1983 to obtain data related to the topographic and geologic setting of slope movements (Pomeroy, 1984a, b, 1985). The area [about 180 square kilometers (km^2)] involves most of the Marietta 7$^1/_2$-minute quadrangle and parts of the Belmont, Willow Island, Valley Mills, Fleming, and Parkersburg 7$^1/_2$-minute quadrangles (fig. 1). About 10 percent of the area is urbanized.

The area had been examined briefly in 1978 by Hackman and Thomas (1978) and others as part of a reconnaissance inventory of the entire Appalachian Plateau region involving several States. I participated in the field checking of the quadrangles in the Marietta area at that time.

Previous comments about slope problems in the Marietta region have been made by Collins and Smith (1977) and Ohio State University (1950). A portion of the Ohio River shoreline in West Virginia opposite Marietta was shown by Lessing and others (1976). Slope stability has been discussed in other regions of southeastern and eastern Ohio by Everett (1963), Fisher (1969, 1978), Fisher and others (1968), Hooper (1969a, b), Hubbard (1908), Lanyon and Hall (1983), Lessig (1966), Marshall (1969), Mast (1980), Mitchell (1941), Philbrick (1962), Savage (1950, 1951), Sharpe and Dosch (1942), Sheley (1969), Van Buskirk (1977), Waltz and Fisher (1978), and Webb and Collins (1967).

The Marietta area, which lies within the unglaciated part of the Appalachian Plateau province, shows a high incidence of slope movements typical of the southeastern Ohio–western West Virginia–southwestern Pennsylvania region. Relief generally is only 91–121 meters (m), markedly less than that in other areas of the Appalachian Plateau, which have an average relief of 152–182 m.

An objective of the current project was to determine the areal distribution of slope movements that would lead to a better understanding of their topographic and geologic setting and of the processes involved. Furthermore, the detailed inventory would enable the investigator to compile a slope stability map that would distinguish areas with different potentials for landsliding (U.S. Geological Survey, 1982, p. 25).The results of the investigation would be applicable to what could be expected in other areas in southeastern Ohio, adjacent West Virginia, and southwestern Penn-

Figure 1. Marietta area.

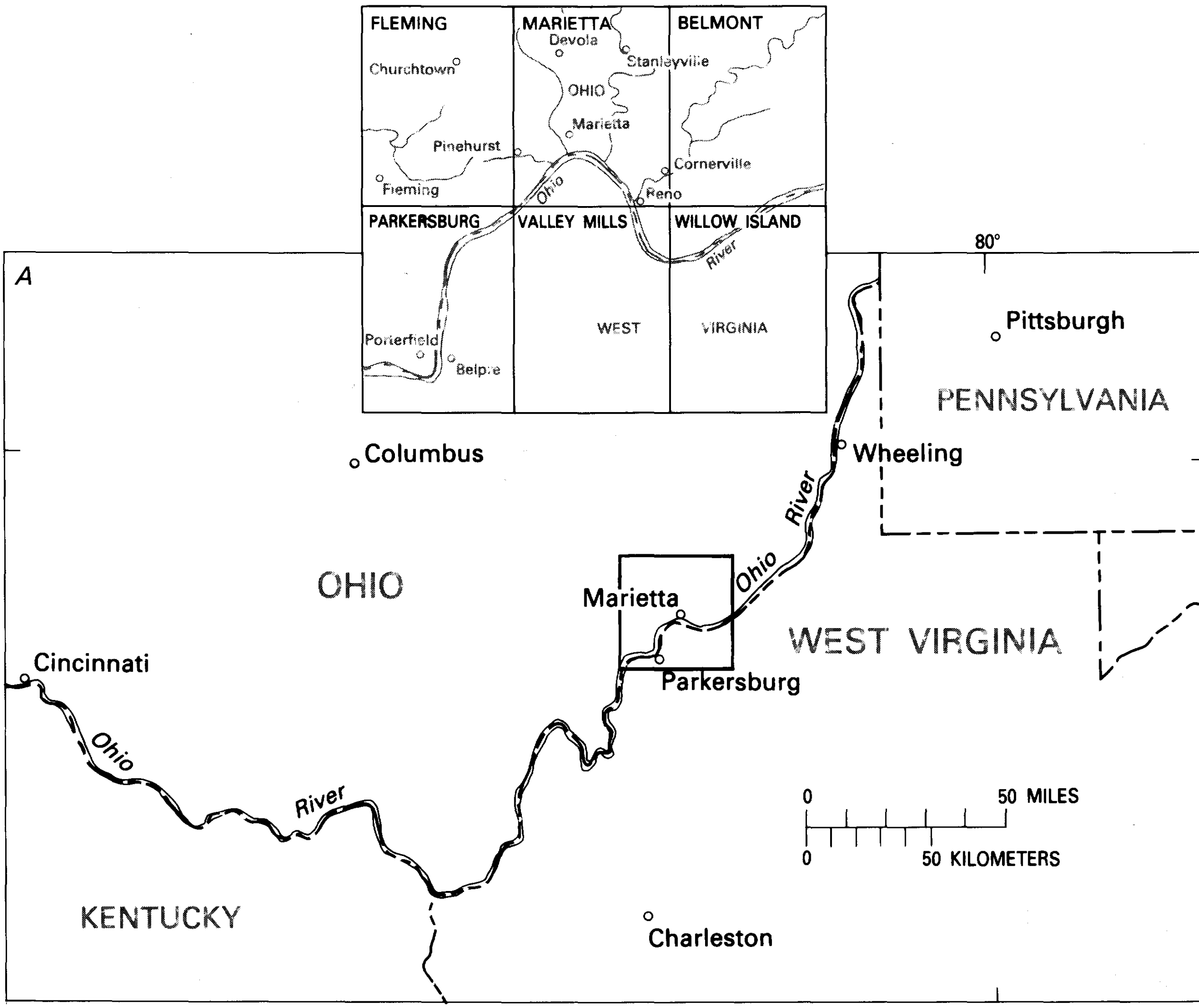


Figure 1A. Location of Marietta.

sylvania and, thus, would serve as a prototype for evaluating landslide susceptibility in this part of the Appalachian Plateau. A basic question to be resolved was the susceptibility to movement of natural, unmodified slopes.

The selection of the Marietta area was based, in part, on the availability of such local sources of information as historical data from the *Marietta Times* and data from the Engineering Office of the Ohio Department of Transportation, the Marietta City Engineer's office, the Soil Conservation Service Office, the National Forest Service, and the Geology Department at Marietta College.

Special acknowledgement is extended to Ted Bauer (*Marietta Times*), Robert Jones (Soil Conservation Service), Robert Badger (City Engineer), Richard Delong (Ohio Geological Survey), Clayton Blaney (Marietta Sewage Treatment Plant), and Victor Wolff (District 10, Ohio Department of Transportation). The author is grateful for the opportunity to discuss his observations and interpretations in traverses with Robert Van Horn (Ohio Geological Survey), Marilyn Ortt (Marietta botanist), and John Batteiger (*Marietta Times*).

TERMINOLOGY

The term "regolith" is used in this report to describe material from rock weathered in place (residuum) as well as weathered material that has moved downslope (colluvium). Although colluvium is commonly at its maximum thickness at the base of the slope, it generally is found along all parts of the slope.

The term "mudstone" is used extensively in this report rather than "clay-shale" or "shale," which were used by previous workers in southwestern Pennsylvania and in southeastern Ohio. Earlier investigators did not differentiate

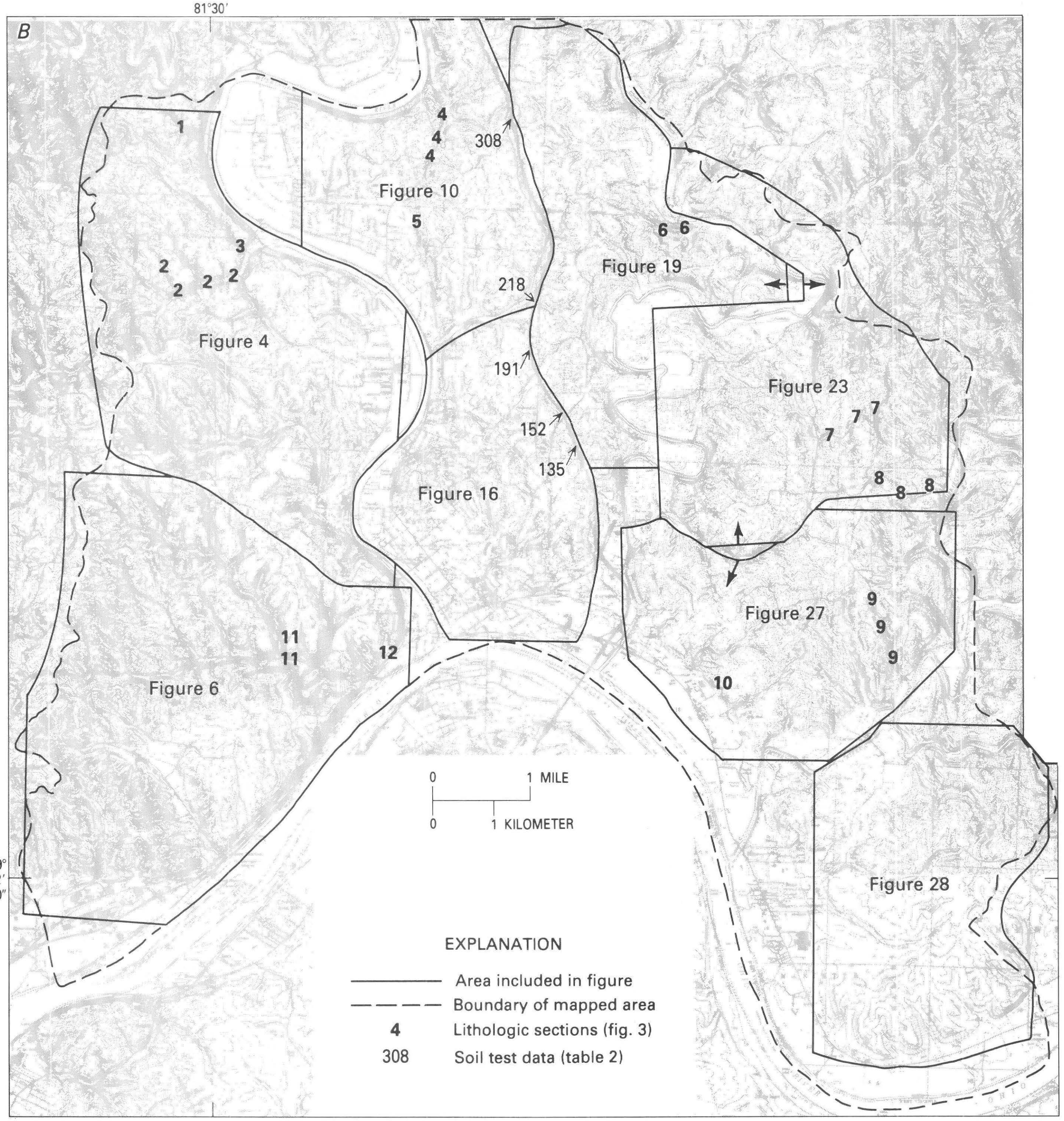


Figure 1*B*. Location of maps used in this report.

between bedded shale and nonbedded mudstone. Berryhill and others (1971) and Collins and Smith (1977) stated that mudstone is a more appropriate term than shale for most of these fine-grained clastic rocks because the rocks commonly lack fissility and are essentially nonbedded. Only where the rocks are bedded or fissile should they be called shale. A claystone is a clay-rich mudstone. The following definitions of rock types (Gary and others, 1972) are cited here:

Claystone.—Indurated clay having the texture and composition of shale but lacking its fine lamination and fissility; a massive mudstone in which the clay predominates over silt. Most claystone is thin and seldom exceeds a few meters in thickness and includes underclay beneath a coal bed.

Mudstone.—Indurated mud having the texture and composition of shale but lacking its fine lamination and fissility; a blocky or massive fine-grained sedimentary rock in which the proportions of clay and silt are approximately the same; or a general term that should be used only where the amounts of clay and silt are not known or cannot be identified precisely. Mudstone is not as fine grained as claystone, is more abundant in the stratigraphic section, and has greater maximum thickness.

Shale.—Fine-grained indurated detrital sedimentary rock formed by the consolidation of clay, silt, or mud and characterized by finely stratified structure and (or) fissility that is approximately parallel to the bedding.

The term "landslide" has been used widely 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 and have used landslide wherever shear failure occurs along a specific or multiple surfaces (Varnes, 1978).

Following the classification of Varnes (1978, fig. 2.1), slope movements in the Marietta area include falls (rockfalls), slides (earth and rock slumps, debris slides), flows (debris flows, earth flows, debris avalanches, soil creep), and complex movements (slump-earth flows, debris slide-earth flows) (figs. 2*A–C*).

Rockfalls are extremely rapid [greater than 3 meters per second (m/s)] free falls of bedrock. Alternating competent and incompetent lithologies, in addition to closely spaced vertical joints parallel to the drainage, are contributing factors to the process. Slides are either slumps or debris slides. Rock slumps and earth slumps are characterized by rotational movement with an upward-curving rupture surface, whereas debris slides take place along planar or mildly undulatory surfaces and are called translational movements. Slide movements can be very slow [1.5 meters per year (m/yr)] to rapid [0.3 meter per minute (m/min)]. Flows are of four types ranging in movement from extremely rapid (greater than 3 m/s)—debris avalanche, to very rapid (0.3 m/s)—debris flow, to rapid (0.3 m/min) to very slow (1.5 m/yr)—earth flow, to extremely slow (0.06 m/yr)—soil creep. Flows consist of moving material that resembles a viscous fluid. Soil creep (fig. 2*C*) is the extremely slow downslope movement of soil and rock material that takes place on many slopes where ground breakage is scant or absent. Accelerated creep may precede sliding.

Many slope movements in the area are complex in that features of two or more basic slope movements are represented. What starts out as rotational-type sliding (slumping) can develop into a translational (or planar) movement which becomes a flowage feature in the lower part (fig. 2*B*). Not only are sliding and flowage combined, but the sliding itself consists of rotational and planar movements. Earth flows in cohesive materials can be considered complex because shear takes place along the flanks and basal surface (note slickensides on fig. 2*D*), and plastic flow may be indicated by the distribution of velocities within the displaced material (Varnes, 1978).

GEOLOGY AND ITS RELATION TO SLOPE MOVEMENTS

The Marietta area lies along the southwestern side of the Dunkard basin. Repetitive sequences of subhorizontal red shale and mudstone interbedded with occasional thin to thick sandstone and siltstone beds of Pennsylvania and Permian age underlie the Marietta area. Limestone, coal, and claystone are minor lithologies. The bedrock dips to the south at less than 1°.

Most of the bedrock belongs to the Dunkard Group, which includes the Waynesburg, Washington, and Greene Formations in areas to the northeast. Because of the absence of mappable Waynesburg coal at the base of the Waynesburg Formation in the Marietta area, a definable boundary for the base of the Dunkard Group could not be delineated (Collins and Smith, 1977, p. 15). The approximately 35-m section usually mapped as Dunkard is included by Collins and Smith (1977) in the underlying Monongahela Group. The Washington coal (at the base of the Washington Formation) is shown on their map as the base of the Permian. Differentiation of the Dunkard Group above the Washington coal into the Washington and Greene Formations was not possible at the scale of their mapping (1:62,500).

In many parts of the Appalachian Plateau, soils (table 1) and weathered rock from certain parts of the stratigraphic section are responsible for a large number of slides in certain intervals (Pomeroy, 1978, 1979, 1982a, b). In the Marietta area, however, the distribution of slope movements is relatively uniform throughout the Monongahela and Dunkard Groups. This characteristic is related to the widespread occurrence of incompetent rock (mudstone, shale) interbedded with competent rock (sandstone, siltstone) (fig. 3). The widespread presence of the silty to clayey regolith and underlying incompetent rock is apparent in table 2.

Rapid facies changes commonly occur within short distances, as revealed mainly by subsurface data (Collins and Smith, 1977), not only in this area but in other parts of the Dunkard basin as well (Pomeroy, 1986). I have found that individual lithologies (except for some coals that serve as marker beds) are seldom traceable for distances greater than 2.0 kilometers (km) throughout the Dunkard basin. Collins and Smith (1977, p. 11) referred to the "nonlayer-cake" nature of the surface rocks that gives rise to correlation problems. Figure 3 shows the lack of continuity in the units when stratigraphic sections at comparable elevations are compared.

In many areas, outcrop distribution can be predicted. On the southwest-facing slopes, 1- to 2-m-thick sandstone

Figure 2. Features of slope movements.

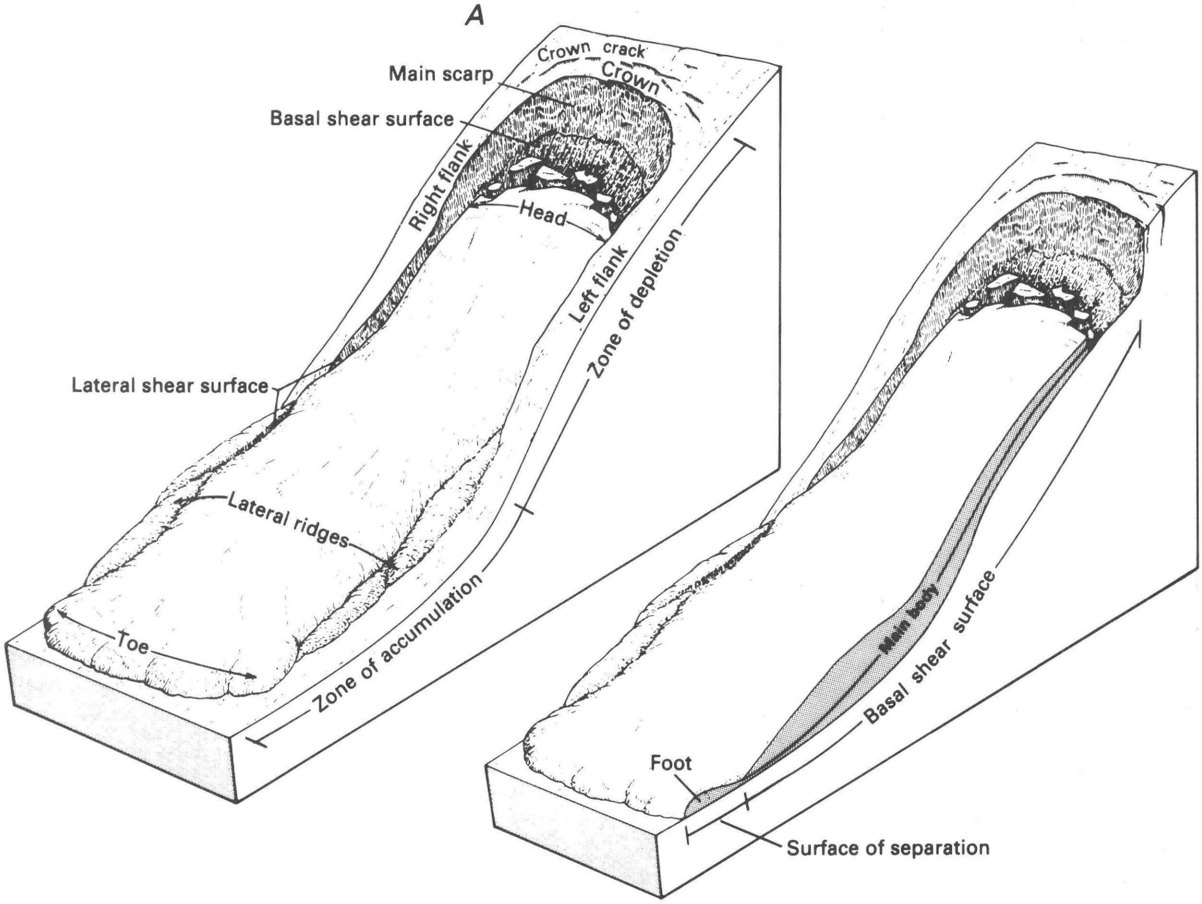


Figure 2A. Idealized earth flows. Left, Surface features. Right, Subsurface features. From Keefer and Johnson (1983).

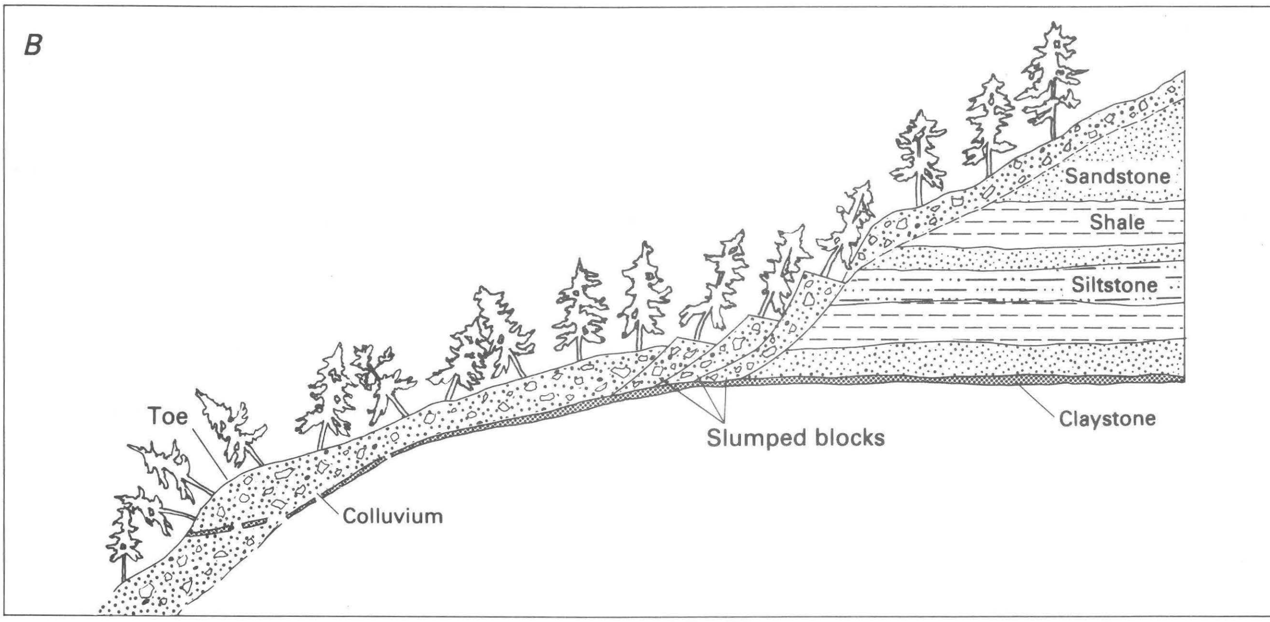
ledges are common, and colluvial cover is generally thin. Colluvial cover usually is thicker along the northeast-facing slopes and commonly masks the sandstone ledges.

Slope failures were noted within colluvium and at the colluvium-bedrock interface. Undoubtedly, subsurface investigations would reveal that some shear planes also occur within weathered bedrock (Pomeroy, 1986). Observations indicate that most slope movements originate at or near weathered clay-rich bedrock.

Subsurface observations of colluvium from trenches (Hooper, 1969a, b; S. F. Obermeier, U.S. Geological Survey, written commun., 1983) and auger borings (Sharpe and Dosch, 1942) along slopes in eastern and southeastern Ohio show that the weaker lithologic rock types, instead of extending horizontally to intersect the slope surface, thin abruptly and bend downslope (fig. 2*C*). Impervious materials (shale, mudstone, claystone) are stretched out roughly parallel to the slope and retard the downward percolation of surface and ground water. In this type of situation, a temporary perched water table (Campbell, 1975) may form during long periods of precipitation or during short periods of intense downpours if infiltration at the surface takes place at a greater rate than deep percolation. The saturated colluvium then becomes vulnerable to some form of disruption, such as earth flow movement.

Colluvial thickness is variable on slopes, and, generally, colluvial deposits are thicker in the lower parts of slopes. Unfortunately, subsurface information is lacking except for Ohio Department of Transportation data along Interstate 77, where thicknesses from 1.5 to 5.4 m are indicated (table 2). Because shale and mudstone commonly predominate in the section, the weathering products are usually silty clays or clayey silts.

Colluvium in the Marietta area may have been generated during the Pleistocene under different climatic conditions. The Wisconsinan glacial boundary lies about 64 km northwest of the Marietta area. Sand and gravel are found in the Ohio and Muskingum River valleys. Remnants of lake silts and clays are found along Duck Creek and the Little Muskingum River. Any discussion of the Pleistocene climate south of the glacial border is subject to considerable speculation and debate. However, Burns (1958) believed that the climate in southen Ohio was cool and moist during the Wisconsinan glaciation. The Pleistocene climate in the



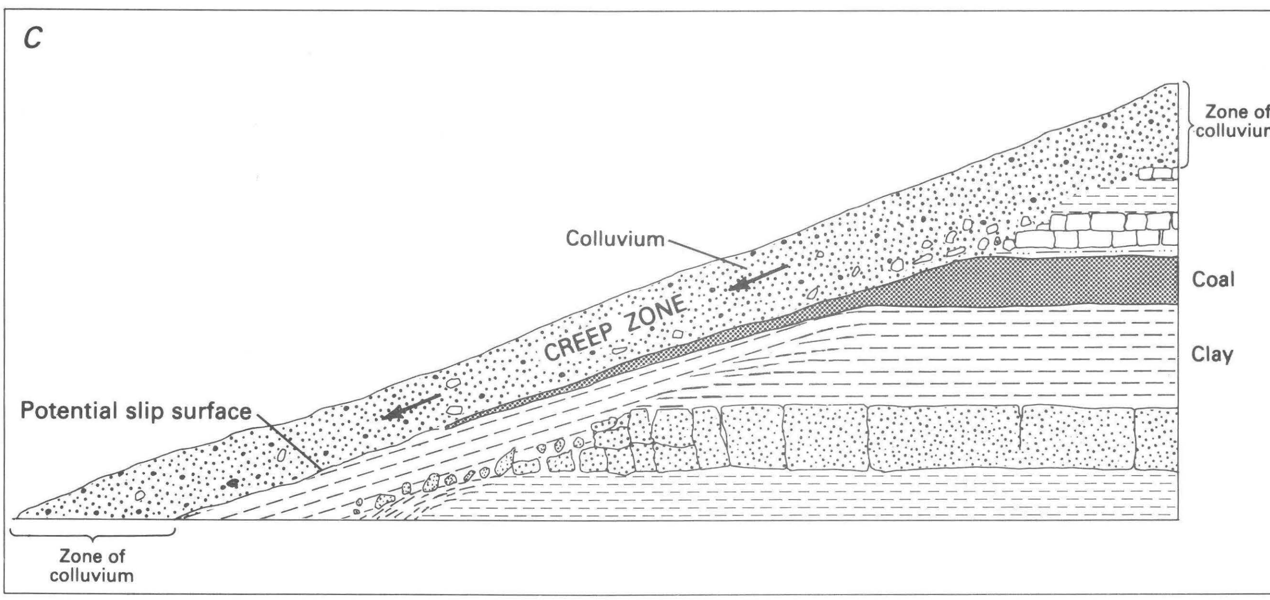


Figure 2*B*. Complex slope movement.

Figure 2*C*. Soil creep as a prelude to landsliding. Modified from Sharpe and Dosch (1942).

nonglaciated Appalachian Plateau region of Pennsylvania, West Virginia, and Ohio is believed to have been conducive to increased weathering resulting in the development of colluvium and slope movements and the masking of bedrock (Gray and others, 1979). Radiocarbon dating of slide planes at construction sites along major drainages in West Virginia indicate a minimum age of 40,000 years (yr) at Weirton (D'Appolonia and others, 1967) and about 8,940 and 9,750 yr at Morgantown and Wheeling, respectively (Philbrick, 1962).

Study of geologic controls on where slope movements occur in the Marietta area is hampered by poor exposures, thinness of lithologic units, and rapid facies changes within short distances.

CLAY MINERALOGY

Twenty-two clay samples were collected from several parts of recent earth flows, including basal shear surfaces as well as from a few areas unrelated to any slope failure. Despite the varied collecting points, the samples contain similar suites of clay minerals. The X-ray diffraction study showed that the dominant suite contains illite, kaolinite, and

Figure 2*D*. Slickensided basal shear surface (A) of a fresh earth flow.

a clay component that may be vermiculite; the other suite contains illite, kaolinite, and a more smectite-type expandable clay (Virginia Gonzalez, U.S. Geological Survey, written commun., 1983). No clear difference in clay mineralogy exists between the basal shear surfaces and the material elsewhere in the landslide deposit or in adjacent soils. The illite is potassium deficient (Gloria Hunsberger, U.S. Geological Survey, written commun., 1983), which is a condition prevalent elsewhere in unstable shales and mudstone of Devonian to Permian age in western Pennsylvania. For southeastern Ohio, Fisher and others (1968, p.79) concluded that "simultaneous deposition of ferric iron with degraded illitic clay prevented reabsorption of the bonding potassium ion in the depositional environment. The continued presence of iron has greatly inhibited the reconstitution of the clay throughout diagenesis and late geologic time." They indicated that degraded illites swell in the presence of water similar to montmorillonite, except that expandability is not as great.

METHODOLOGY

Expectations were that a better understanding of slope processes could be achieved simultaneously with production of a detailed inventory map (U.S. Geological Survey, 1982, p. 24). Field data were obtained for areas shown in figure 1*B* over a period of approximately 75 to 80 days (d) along a series of closely spaced traverses. Black and white aerial photographs from 1943 to 1981 proved useful for comparison studies (table 3).

The features mapped as recently active landslides in figures 4, 6, 10, 16, 19, 23, 27, and 28 show a main scarp and toe (fig. 2*A*). The most prevalent type is an earth flow (fig. 2*A*); other types include slumps, debris slides, and complex forms, which show characteristics of slumps and earth flows (fig. 2*B*). In addition to discrete lobate landslides, the landslide designation also includes areas of coalescing slope movements.

The main scarp and toe commonly measure from 0.5 to 1.5 m in height. The surface of the landslide is hummocky and generally cracked, shows tilted trees, and may have small areas of standing water. Springs may develop in the head areas of the landslides or above and also may develop at the frontal margin of the toe. A slickensided basal shear surface is common in the head area and still may be evident in fresh landslides (fig. 2*D*). The material involved in the movement is sliding on these striated (slickensided), clayey surfaces. Subsurface investigations by means of backhoe trenching elsewhere in the Appalachian Plateau

Table 1. Slope-failure-prone soils, estimates of soil properties, and engineering interpretations, Marietta area
[Based on Lessig and others (1977)]

Soil series	Soil mapping unit	Parent material	Percentage of area (approximate)	Classification (AASHO)[1]	Shrink-swell potential	Permeability	Available water (moisture) capacity	Suitability as source of roadfill; soil features affecting highway location, ponds excavations for dwellings
Upshur	Gilpin-Summitville-Upshur complex; Upshur silty clay loam; Upshur associated very stony; Upshur-Gilpin complex; Upshur clay.	Red shale (mudstone) residual to colluvial.	>50	A–7[2]	Moderate to high.[2]	Slow[2]	Moderate[2]	Poor; unstable clayey material subject to slippage.
Vandalia	Vandalia silty clay loam	Colluvium (mudstone and red clay), thick deposits on foot slopes.	<5	A–6, A–7	Moderate to high.	Slow	do	Do.
Hayter-Vandalia	Hayter-Vandalia channery loams and stony complex.	Colluvium (shale, mudstone, red clays, and coarse textures).	<2	A–4, A–6, A–7	Low to high	Variable	do	Fair to poor; considerable unstable material subject to slippage.
Belpre	Belpre clay	Calcareous shale, mudstone, residual to colluvial.	<1	A–7	High	Slow	do	Poor; unstable clayey material, subject to slippage.
Brookside	Brookside silty clay loam	Colluvium, thick deposits on foot slopes.	<1	A–6, A–7	Moderate	Moderately slow.	High	Do.

[1]American Association of State Highway Officials system. A soil is classified in one of seven groups ranging from A–1 through A–7 on basis of grain-size distribution, liquid limit, and plasticity index. A–7 soils are clayey, have low strength when wet, and are the poorest soils for subgrade (Lessig and others, 1977; p. 62).

[2]Applies to Upshur part of complexes.

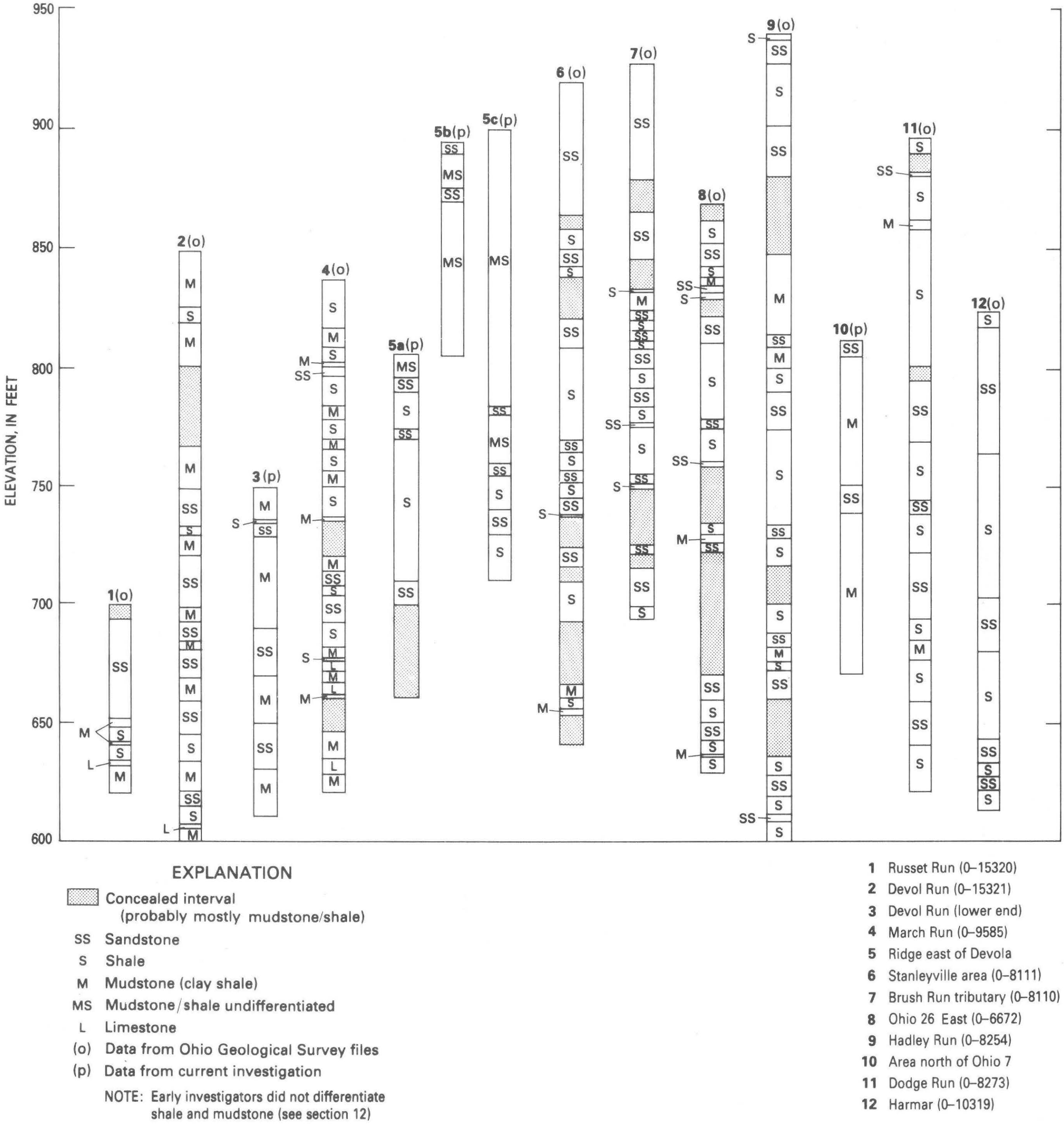


Figure 3. Lithologic sections, Marietta area, Ohio. See figure 1*B* for locations.

(S. F. Obermeier, U.S. Geological Survey, written commun., 1983) indicate the presence of multiple shear planes within any particular earth flow.

Movements of less than 10 m in maximum dimension are not shown on the maps. The slope failure designation does not include rockfall or soil creep; the latter is prevalent on all slopes in the Marietta area.

At each site, I recorded the type of movement, approximate dimensions, orientation, vegetation, elevation of head and toe, configuration of and position on slope, angle of adjacent slope, character of material in the main body, proximity of bedrock, influence of slope modification (if any), surface drainage, and presence of seeps. At a small number of fresh landslide sites, the distance and angle of the basal shear plane to the surface could be measured.

Two U.S. Geological Survey open-file maps (Pomeroy, 1984b, 1985) were prepared from these data and are available as supplementary material to this text. The first map is a detailed inventory map of recently active slope failures, and the second is a map of relative slope stability.

REGIONAL DESCRIPTION OF SLOPE MOVEMENTS

Figures 4, 6, 10, 16, 19, 23, 27, and 28 show recently active landslides. Each map figure is outlined on figure 1*B*. Complete data are presented in the Appendix, and only selected localities are described in the following text.

Area West of Muskingum River

North of Ohio 676 (Figure 4)

Examination of the lower slopes below the 700-foot (ft) contour along Devol and Russet Runs reveals scant slope movement activity. Lithologic data indicate that sandstone makes up 50 to 60 percent of the section.

However, an extremely unstable interval of mostly mudstone and shale lies between 800- and 890-ft elevation

Table 2. Summary of selected soil test data and character of underlying bedrock along Interstate 77 (fig. 1*B*)
[From Ohio Department of Transportation, District 10]

Location No.	Approximate elevation, in feet	Thickness interval, in feet	Depth to bedrock, in feet	Aggregate, in percent	Coarse sand, in percent	Fine sand, in percent	Silt, in percent	Clay, in percent	Liquid limit	Plasticity index	Percent H_2O content	AASHO rating*
135	790	0.5– 3.0		0	0	2	28	70	47	28	16	A–6, 7
		3.0– 7.5		0	1	14	50	35	25	7	8	A–4
		7.5– 9.0	9.0	27	2	3	40	28	30	11	7	A–6
	781–772	9.0–15.0			red weathered indurated clay						7	--
		15.0–18.0			light-gray weathered indurated clay						3	--
	772–763	18.0–23.0			broken red shale						6	--
		23.0–27.0			---------- do ---------						9	--
152	790	0.2– 3.0		0	3	6	52	39	33	11	17	A–6
		3.0– 5.0	5.0	45	2	5	23	25	34	11	24	A–6
	785–781	5.0– 9.0			brown weathered sandstone					--	--	--
	781–760	9.0–14.0			red weathered indurated clay					13	--	--
		14.0–19.0			---------- do ---------					11	--	--
		19.0–25.0			---------- do ---------					9	--	--
		25.0–30.0			---------- do ---------					9	--	--
191	780	0.5– 5.0		0	2	6	38	54	40	14	16	A–6
		5.0–10.0	10.0	0	1	1	39	59	34	12	13	A–6
	770–755	10.0–15.0			weathered indurated clay						--	--
		15.0–20.0			---------- do ---------						--	--
		20.0–25.0			---------- do ---------						--	--
218	640	0.2– 5.0		0	1	4	40	55	48	23	22	A–6, 7
		5.0– 8.0		0	0	1	46	53	44	22	27	A–6, 7
		8.0–12.0		0	1	10	47	42	35	16	25	A–6
		12.0–15.0		47	2	24	12	15	22	2	14	A–2–4
		15.0–17.0		17	2	7	33	41	36	13	17	A–6
		17.0–18.0	18.0	0	5	6	18	71	47	18	19	A–6, 7
	622–620	18.0–20.0			black coal blossom							
	620–617	20.0–23.0			broken gray sandstone							
308	860	0.0– 3.0		0	3	6	35	56	40	17	14	A–6
		3.0– 8.0		25	1	1	27	46	37	14	13	A–6
		8.0–11.0		4	0	1	34	61	36	14	10	A–6
		11.0–16.5		13	2	6	35	44	32	11	10	A–6
		16.5–18.0	18.0	24	1	2	36	37	35	12	16	A–6
	842–829	18.0–21.0			red, brown, and gray weathered indurated clay							
		21.0–24.0			gray weathered shale							
		24.0–26.0			brown and gray weathered shale							
		26.0–29.0			red weathered indurated clay							
		29.0–31.0			broken brown silty shale							

*See table 1, footnote 1.

Table 3. Aerial photographs used in investigation

Year	Scale	Flight series—Photograph numbers	Source of negatives
1943 (6/23)	1:20,000	CMD–2A–74 to 84	U.S. Department of Agriculture
		2A–88 to 95	Do.
		3A–26 to 28	Do.
		3A–42 to 51	Do.
		3A–62 to 66	Do.
1956 (3/20–21)[1]	1:31,000	FGS–CCD–2–23 to 27	U.S. Geological Survey
		BGS–CCD–3–2 to 7	Do.
		3–56 to 61	Do.
1958 (4/8)	1:28,000	VSW 1–3 to 9	Do.
1968 (5/7)	1:18,000	VBXD 1–35 to 45	Do.
		1–53 to 62	Do.
		1–67 to 76	Do.
		2–5 to 14	Do.
		2–18 to 26	Do.
		2–133 to 143	Do.
1975 (5/2)	1:78,000	VDLT 5–133 to 136	Do.
1976 (3/22)		VDLT 7–26 to 29	Do.
1980 (10/30)	1:24,000	RSU 188–191	Ohio Department of Natural Resources
		RSU 218–224	Do.
		RSU 239–245	Do.
		RSU 267–276	Do.
		RSU 281–284	Do.
1981 (6/11)		RSU 45–48	Do.
		RSU 80–85	Do.

[1]Oblique (cannot be viewed stereoscopically).

south of both drainages with head scarps of most earth flows occurring between 870 and 890 ft (locality A). Drainage channel heads begin from about 5.0 to 6.0 m downslope from the toe of a few earth flows; in general, a surface drainage network does not exist along that part of the slope covered by recent movements.

The southwest-facing forested slope (locality B) of the unnamed drainage to the south of Russet Run is devoid of any recent failures and has well-defined surface drainage channels. The slope is better drained and less hummocky and supports a much less varied vegetative cover than part of the opposing north-facing slope (to the southwest), which shows several recent earth flows. Slopes with closely spaced drainage channels are inferred to be well drained.

The unstable forested slopes south of Russet and Devol Runs have wide areas of contour concavity (hollowed out) that represent areas of coalescing older (prehistoric) failures. Such areas exhibit only slight development of surface drainage channels. Earth flows in this area have developed without any slope modification by man.

Slopes bordering Indian Run and its tributaries generally show many failures. The most severely affected slope is a northeast- to north-facing slope (locality H) with a nearly continuous 1.3-km-long zone of scarps, disoriented trees, and ponding. Although slumping is locally prominent, most of the movements are shallow planar earth flows. A marked decrease of slope movements is apparent on the opposing southwest-facing slope in addition to the mostly well-drained, southwest-facing slope on the other side of the ridge road. Most of the failures along Indian Run are natural earth flows and complex movements involving some slumping. Slopes adjacent to head areas of these movements range from 13° (22 percent) to 27° (55 percent). A sandstone ledge at about the 800-ft contour lies above a poorly exposed, dominantly red mudstone-shale slope and is the upper limit to a well-defined zone of intense slope movement on the southern side of Indian Run.

A major failure above Leland and Gilman Streets (locality J; fig. 5) damaged three houses, which were later razed. Most of the colluvial material has been removed from an area where movement had accelerated in March 1976. Costs arising from repurchase of the condemned properties and remedial work exceeded $350,000. The movement apparently developed after Gilman Street was widened (fig. 5). Slow movement (mostly creep) is continuing in the lower part of the area and still is affecting sections of Leland and Gilman Streets, as well as the railroad track ballast. The lower slope has a subtle hummocky surface of low relief. The problem is compounded by a movement of water-saturated fill from under the road into the Muskingham River, resulting in some subsidence of Gilman Street (Robert Badger, *Marietta Times,* September 20, 1980). Efforts to intercept the drainage continued in 1984.

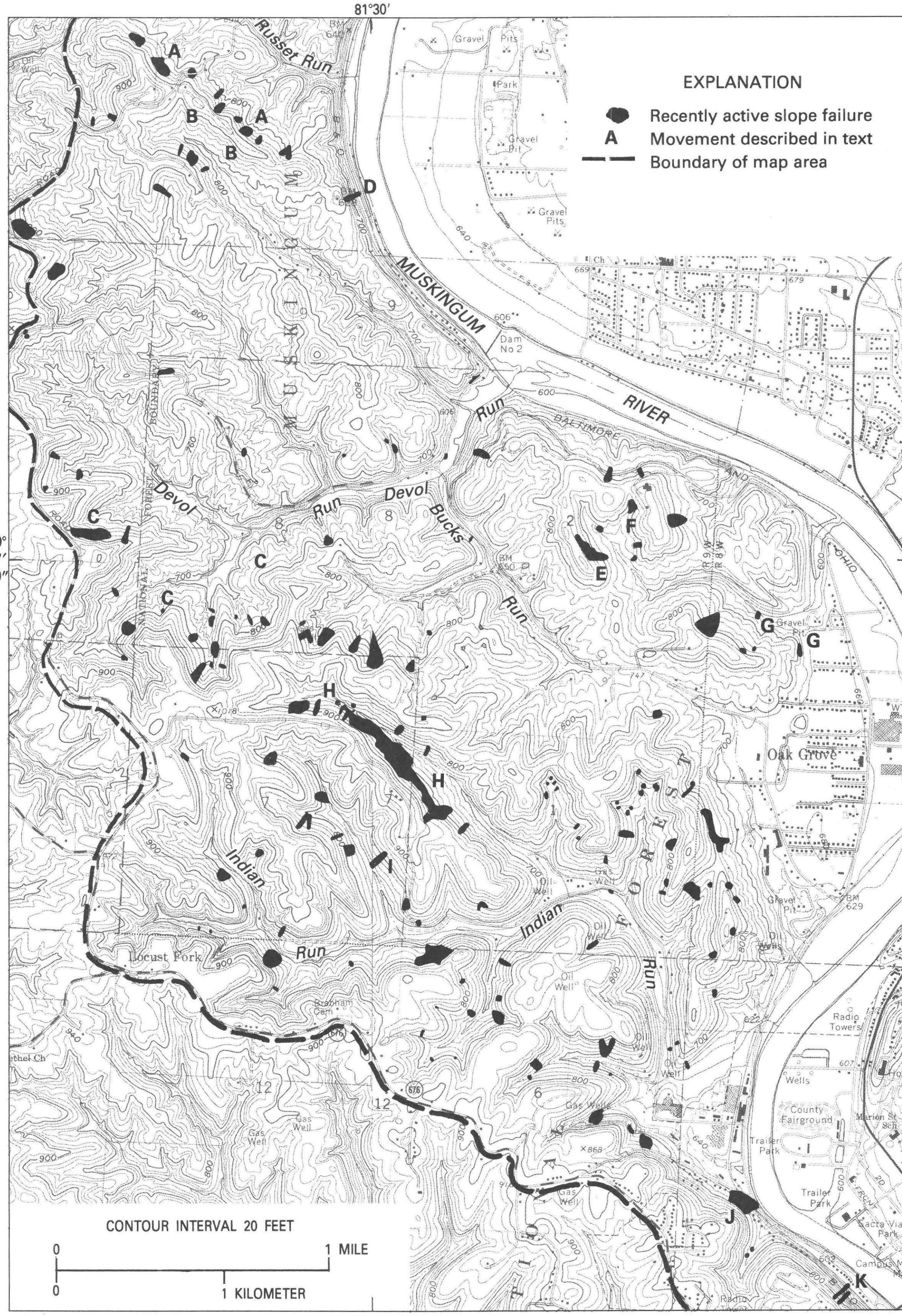


Figure 4. Area north of Ohio 676.

Figure 5. Site of the slope failure above Gilman Street (fig. 4, locality J). Shown are the base of the sandstone ledge (A), Leland Street (B), the railroad track (C), and Gilman Street (note "Bump" sign) (D).

Two debris avalanches (locality K) southeast of locality J are discernible from the eastern bank of the Muskingum River. The northern debris avalanche originates from an approximately 20-m-wide, crescent-shaped wet area below three houses and extends to the railroad tracks. The wetness is caused by a drain pipe that leads into the southern side of the cove from one of the houses. The head scarp of a younger debris avalanche to the south is hidden by high brush below the front of a backyard porch. The floor of the head area is wet, suggesting seepage.

South of Ohio 676 (Figure 6)

The slope above Ohio 7 at Harmar and its continuation to the southwest has stability problems of various types. An essentially continuous zone of creep and coalescing earth flows extends laterally for about 1 km. The area involving Lancaster Street (locality A) has been particularly troublesome. Nearly 240 m of piling installed across an approximately 18-m-wide area cost the city $16,000 (Robert Badger, *Marietta Times,* September 2, 1980), but that amount did not include the curbing, gutter, and drainage renovation. Movement also is occurring along the lower slope about 30 m downhill along Lancaster Street opposite Douglas Street, where steel beams support a suspended sidewalk. Slow movement continued at both Lancaster Street locations in spring 1984.

Slow earth flow movements and creep are widespread along the same slope to the south adjacent to other streets that cut diagonally across the slope (locality B). Old steel and concrete walls (some with vertical steel beams, along with more recent steel cribbing), barely discernible 0.3-m-high earth flow toes, occasional ground cracks, and a conspicuous hummocky appearance of the lower slope attest to historic activity taking place downslope from a 7.5- to 9.0-m-thick sandstone.

A rockfall hazard lies above Ohio 7 to the southwest (locality C). When the highway was constructed in 1940, considerable excavation was necessary to provide adequate width for increased traffic. Two large rockfalls occurred in the 1940's, and another, on January 31, 1950. The latter rockfall is pictured in the Ohio State University Engineering Experiment Station News (Ohio State University, 1950) along a 3.0- to 4.5-m-thick mudstone and minor shale slope overlain by 9.0 to 11.0 m of thick-bedded sandstone (fig. 7). Separation along nearly vertical joints in the sandstone and rapid weathering of the underlying mudstone continues to cause additional rockfalls.

At locality D, recent movements have disrupted an older macadam surfaced road that was built largely on red mudstone-shale fill between the highway and the river as shown on photomaps (Lessig and others, 1977). Slippage originated beneath a 9-m-thick sandstone ledge below Ohio 7 and above the railroad tracks. The composition of the fill and the possible rerouting of drainage from the highway above are probable factors in the severe surface disruptions throughout this area.

A rapid debris slide (locality G; fig. 8) took place along the steep slope opposite the slump-earth flow (locality F) in early May 1983 during an extremely wet period.

A strong lithologic control on the slope movements is demonstrated in the vicinity of Pinehurst. The earth flows

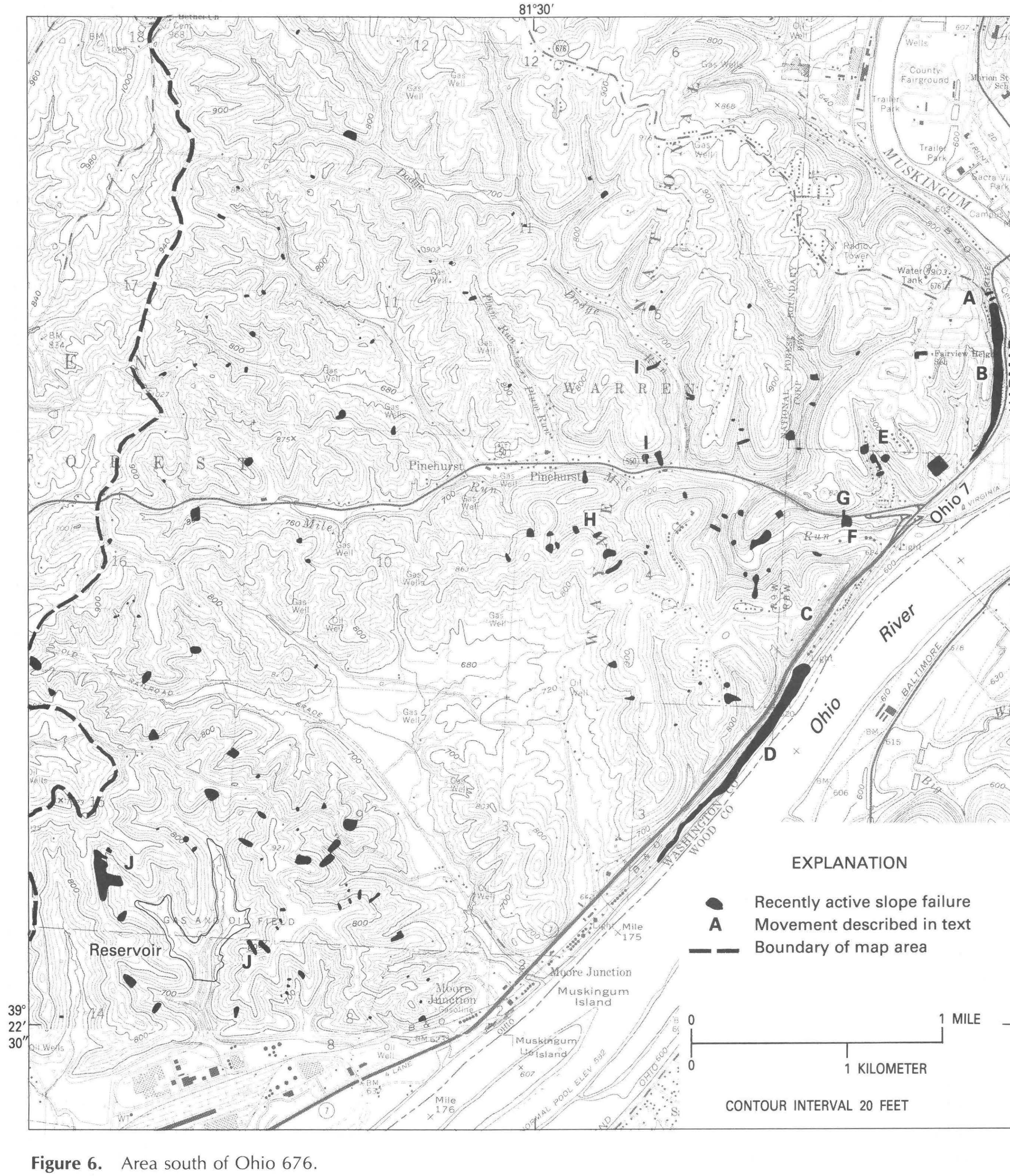


Figure 6. Area south of Ohio 676.

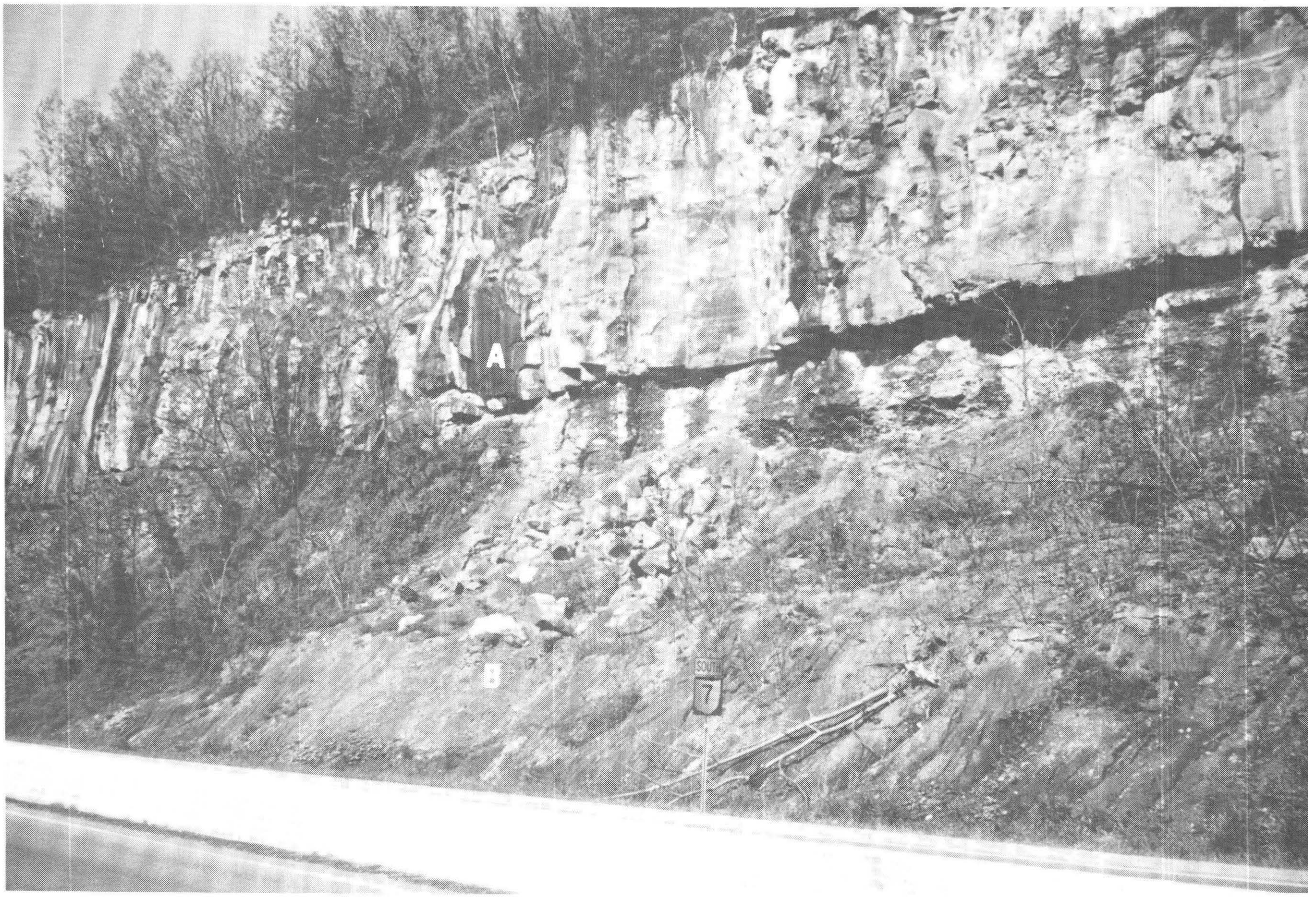


Figure 7. Rockfall area along Ohio 7 (fig. 6, locality C) to the southwest of Marietta. Shown are the lower part of a major sandstone bed (A) and mudstone with some shale (B).

and the slump-earth flows along a northwest- to east-facing slope to the south of Pinehurst (locality H) have head scarps at elevations of from 810 to 830 ft. On the northern side of Ohio 550, three movements (locality I), dating from pre-1980, April 1982, and post-late April 1983, took place at an altitude of 770 ft below a 7.5-m-thick sandstone. Furthermore, unstable slopes to the northwest and west of Moore Junction (fig. 9) occur in the regolith derived from largely shale and mudstone below a sandstone ledge.

Area Between Muskingum River and Duck Creek

West of Interstate 77

North of Ohio 821
(Figure 10)

A massive, 350-m-wide earth flow in fill and the subjacent slope (locality A) took place before May 1968 during or after the Interstate 77 construction (fig. 11). Red shale-mudstone fill from the highway cut to the east had been added to the northwest-facing slope. No documentation was available as to the approximate timing and rate of movement. The May 1968 aerial photographs show a damming of the drainage because of the slope movement. A smaller, 100-m-wide earth flow (locality B), 0.7 km to the north, had not shown failure before May 1968 but shows movement on the 1980 aerial photographs.

Two different environments for slope failures have occurred along the hillsides to the north of Devola. Composed largely of fill, the backyards of six houses failed in the early part of 1979 on the eastern side of Strecker Way (locality E). Renovation of the 160-m-wide slope took place in spring 1979 (Robert Jones, Soil Conservation Service, oral commun., 1983) resulting in a reduction of gradient. The overextension of fill for the backyards and its surcharging of the subjacent slope probably accounted for the resulting instability.

Houses have been built along a natural slope to the east of locality E on the eastern side of Sylvan Way (locality F). The use of fill has been minimal in backyard areas in contrast to the Strecker Lane locality. The head scarp of one earth flow is only 1 m from the foundation of one house. The rear porch sloped downhill in April 1983 (fig. 12). Other earth flows in the immediate vicinity include a 24-m-wide hollowed-out slope with one large beech tree near the base of the movement, a smaller earth flow below the backyard of the house adjacent to that shown in figure 12, and a

Figure 8. Debris slide along Ohio 550 (fig. 6, locality G) during the early May 1983 wet period. Shown is the seep at the base of the sandstone (A).

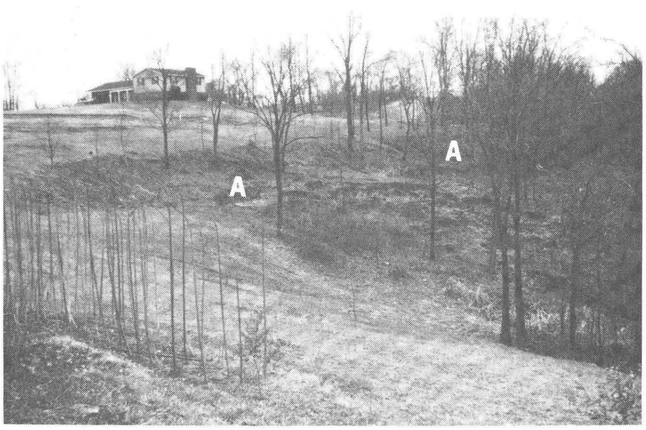


Figure 9. Earth flow 2 km northwest of Moore Junction. Shown are the base of the sandstone ledge (A), seepages common at contact with impermeable mudstone-shale, and an earth flow immediately below contact.

vacant lot earth flow. The earth flows head at slightly above or below 700 to 710 ft.

The western side of the forested highland to the east of Ohio 60 shows many slope movements. A 340-m-wide failure (locality G) extending in elevation from as high as 850 ft to as low as 620 ft lies mainly to the south of the ruins of a large house built in 1968 (fig. 13). Slope modification in the immediate vicinity of the house probably triggered movement locally but is not believed to have had any influence on the larger part of the movement to the south. The movement probably is classified best as an earth slump, but a deeper seated rock slump cannot be ruled out. Tilted sections with small ponds in the head area plus an obvious backward dip of the basement and first floor of the house (fig. 13) suggest a slide deeper than the usual shallow planar earth flow of the area.

According to information given Marilyn Ortt (Marietta botanist, written commun., 1984), the house was built in 1968. Slippage first occurred during spring 1975. The contractor did extensive renovation, including reinforcement of the rear concrete block wall, in December 1975. Trees and soil were removed from behind the house after recommendations by "authorities." A local real estate salesman took a 1-yr option to buy and moved in at the beginning of 1979 or 1980. No apparent movement had occurred during the interval that had elapsed since the "repair work." During an especially wet spring in 1979 or 1980, the occupant noticed that a drainpipe parallel to the basement wall jutted into a room within the period of 1 d. The house was abandoned after the occupant confirmed his

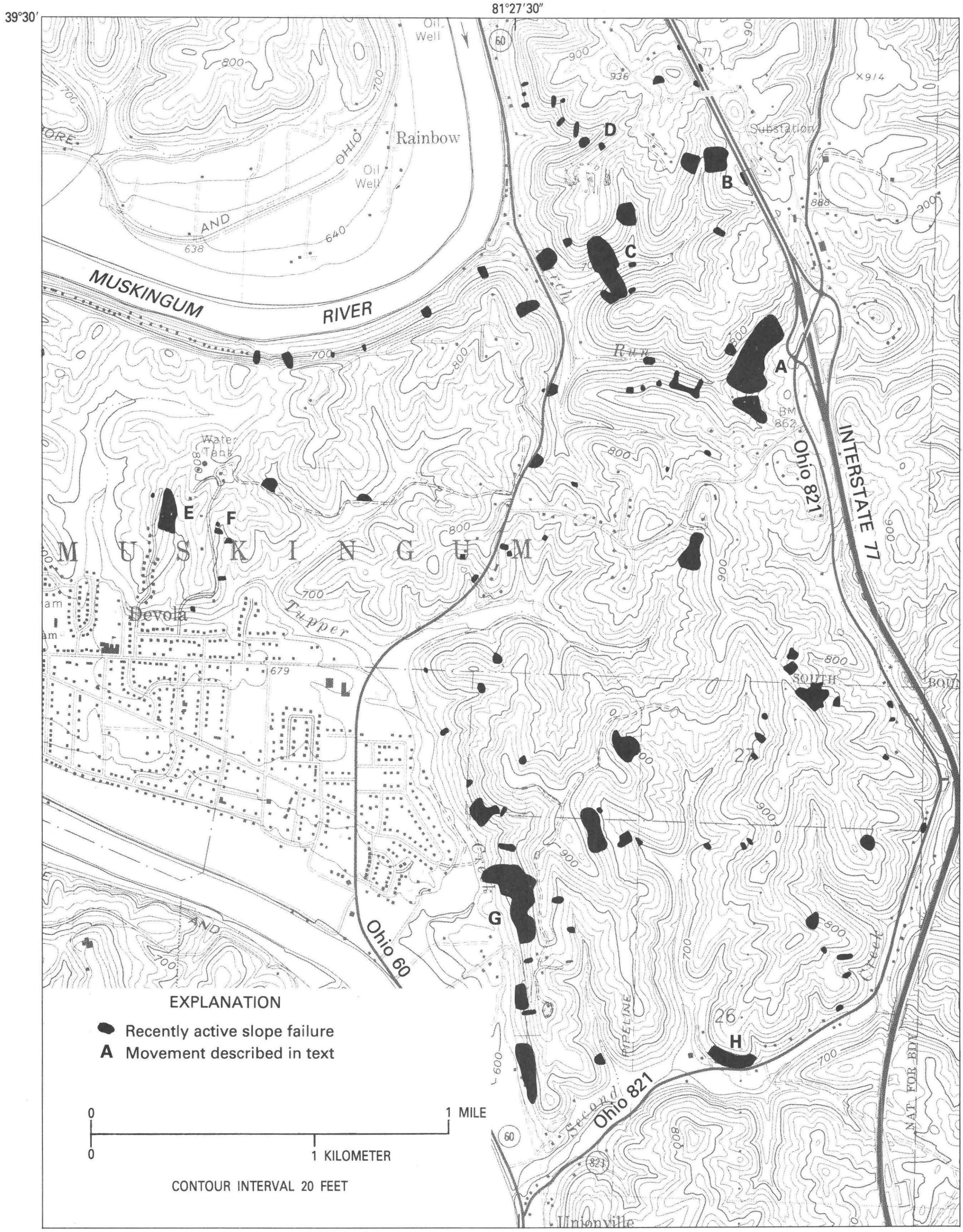


Figure 10. Area north and west of Ohio 821.

Figure 11. Fill and subjacent slope failure along the western side of Interstate 77 (fig. 10, locality A). Shown are the toe of the 350-m-wide movement (A) and the edge of Interstate 77 (B).

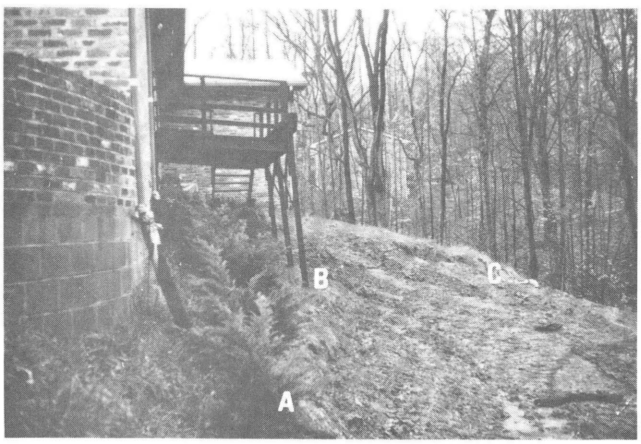


Figure 12. Backyard failure in Devola (fig. 10, locality F). Shown are the head scarp (A), the out-of-plumb porch column (B), and the lateral margin of the earth flow (C).

Figure 13. Ruins of a large house at the northern end of a 340-m-wide slope failure (fig. 10, locality G) to the east of Devola.

suspicions that the house was shifting by checking the floor with a level. The house was dismantled in either 1981 or 1982 after continued movements precluded habitation.

The events described above can be correlated with the rainfall record at Marietta (fig. 14). The house was built at the end of a drier than normal period. Above normal rainfall for most of the period 1970 to 1975 saw a buildup of ground-water levels in a monitored well (U.S. Geological Survey, 1965–77). Pore-water pressures at the house site probably also increased. Renovation of the slope behind the house plus a couple of slightly below normal rainfall years (1976–77) probably relieved the rate of slope movement temporarily. Resumption of noticeable movement in 1979 or 1980 correlates with the probable high pore-water pressures caused by above normal rainfall in 1979 and 1980. Examination of late-1980 aerial photographs shows that the areal extent of inclined and downed trees is almost as extensive as what one would expect to see on aerial photographs taken at the time of the 1983–84 investigation. In contrast, 1968 aerial photographs do not indicate any major slope failure area. The freshness of the ground cracks and scarps along the slope attest to the very recent movements at locality G.

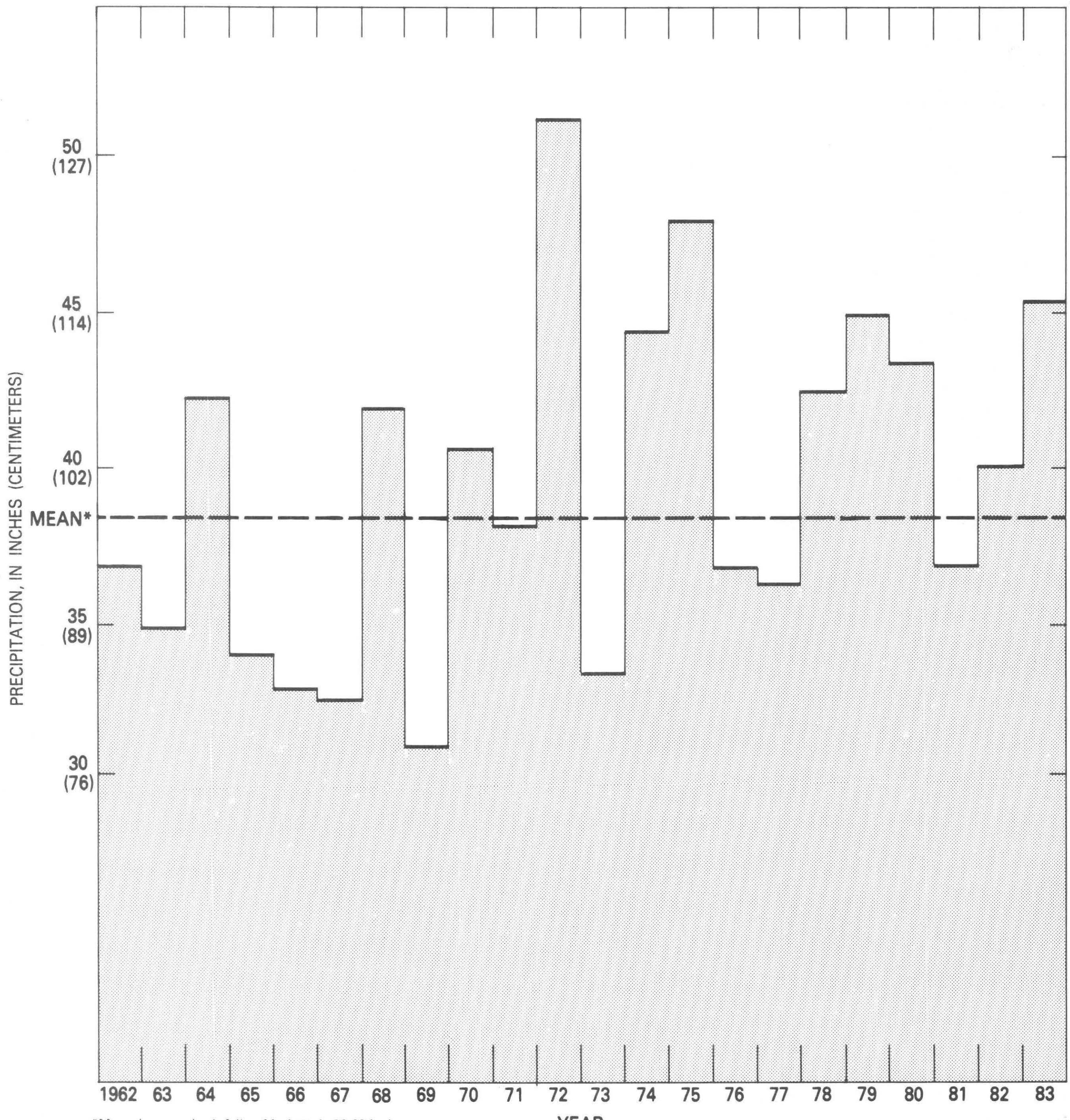
A preferential siting for many earth flows is suggested in several locations other than those along the Muskingum River and Second Creek. Slope movements along northwest- to east-facing slopes to the east and northeast of locality G are more numerous than those along other slopes. In general, well-defined drainage channels are dominant along southwest-facing slopes. Surface drainage development is more pronounced along these slopes than along north- and east-facing slopes. Natural channels spaced about every 30 to 60 m across the slope (fig. 15) seem to be sufficient to drain hillside slopes and prevent high pore-water pressure buildup in soil and colluvium. Consequently, these southwest-facing slopes show few movements.

South of Ohio 821
(Figure 16)

A dense pattern of slope failures occurs in the highland area south of Colegate Road and north of the central part of Marietta. One of the better known movements (locality A) took place behind the Army Reserve Center and involved the parking area. This 80- to 90-m-wide slump-earth flow took place in fill and subjacent slope after May 1968. The 1968 aerial photographs show some flowage of earth material in the lower extremities of the fill emplacement, but the parking area was intact at that time. The head area on the western side of the slump-earth flow had retrogressed to the foundation wall of the garage in April 1984, but that structure still was sound without any foundation cracks.

Development of the northwest-facing slope to the southeast of Muskingum Drive (Ohio 60) has been threatened by earthflows and creep (locality B). One earth flow has caused extensive property damage despite remedial measures (fig. 17).

Several landslide areas became well known to Marietta residents in 1980 following greater than normal rainfall during the spring and summer of that year (*Marietta Times*, selected issues, 1980). A small slope movement is reported to have caused the main water line to Memorial Hospital to break along Strecker Hill (street) (locality C). A water line under Ray Street (locality D) broke twice in 3 d because of a slow earth flow that threatened several houses; two houses on Ray Street showed collapsed foundations during this investigation. The hillside below Ray Street is part of an ancient failure nearly 100 m wide. Other failures, including Cullen Avenue (locality E), documented as mov-



*Mean (average) rainfall at Marietta is 38.62 inches (98.09 centimeters) for 63 years of record. Figure is based on data provided by John Hughes (National Oceanic and Atmospheric Administration, Asheville, N.C., oral commun., 1986)

Figure 14. Rainfall at Marietta, 1962–83.

Figure 15. Slope drainage channels prevalent along the southwest-facing slopes. Shown are the drainages (A) along the slope lacking in recent failures.

ing slowly in 1980 (*Marietta Times*), appeared active in 1983.

The Walnut Hills Drive slope failure (locality F), probably the best-known slope movement in Marietta, lies below Grandview Avenue and is part of a prehistoric(?) failure that extends to the railroad tracks below Greene Street. The hummocky head area is downslope from a thick-bedded sandstone that underlies Grandview Avenue. Springs at the base of the sandstone contribute to a wet slope. The 350-m-wide, very slow movement has sealed off Walnut Hills Drive, which cuts diagonally across the affected slope. The city officially closed Walnut Hills Drive on August 29, 1972, because of the slow continual damaging earth flow accompanied by some slumping in the head area. The macadam surface of the closed Walnut Hills Drive has been overgrown by vegetation and is cracked locally (fig. 18). The few houses along the Drive, as well as a larger number along the northern side of Greene Street, have been removed. A total of approximately 18 houses has been razed within this large earth flow [approximately 54,000 square meters (m^2)].

The appearance of the slope on aerial photographs during the 25-yr span between the 1943 and the 1968 flights reveals no significant differences. However, a major change in land use is apparent (with the removal of houses) when comparing 1968 with 1980 aerial photographs. The effect of a wetter climate during the decade of the 1970's probably is the major contributing factor in the slow, but destructive, earth movement.

Houses on the southern side of Greene Street show foundation cracks and some slightly out-of-plumb frames. Only one house on the northern side of Greene Street, just west of the Phillips Street intersection, still is standing. The eastern side of the upper part of the movement shows retaining walls of various ages that have moved downslope. Yellow clay was found nearly 7 m below the surface at the toe, according to records kept by the City Engineer. Whether or not this clay served as the sliding plane is conjectural. Seepage from the slope above Greene Street has caused hazardous icy conditions on the road during the winter. Small sections of the lower western end of the movement occasionally have moved out into Greene Street during wet periods.

East of Interstate 77 (Figure 19)

The major areas of slope movement in this region are the northeast- and east-facing hillsides facing Duck Creek. The mostly northeast-facing slope opposite of Stanleyville and extending northwestward along a tributary drainage shows a high density of mostly earth flows (frontispiece; fig. 19). Slumps and slump-earth flows are only locally common.

Figure 20 shows two earth flows (locality A) on the property of Frank Vaught, which is opposite of Stanleyville. These earth flows are obvious on the 1980 aerial photographs but cannot be seen on the 1968 aerial photographs. The property owner believed that the removal of locust trees in the head areas might have been a factor in the initiation of the earth flows. Slumping is absent from the head areas of both earth flows. The movements are strictly planar with up to 1 m of earth material removed from the head area. Both earth flows show renewed activity in the form of transverse cracks at the edge of the 760-ft bench. An older earth flow (locality B; fig. 20) lies adjacent to the easternmost earth flow. To the northwest, other earth flows (localities B, C; figs. 21, 22) are typical grassland and woodland slope movements.

Area Between Duck Creek and Little Muskingum River

North of Ohio 26 (Figure 23)

Much of the slope movement activity begins at about the 700-ft contour from the Stanleyville area southward along Duck Creek to Ohio 26.

Earth flow (planar) movement, whether in forest or grassland, is the most common type of slope failure (localities A, B; figs. 24, 25). Earth slumps along creeks such as one along Brush Run (locality C; fig. 26), are rarely large enough to show on a 1:24,000-scale map. Unmapped smaller slumps along Duck Creek imply that the base of the movements is below the creekbed.

A 400-m-wide area of a slow-moving regolith lies north of Lynch Church on the Duckworth farm (locality D). The owner reported that the slope surface now occupied by a massive earth flow was smooth during the early 1960's. Replaced telephone poles across the area are leaning, and the pond is being threatened by the moving hummocky mass. Because no manmade modification of the slope has been made since 1964, the high ground-water level brought

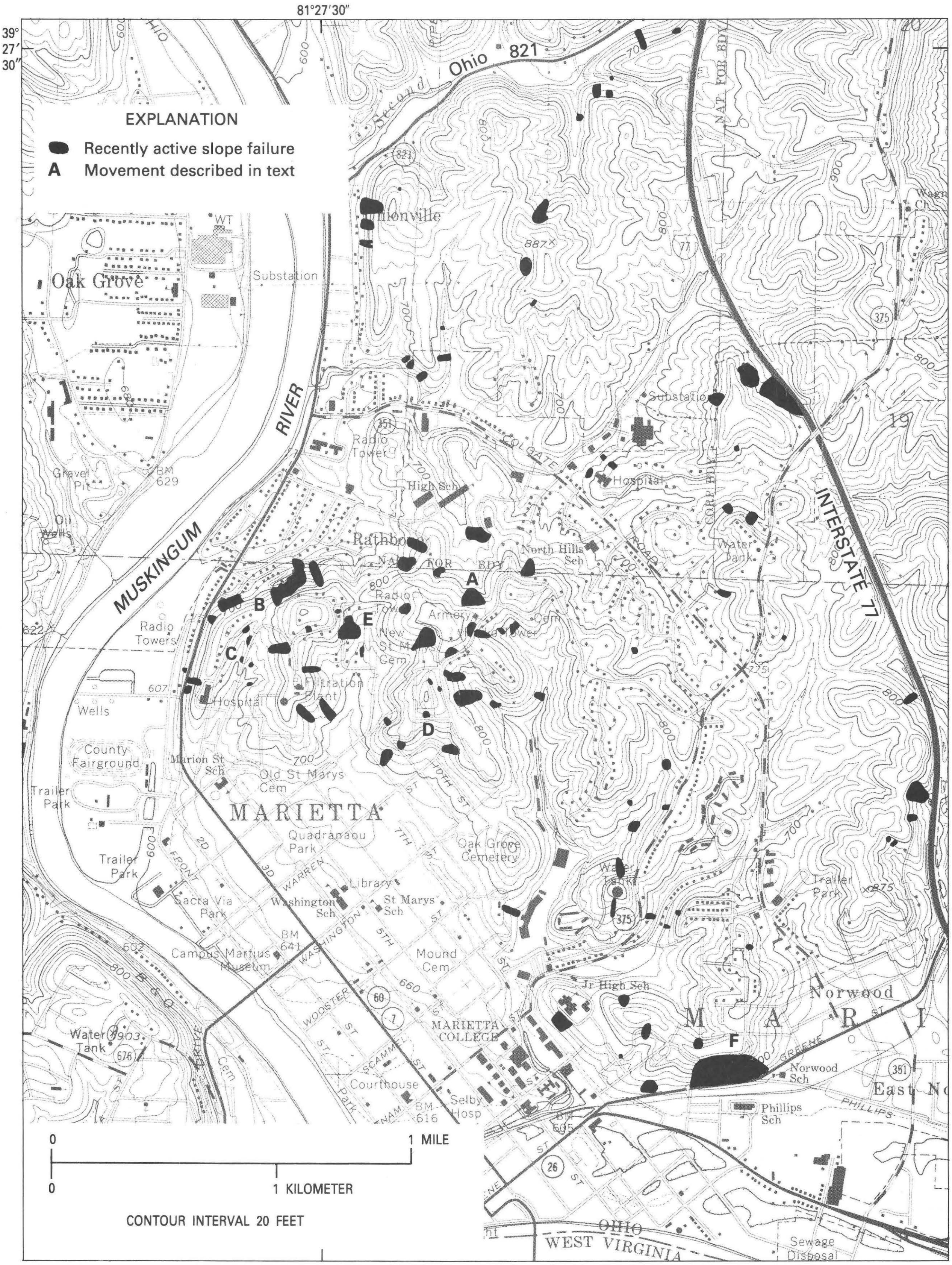


Figure 16. Area south of Ohio 821.

Figure 17. Crib failure behind the motel to the east of Ohio 60 (fig. 16, locality B). Shown is the toe of the earth flow that pushed in an exterior wall (A) and the cribbing that moved downslope and almost touched the structure (B).

Figure 18. Walnut Hills Drive slope movement (fig. 16, locality F). Shown is one of the many scarps in the upper areas of the 350-m-wide movement (A). Macadam surface is a vestige of Walnut Hills Drive.

on by the above normal rainfall from 1970 to 1983 is probably the triggering mechanism.

A traverse along Brush Run reveals a complete lack of recent movements along the west- to southwest-facing slope. Thin sandstone ledges can be discerned at various elevations along this slope with thin colluvium covering intervals between the ledges. In contrast, the opposing east- to northeast-facing slope has many earth flows, extensive colluvial cover, and hummocky ground.

Burchs Run, Negro Run, and several small north-south drainages to the east (locality F) show few slope movements. Sandstone outcrops are numerous along these slopes, which have networks of surface channels and lack ponds or wet areas. Section 7 (fig. 3), which occurs along the road eastward from Brush Run, indicates that about one-half of the bedrock is sandstone without any shale-mudstone interval greater than 8 m.

An abrupt increase in earth flows and complex movements southward to Ohio 26 (locality G) reflects a change in bedrock facies where mudstone and shale become more dominant. Few sandstone ledges were seen in this area. Section 8 (fig. 3), which is along Ohio 26, shows a significantly higher proportion of mudstone-shale to sandstone than does section 7. North- and northeast-facing slopes are the favored areas for the failures.

South of Ohio 26 (Figure 27)

The highland area to the east of Duck Creek shows heads of recent slope movements in the vicinity of the 680-

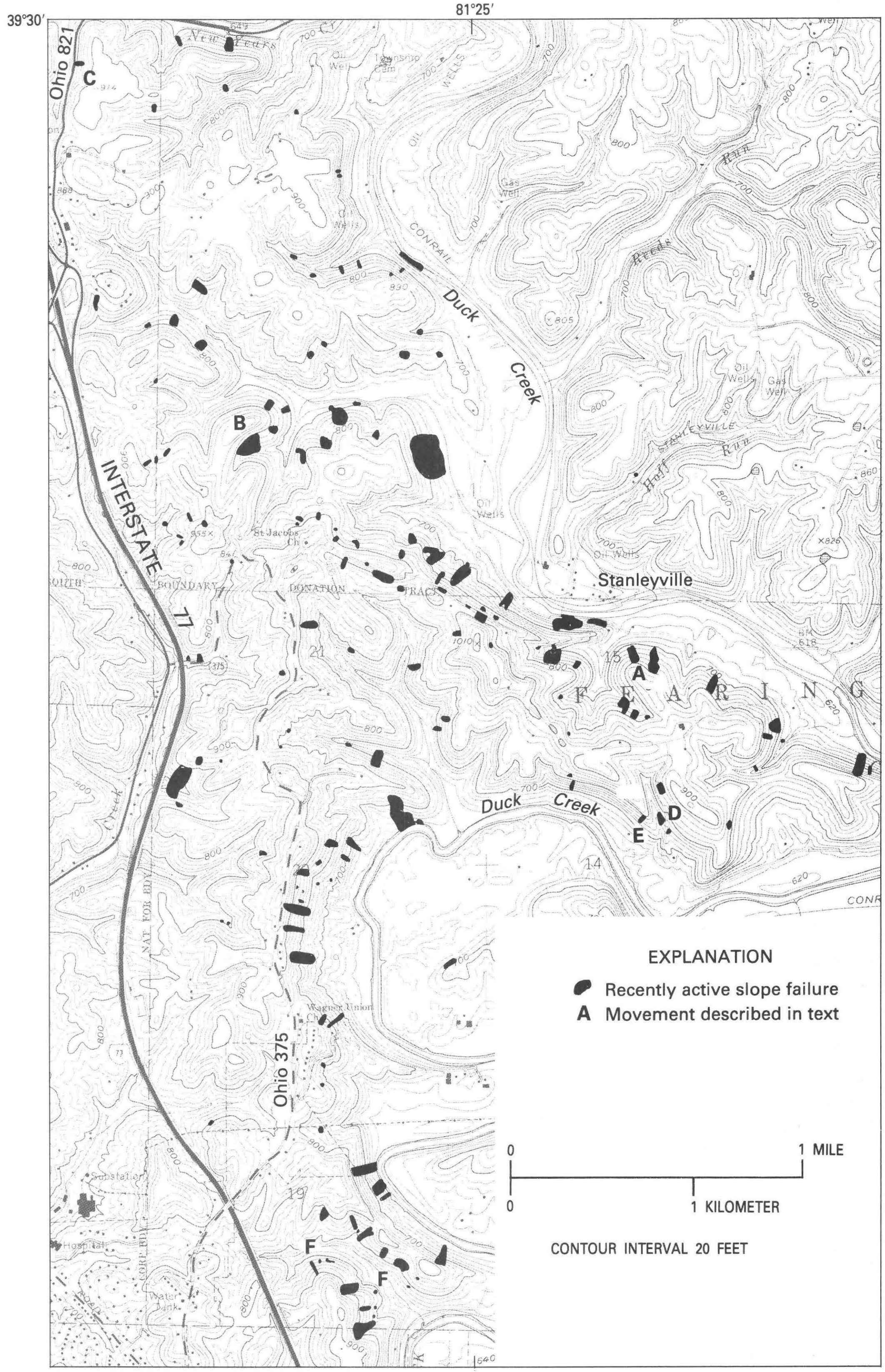


Figure 19. Area east of Interstate 77 and west of Duck Creek.

Figure 20. Earth flows opposite of Stanleyville (fig. 19, locality A). Shown are recently active earth flows (A_1 and A_2), the toe of an old earth flow (B), and the natural bench below the currently active part of earth flow A_1 (C).

and 800-ft contours. Most of the larger sized movements postdate the 1968 aerial photographs. The largest failure, an earth flow-slump (locality A), is a nearly 100-m-wide, relatively thin planar movement. A nearly 1.0-km-long segment of Duck Creek was rerouted sometime before 1956 to its present alignment along a more direct route against the slope. During high water, the lower slope probably is subject to increased pore-water pressure and resultant reduction in shear strength. Also, increased lateral erosion by Duck Creek probably has reduced the stability of the lowermost slopes by unloading support from the toe slope.

A 140-m-wide zone includes two closely spaced, very recent movements mapped as one (locality B). One of the movements is traversed diagonally by an access road, whereas the other is bordered laterally by a pipeline. Slope modification that impeded the natural drainage probably caused the failures. Natural drainage channels border this area to the north and south where no recent slope movement exists. The presence of these drainage channels might account for the lack of slope movements in the adjacent area. Particularly significant is the well-drained cove north of locality B that shows no slope failures.

Slopes bordering major drainages have a high failure density. A large, very irregular, 140-m-wide earth flow (locality D) with a 1.5-m-high head scarp lies behind a recently enlarged industrial building. Because the toe lies several tens of meters beyond the back lawn of the building, modification at the base of the slope did not cause the movement. The toe of a much smaller earth flow to the northwest, however, is only 1 m from the northwestern end of the building and probably was initiated by lower slope modification. A north-northwest-trending valley (locality E) to the north of Cornerville has a southwest-facing slope with many first-order drainage channels and only a few small recent movements and a northeast-facing hummocky slope with numerous recent failures.

Slopes in the vicinity of Hadley Run and the next drainage to the east show failures at various elevations. A predominance of shale-mudstone over sandstone with several moderately thick (more than 10-m) intervals of weaker rock accounts for a higher than average occurrence of landslides in this area. The nearly 100 m of this section (section 9; fig. 3) shows a ratio greater than 2 to 1 of shale-mudstone to sandstone.

The 0.4-km-long northeast-facing slope along the northwest-trending creek (locality F) 1.5 km northeast of Hadley Run is hummocky but without any recent slope failures, whereas the 0.6-km-long southwest-facing slope

Figure 21. Looking across the less than 100-m-wide earth flow (fig. 19, locality B). Shown are the lateral margins (A), the repaired pipeline aligned parallel to the direction of movement (B), and the ponded area (C).

Figure 22. Head area of earth flow to the east of Ohio 821 (fig. 19, locality C). Shown are part of the north lateral margin (A), the basal shear surface (B), and the clump of a displaced regolith (C).

shows numerous recent movements. Examination of a 1.8-m-thick sandstone and shale sequence in the creekbed shows no inclination indicating that structure cannot explain the selective occurrence of the failures.

Area South of Little Muskingum River (Figure 28)

The most intense area of landslides (mostly earth flows) anywhere in the Marietta area lies north of Ohio 7 (and the Ohio River) and south of Coal Run. This forested area (4.5 km^2) with 120 m of relief contains about 90 mappable, recently active landslides ranging in size from 100 to 50,000 m^2. Outcrops are scarcer than in areas to the northwest despite the steeper slopes and greater relief.

The slope failures are controlled lithologically; a large number have heads at the 800- and 900-ft contours. A discontinuous sandstone ledge of varying thickness commonly lies above each head area, and seeps are common at the contact. Poorly exposed red mudstone and shale underlie the sandstone. No one direction is preferred in the siting of landslides.

No houses are along the hillsides and ridge crests. Although indications of former and current oil and gas exploration are apparent in the form of sometimes poorly defined access roads, their influence on slope failures in this area is believed to be minor. Most of the movements are largely "natural" in cause and are believed to have been

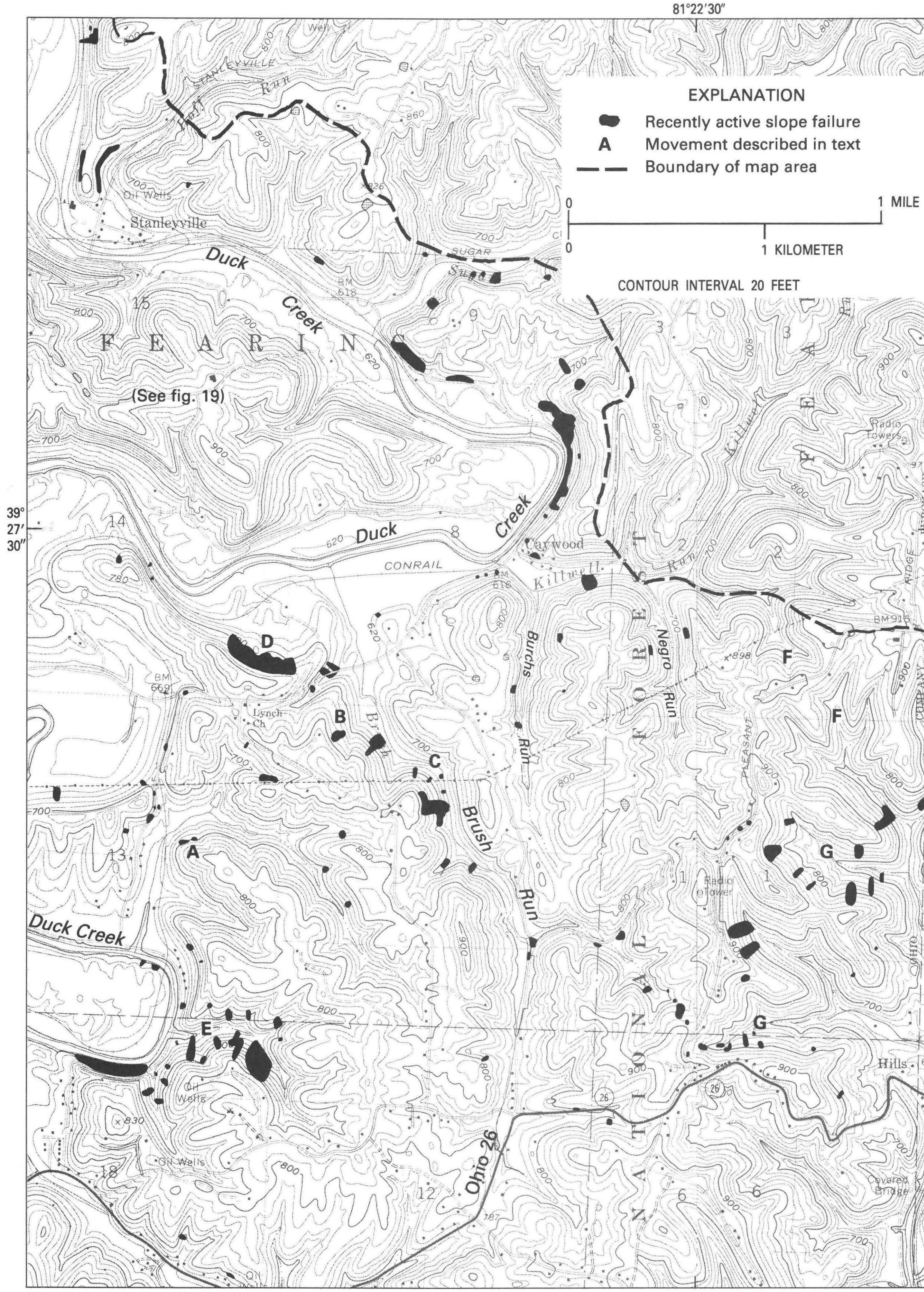


Figure 23. Area north of Ohio 26.

generated by above normal rainfall.

A wetter and warmer than normal December 1974 and January and February 1975 probably caused high pore-water pressure buildup in the soils and triggered a massive movement (180 m wide and 90 m long) that threatened three houses at the foot of the slope above Ohio 7 in early March 1975 (locality A) (*Marietta Times,* March 13, 1975). Fortunately, the houses still are standing (as of 1984) despite the ominous 2-m-high toe of the movements a few meters away from the rear wall of one of the houses.

Examination of the slope above the houses in 1983 revealed no fresh transverse cracks. Areas laterally adjacent

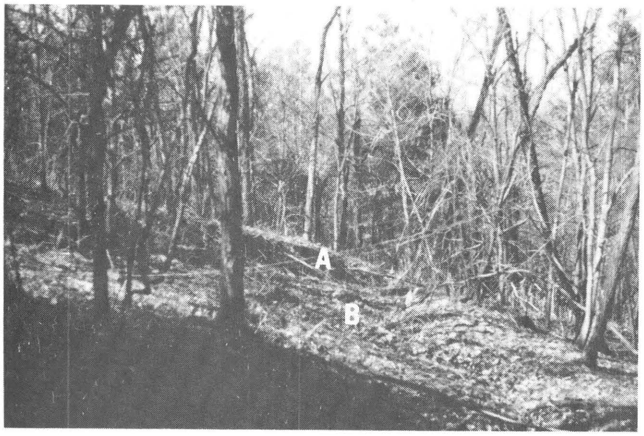


Figure 24. Head of the earth flow (fig. 19, locality A). Shown are the upper left margin of the scarp (A) and the basal shear surface (B).

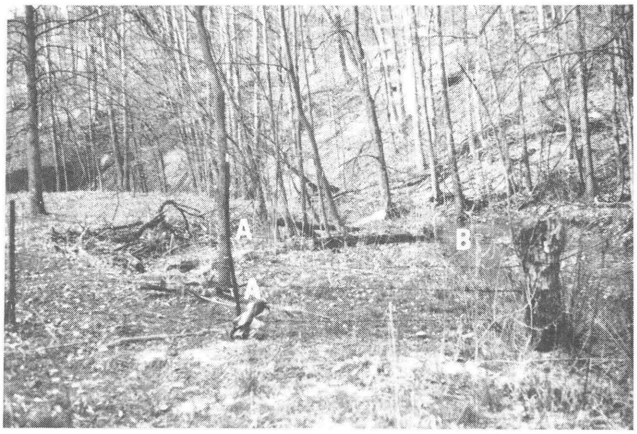


Figure 26. Earth slump along Brush Run (fig. 23, locality C). Shown are the lateral margins (A) and the creek (B). Note the group of rotated trees between A and B.

Figure 25. Earth flow within the concave slope (contour cavity) (fig. 23, locality A). Shown are the less than 1-m-high head scarp (A), the toe (B), and the dense, brushy area that conceals the seep (C).

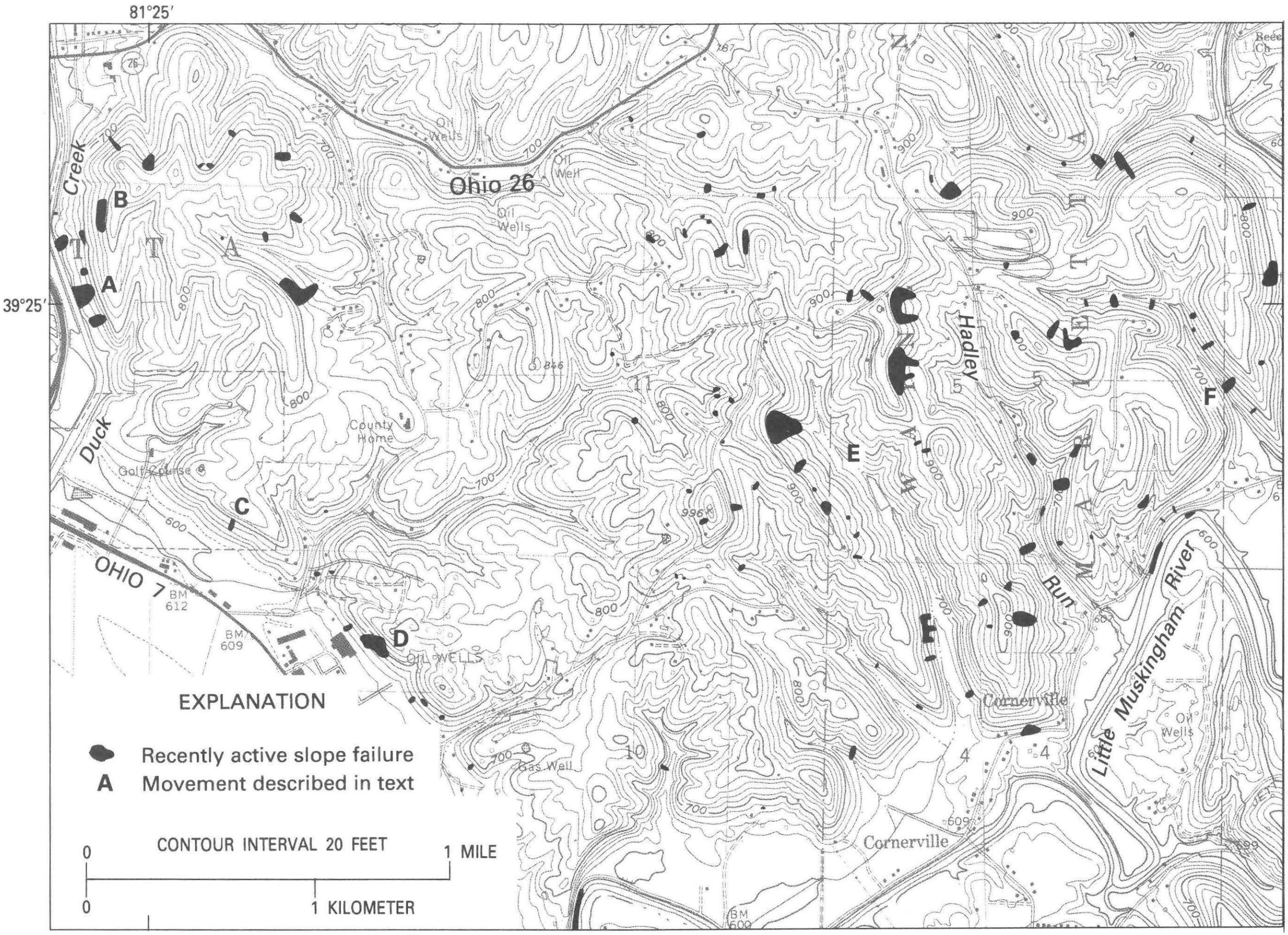


Figure 27. Area south of Ohio 26.

to the threatening movement showed several episodes of probable contemporaneous or slightly older slope failures with successive fronts. Heads of major failures are at the 800- and 900-ft contours along a 27° (52-percent) slope. Shallow planar earth-flow-type movement is suggested for the 1975 failure, during which soil and colluvium as much as 1.8 m thick was removed from the head area. Deep-seated (rock) slumping cannot be discounted for older movements, however.

Elsewhere in the area, slopes adjacent to the heads of earth flows range from 8° (14 percent) to 28° (54 percent) with the average being about 18° to 19° (33–35 percent). Some slumping (mostly shallow) in head areas takes place in about 20 percent of the movements. Lithologically controlled earth flows are apparent at the 800-ft contour along the north-facing slope above Long Run in the northern part of the area.

DISCUSSION OF GEOLOGIC AND OTHER FACTORS INVOLVED IN SLOPE FAILURES

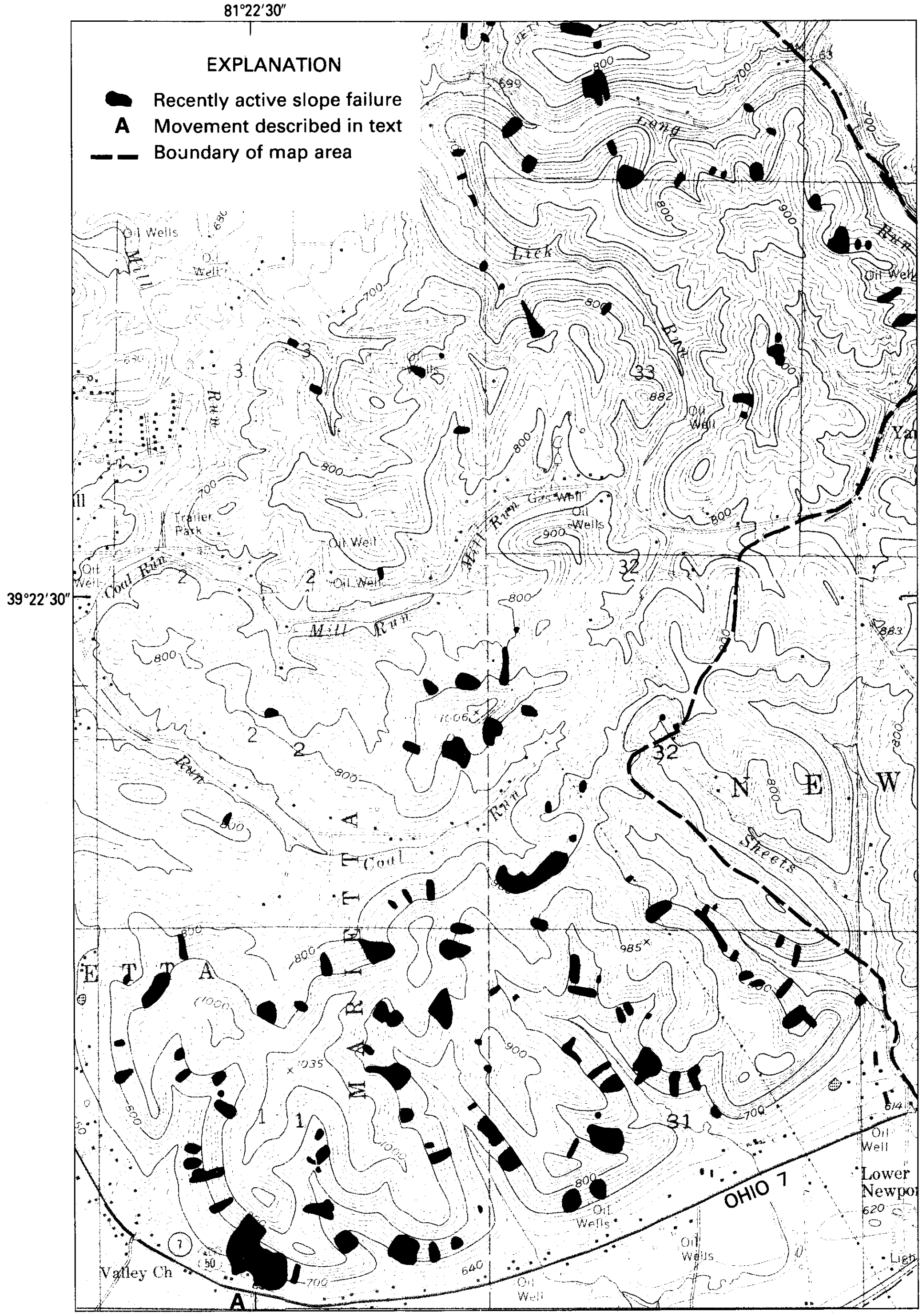
Lithology, Stratigraphy, and Structure

The slopes most susceptible to movement are those slopes overlying relatively thick intervals (greater than 8–10 m) of shale-mudstone with a few sandstone interbeds. The proportion of shale versus mudstone in the interval does not seem to be critical. Generally, competent rock (sandstone) comprises no more that 15 percent of the sections underlying severely slide-prone slopes; for example, lithologic sections (fig. 3) at March Run, Hadley Run, Ohio 26 East, Stanleyville, and the ridge to the east of Devola include a high percentage of weak rock relative to competent rock.

Conversely, the lack of significant slope movements near the eastern edge of the study area to the east and northeast of Brush Run (figs. 3, 23) is a reflection of the greater abundance of sandstone and thinner units of shale-mudstone in the section. Also, the dominance of sandstone along the lower slopes bordering Devol and Russet Runs and the upper part of Dodge Run (figs. 3, 4, 6) in the western part of the region seems to prevent the development of landslides in that area.

Seeps are common at the contact of permeable cliff-forming sandstone and underlying less permeable, poorly exposed shale and mudstone that form more moderate slopes. Movements in the colluvium and at the colluvium-bedrock interface (figs. 2*B–C*) originate below the seeps.

Slope movements are not concentrated within any particular stratigraphic unit. The density of slope move-



0 — 1 MILE

0 — 1 KILOMETER

CONTOUR INTERVAL 20 FEET

Figure 28. Area north of Ohio 7.

ments is fairly uniform throughout the Monongahela and Dunkard Groups. Also, no discernible difference in the stratigraphic units is apparent with respect to proportion of competent and incompetent units. More than 90 percent of the slope movements occur in the Upshur soil series (table 1).

Structure contours (Collins and Smith, 1977) indicate a regional dip of less than 1° to the south, southwest, and southeast. No relation exists between the regional dip and the landslide distribution. In fact, most slope movements are on east- and north-facing slopes except for those facing the Ohio River. No correlation between dip direction and landslide occurrence was found in West Virginia (Lessing and others, 1983) or in the Pittsburgh region and Greene County, Pa. (Pomeroy, 1982a, 1986).

Slope Features

Configuration

Recent and old slope movements occur more commonly on concave slopes (contour concavity as well as profile concavity). About 60 percent of the recent movements have failed along concave slopes. This percentage is similar to that reported by Lessing and others (1983) in West Virginia and by Pomeroy (1982b) in Washington County, Pa. Approximately 32 and 8 percent occur on laterally planar and convex slopes, respectively. Convex slopes are expected to be better drained than adjacent slopes because soil moisture diverges from the slope. Soil is also usually thinner on noses of slopes.

Areas of contour concavity are responsible for the convergence of surface and subsurface flow that increases pore-water pressure and decreases shear resistance. Rapid weathering of the regolith is characteristic of concave slopes because of the overall wetness.

Angle–Grade

Areas adjacent to the head areas of earth flows and related forms have slope angles from 8° (14 percent) to 33° (65 percent). Most took place on slopes that have a 20- to 35-percent grade (12°-20°), and movements were less common on slopes of less than 20-percent grade (12°) and were rare on those of less than 15-percent grade (9°). Studies of slopes in other areas with abundant earth flows (San Francisco Bay area, California, southwestern Pennsylvania, and central and western West Virginia) yield comparable data (Keefer and Johnson, 1983; Pomeroy, 1982a, b; Lessing and others, 1976).

Orientation (Aspect)

The relation between slope aspect and slope failures was investigated for the entire region. Approximately 1,500 point samples of slope aspect chosen from a grid overlay demonstrates a lack of any particular trend in aspect distribution. Orientations of slope movements were tabulated for all parts of the region, and a summary graph showing the number of recently active movements versus direction was constructed (fig. 29).

Slightly more than 60 percent of the movements face east or some component of north. Slightly more than 69 percent of the failures *larger* than 100 m in maximum dimension face east or some component of north. Numerous examples of aspect control on slope stability have already been given (fig. 4, localities A, B, H; fig. 23, locality G). In general, hummocky ground is more common on north-facing slopes than on south-facing slopes.

Several factors contribute to the high incidence of earth flows and slumps on north- and east-facing slopes. Slopes facing north receive less exposure to the sun; after a rain, soils remain wet longer than soils on south-facing slopes. East-facing slopes receive early morning sunlight, but the drying effect on soils is ineffective because of the low temperatures at that time of the day. Snow cover lingers longest on slopes facing northwest clockwise to east. Conversely, higher rates of evapotranspiration are found on

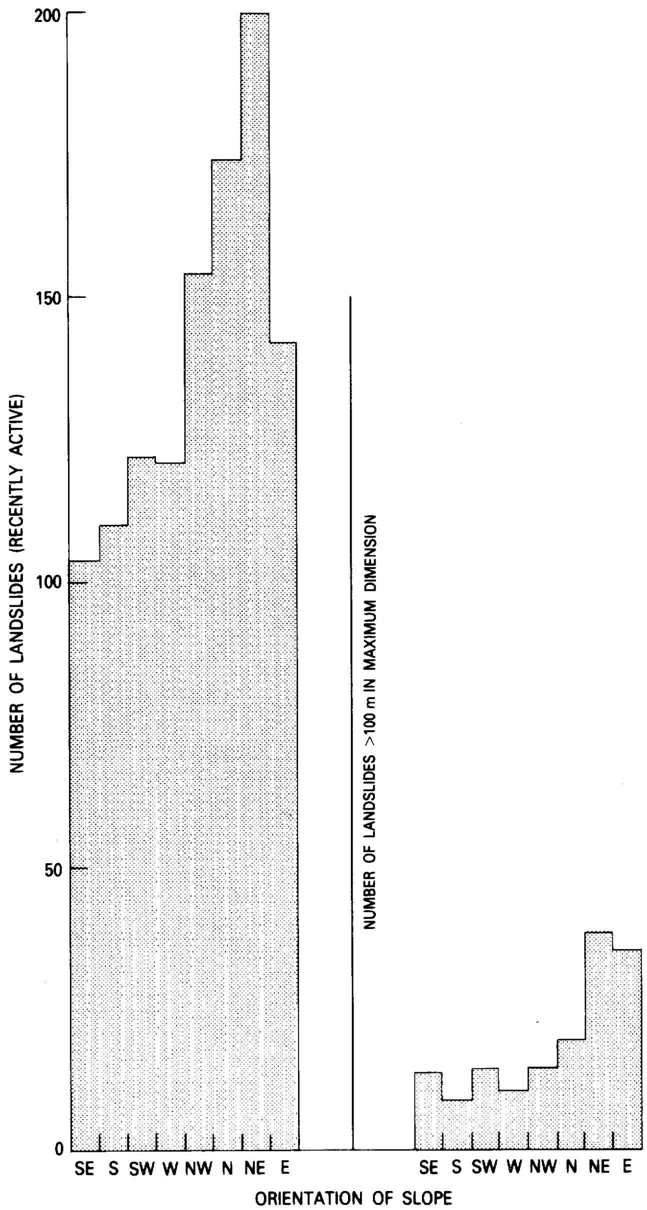


Figure 29. Orientation of recent slope failures in the Marietta area.

south-facing slopes. As a result, north- and east-facing slopes generally have a higher moisture content than do south-facing slopes. These slopes tend to be more unstable with the advent of additional precipitation.

Surface Drainage and the Influence of Microclimate

Slopes with a well-developed surface drainage network (fig. 15) show relatively few movements. Surface drainage networks should speed runoff and lower local slope water tables to give drier, well-drained slopes. Hence, drainage channels minimize pore-pressure buildup and convey stability. Well-drained slopes with linear channels spaced at least every 30 m (across slope) were noted at 31 localities in the Marietta area. More than 45 percent of these well-drained slopes fall southwest, and an additional 26 percent face west and south. South-facing slopes receive significantly more solar radiation than do other slopes at the time of winter and early spring thaws of snow, yielding greater runoff and channel erosion. Repetition of these conditions over thousands of years has left a drainage imprint that is apparent, at least locally.

Microclimatic influences on southwest- and northeast-facing slopes became apparent during the investigation. Southwest-facing forested slopes show an abundance of mixed oak species, whereas a more heterogeneous assortment of trees, dominated by faster growing varieties, but including oak, and accompanied by more brush and vines, characterizes the northeast-facing slopes. The dominance of undergrowth under a mature forest is common on poorly drained, generally unstable slopes; for example, locality K in figure 6 is a northeast-facing wet slope that was difficult to traverse in early spring because of dense undergrowth. No recently active landslides could be detected on this slope; however, a widespread, somewhat subtle hummocky surface of low relief indicates continuing soil creep and periods of old landsliding. The appearance of this slope is in marked contrast to the well-drained (dry) woodland without undergrowth and noticeable creep on the opposing southwest-facing slope. Similar distinctions have been recognized elsewhere in the Appalachian Plateau region of southeastern Ohio at Neotoma Valley, Hocking County (Finney and others, 1962), where rocks of Mississippian to Pennsylvanian age underlie the surface.

Excellent examples of controls on the distributions of outcrops, colluvium, and landslides are ubiquitous throughout the tributary valleys to major streams but particularly on the slopes along the most deeply entrenched 1.5-km-long part of Brush Run which empties into Duck Creek (fig. 23). Similar controls have been noted by Wolfe and others (1943) at Neotoma Valley in Hocking County, where considerable differences in sunlight, soil temperature, and moisture have been recorded between northeast- and southwest-facing slopes (Finney and others, 1962). These factors might tend to produce a more deeply weathered and thicker mantle of rock and soil on northeast-facing slopes and a greater density of slope movements in the Marietta area.

In addition, snow on south-facing slopes melts faster, increasing the probability that snow melt will be dispersed as runoff over saturated soils. Snow on north-facing slopes melts slower allowing for slower, more even infiltration and dispersal of moisture as subsurface flow. I have observed moderate to rapid thaw periods in late March when south-facing slopes, almost bare of snow, show running water. At that time, the north- (and east-) facing slopes do not show rapid melt, and a thin snow veneer is still present. Rill wash and sheet wash were noted on the southwest-facing slope in the Neotoma Valley (Everett, 1963).

The effects of microclimatic differences on slopes can be recognized in the Marietta area. Because southwest-facing slopes are generally better drained and a thicker regolith seems to exist on northeast-facing slopes, instability is more common on the latter slopes. A surface drainage network produces a deeper water table; a lack of network shows a higher water table over longer periods during the year.

Valley Stress Release

Stress release might be a significant factor in controlling the siting of slope failures along major drainages. Ferguson (1967) made observations about stress release at foundation excavations for dams in the Appalachian Plateau. Further discussion by Ferguson and Hamel (1981) and application to other areas of the Appalachian Plateau by Wyrick and Borchers (1981) and Pomeroy (1982a, 1984c) showed that stream erosion, having removed horizontal support from valley walls, has caused an unequal stress distribution resulting in vertical fracturing and bedding-plane slippage along valley sides. These steeply dipping to vertical joints are parallel to major drainages and many tributary valleys throughout the Appalachian Plateau. Stress release intensified during the Pleistocene, when melt water from the retreating icecap deepened valleys.

Fractures inferred to be stress relief features alter hillslope hydrology and promote weathering. As contended by Wyrick and Borchers (1981), meteoric water moves through stress relief jointed rock (secondary permeability) penetrating downward to an impermeable horizon, such as mudstone or shale, where it is emitted to the soil surface as a seep. Water passing through vertical fractures to an impermeable horizon has been implicated in the origin of rock and earth slumps (Pomeroy, 1982a, 1984c). In addition, bedrock subjected to secondary permeability is weathered easily because of increased infiltrating water.

Slopes facing major drainages, such as the Ohio River, are particularly prone to downslope movements because of the accumulation of weathered bedrock. Blocks have separated along joints and moved downhill; some rock masses have slumped or failed along subsurface planar surfaces.

In the Marietta area, closely spaced, wide vertical to near vertical tension joints are found along the Ohio River and, to a lesser extent, along the Muskingum River and Duck Creek. Prehistoric rock slumping and rock fall, probably taking place along stress release fractures, occurs along the southeast-facing slope northwest of Lower Newport (fig. 28). A possible rock slump might have been generated by the same process along the west-facing slope to the east of the Muskingum River (fig. 10, locality G).

Vegetation

An attempt was made to correlate slope movement with forest cover (or lack of it). The percentage of the area covered by woodland has increased from 1943 to the present time. The reforestation has been caused mainly by abandonment of land used for crops and pasture. One might assume that the likely continuation of this trend possibly could stabilize slopes in time, assuming a period (decade?) of decreased precipitation and limited slope modification.

I have already noted that poorly drained, unstable slopes commonly are characterized by dense undergrowth. Undergrowth develops quickly along a slope where failure has taken place. Extensive disruption of the land surface commonly kills the mature forest growth.

My studies suggest that recent movements are just as likely to occur along longstanding forested slopes (based on 1943 aerial photographs) as on grassland slopes. Also, grasslands that existed in 1943 and whose vegetative cover has not changed are sites for continued movement (frontispiece). One cannot overlook the fact that many areas showing a high concentration of slope movements are forested (fig. 4, locality H; fig. 10, locality G; fig. 16, locality B; fig. 28). Of course, steep slopes generally are not cleared.

However, Riestenberg and Sovonick-Dunford (1983) reinforced the belief of most slope movement mappers that tree roots increase the factor of safety against sliding several fold. They found that tree roots markedly stabilize colluvium on steep hillsides in southwestern Ohio and cited the findings of several investigators who demonstrated either that roots increase the stability of soils or that soil strength decreases as roots decompose. Consequently, slope movement increases with time after deforestation. An alternative hypothesis by some researchers suggested that roots force cracks open deep in the regolith, thereby increasing the zone of weathering. In addition, slopes may be destabilized by the weight of the forest. Finally, some investigators pointed out that the trees intercept precipitation in the crown area, release water vapor to the atmosphere by transpiration, and, thereby, decrease the quantity of water absorbed by the slope mantle.

Tree roots, undoubtedly, contribute to the stability of slopes. However, other factors may play an equal or greater role in determining the susceptibility of a slope to sliding. The fact that recent landslides in the Marietta area take place on longstanding forested slopes implies that other causes can be dominant.

Precipitation

Precipitation is the most important factor in the frequency of slope movements. The vast majority of slope failures are related directly or indirectly to precipitation, and the relation is complex rather than simple (Sangrey and others, 1984; Wieczorek, 1981). Most slope failures are believed to take place when the ground-water surface is high.

Climatic records from Marietta since 1962 (National Oceanic and Atmospheric Administration, 1963–84) indicate that the 1960's generally were drier than normal, whereas the period beginning with 1970 and extending into the 1980's to the time of the present investigation has been wetter than normal (fig. 14).

Two observation wells at Marietta are in unconsolidated sand and gravel aquifers (U.S. Geological Survey, 1965, 1970, 1974, 1977, 1971–85). Although the records are incomplete, the yearly ground-water table low generally occurs toward the end of summer or early fall, whereas the yearly high commonly occurs between March and June, when recharge from snowmelt and spring storms is greatest. Data for water levels in bedrock in the Marietta area is lacking. Generally, these water levels can be expected to fluctuate more slowly in response to delayed recharge (Harstine, 1975–85).

Exceptions to this seasonal pattern do occur because of excessive precipitation caused by aftereffects of tropical storms such as those that took place in September 1975 and 1979. A combination of scant snowpack and below normal rainfall coupled with above normal temperatures during the spring months will tend to keep ground-water levels low later in the year. Summer thunderstorms generally have little effect on the overall ground-water storage because of high evapotranspiration rates at that time.

The period between October 1978 and November 1980 in Marietta stands out as a time of unusually heavy precipitation and high ground-water levels (National Oceanic and Atmospheric Administration, 1963–84; U.S. Geological Survey, 1971–85). Within this 26-month (mo) period, above normal precipitation took place during 18 mo. Furthermore, monthly precipitation in excess of 5 inches (in.) occurred for nine of these months with a record amount of over 10 in. recorded at Marietta in August 1979 (National Oceanic and Atmospheric Administration 1963–84). The highest ground-water level in 34 yr was recorded in early March 1979 at one of the observation wells; it followed a record-high reading at the other well by a few days (U.S. Geological Survey, 1971–85). Throughout most of southern

Ohio, high ground-water levels resulted from recharge produced by melting snow and heavy rains following a late February 1979 thaw (Harstine, 1975–85). Ground-water levels remained especially high during the remainder of the year because of below normal temperatures in late spring (reducing evapotranspiration rates) and above normal rainfall for most of the second one-half of 1979. High ground-water levels continued into 1980 with below and above normal precipitation in winter and spring followed by heavy rains during the summer months.

No data exists that would allow one to evaluate the extent of landsliding during the late 1978 to late 1980 period. However, about 75 percent of the newspaper articles from 1973 to 1981 referring to landsliding appeared during 1979 and 1980.

In interviews with long-time residents of the area, statements to the effect that more "slides" are occurring than ever before are typical. Remarks pertaining to "slips" not being as numerous when "they" were younger are common. Discussions with veteran Soil Conservation Service personnel in southwestern Pennsylvania and more recently in southeastern Ohio indicate a relation of slope failures to increased precipitation and a general rise of ground-water levels in the regolith. High ground-water levels cause pore-water pressures in the regolith to be built up during and immediately following any intense rainstorm or period of persistent rainfall along with an accompanying decrease in shear resistence of the regolith. This excess water contributes to new slope movements, as well as reactivating older slope failures. Gray and Gardner (1977) believed that a large-scale slope failure at McMechen, W. Va., was triggered by high pore pressures in the soil caused by a period of abnormally high precipitation.

ADVICE FOR RESIDENTS

Landslides are common throughout southeastern Ohio. Slope movement activity in the Marietta area is, perhaps, slightly greater than in other areas of southeastern Ohio because the higher population density requires frequent cut-and-fill slope modification.

Slope movement is indigenous not just to southeastern Ohio but is widespread in neighboring West Virginia, Pennsylvania, and Kentucky, as well as southwestern Ohio (Radbruch-Hall and others, 1982). Hamilton County, Ohio, which includes Cincinnati, has a higher annual cost of damage per capita than either the San Francisco Bay or the Los Angeles areas (Fleming and Taylor, 1980).

Slope failures in the Marietta area are generally slow-moving resulting in few deaths and injuries. Rockfalls are the chief exception and possess a high potential for serious injury or death. Fortunately, major areas of potential rockfall hazard in the Marietta area are not as numerous as in other areas of the Applachian Plateau due, in part, to lower relief and more moderate and fewer modified slopes. The most critical location for rockfalls is along Ohio 7 southwest of Marietta (fig. 7, locality C). Interstate 77 cuts have posed fewer problems, in part, because of fewer sandstone exposures.

Identification of a Slope Failure

The following features indicate that a property may have a potential or ongoing slope problem:

1. *Hummocky ground.*—Hummocks, low uneven or lumpy mounds or knolls, are common, irregularly spaced features of the toes and lower slope surfaces of recent and old landslides (figs. 11, 17, 25). Topographic maps in the area may show an unevenness and irregularity of contours in the lower (sometimes upper) part of a slope indicative of an old (probably prehistoric) movement. Because of a commonly low gradient in the lower part of a slope, development might seem feasible. However, the possibility of future slope reactivation is a potential hazard.
2. *Cracks in the ground.*—If the property is at the edge of a ridge crest, then an investigation for ground cracks more or less parallel to the slope below is necessary. Surface cracks could indicate that the site is within the crown area (fig. 2*A*) of a slope movement. The slope downhill from the property also should be examined. Any cracking across the slope points to active movement.
3. *Seeps and springs.*—Unusually wet ground anywhere along a slope is indicative of a seep or spring. The time of the year is meaningful in that wet ground is common along many slopes, especially between March and May, whereas the same area might not be wet in late summer or fall. Seeps and springs are common at the toes of movements, but they are, perhaps, more common just above or in head areas of slope failures. Standing bodies of water anywhere along the slope are probably within an area of downslope movement. Wet or saturated ground along slopes is, at least, potentially unstable in response to gravitational downslope movement. Any poorly drained slope area is best left alone unless the intended land use justifies the cost of renovation.
4. *Areas of grapevines, reeds, horsetails, cattails, and tilted trees.*—Grapevines and reeds have been observed on many old landslide deposits. In these areas, mature trees are lacking; older trees are commonly dead. Poor drainage, which can lead to the development of inpenetrable brush along a slope, might indicate instability. Tilted trees do not necessarily imply instability (Phipps, 1974) because trees on slopes tend to bend outward somewhat as they seek sunlight (a phototropic response). However, trees leaning at appreciable angles or numbers of trees leaning in different directions strongly suggest areas of slope failure.

5. *Erratic alignment of utility lines and surface pipelines.*— Appreciable tilting of poles with variations in the amount of sag of the conduits usually indicates slope movement. A bowed pipeline across a slope indicates downslope failure. Evidence of former pipeline breakage might lie adjacent to the site.
6. *Cracks in houses and buildings.*—Cracks tend to concentrate around openings (doors, windows). Distortion or warping of the frame of a house because of slope movement will cause doors and windows to jam or stick. However, the cause of cracking may not be attributed necessarily to a slope failure.
7. *Cracks in manmade features adjacent to dwellings.*— Asphalt driveways and brick and concrete walls in yards usually rest on soil and are sensitive to slope failure, which can cause cracking. Any enlarged cracks or out-of-plumb structures probably are caused by accelerated creep that may indicate incipient slope movement involving ground breakage.
8. *Drainage ditches that are partially filled in by soil (and rock) debris either along the slope or at the base of the slope.*—Depending upon the date when the ditch was last cleaned, this detection could signify accelerated movement.
9. *Recognition of segments of an abandoned road and (or) house foundation ruins that are covered partially with slope debris.*—Such an identification indicates past slope failure and likelihood of future slope movement.

The prospective buyer or developer should bear in mind that properties on level ground, either on a ridgetop or in a valley adjacent to a slope, also need to be scrutinized closely. Level land behind a valley-sited house might be partially covered by a slope movement at a future date. Also, land at the edge of a ridgetop could be subject to movement either from the slope below or from failure of the material making up the land if the area has been filled.

Practices That Cause Slope Failures

Most slope movements in the Marietta area result from natural conditions, mainly precipitation. However, within the town of Marietta, many slope failures are caused by man-induced activities. The three most commonly committed practices are shown by sketches (figs. 30–32) that illustrate possible results from these actions. These practices are applicable to areas elsewhere in Ohio and the Appalachian Plateau part of adjacent States. No corrective actions should be taken without a site investigation by a geotechnical engineer or engineering geologist.

1. *Fill emplacement on slopes.*—Figures 30*A* and *B* show the practice of backyard fill placed on a slope improperly and its potential consequences; figures 30*C* and *D* show a less common occurrence. The most common loading of a slope takes place when earth materials are emplaced as a fill, usually to extend the backyard of

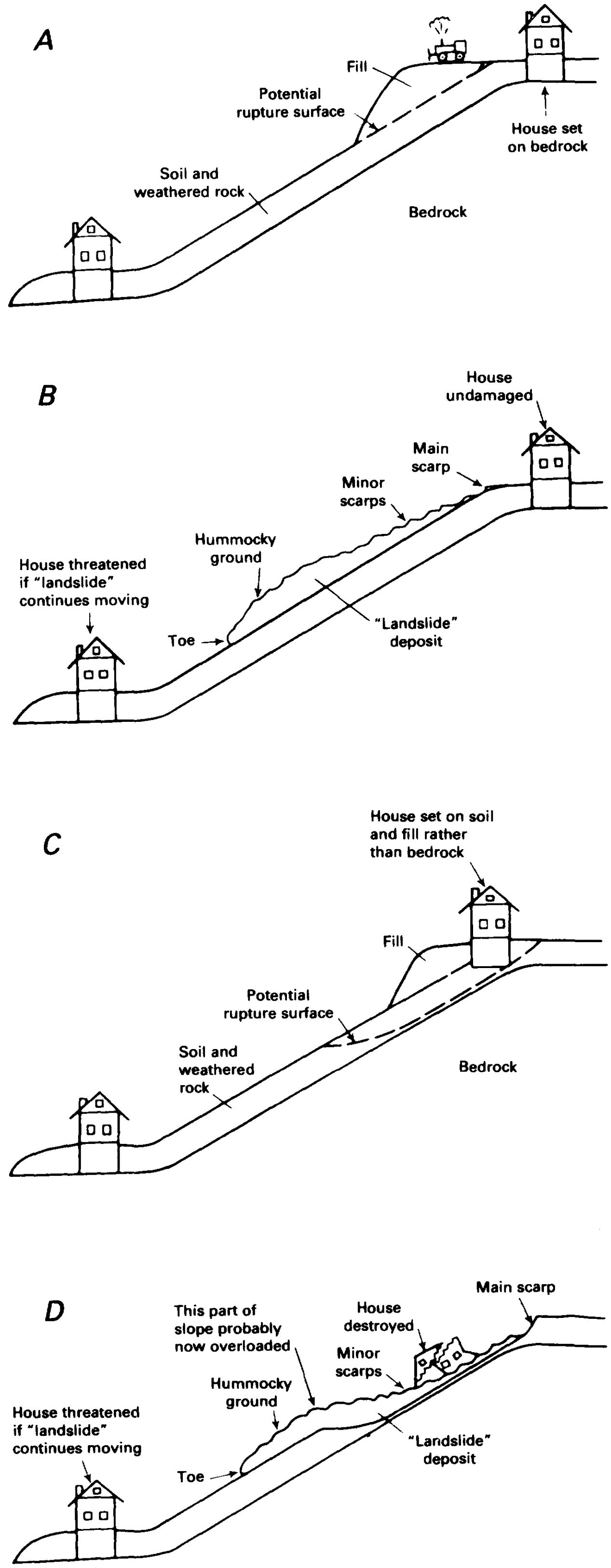


Figure 30. Possible effects of backyard fill placement. *A*, Backyard fill placed on the slope improperly. *B*, Potential consequences thereof. C, Sensitive slope overloaded by backyard fill and house set on soil and fill. *D*, Potential consequences thereof. Slope and soil thickness exaggerated.

a house on a slope or on a ridgetop. A surface of separation might result within the fill, between the fill and soil surface, within the soil and weathered rock, or at the contact of the weathered and unweathered bedrock. Most fill failures probably occur between the fill and soil surface. The Strecker Lane (Devola) fill failure (fig. 10, locality E) is an example. The extensive slope movement along the western side of Interstate 77 (fig. 10, locality A) about 3 km east-northeast of Devola is probably another example.

Proper construction of a fill on a slope involves engineering expertise and should be designed for the particular slope on which it is to be placed; it includes removal of natural vegetation before emplacement and lift-by-lift compaction (Briggs and others, 1975). If vegetation is not removed, then surfaces of slippage can focus on decaying vegetation between the new fill and the former natural slope; if fill is not compacted properly, then failure can take place within it.

Care must be exercised not to fill natural drainage or swales with fill. Filling of the drainages commonly results in a rise of the ground-water table, which leads to an unstable supersaturated soil mantle during and (or) following an intense or prolonged rainfall.

2. *Slope cutting.*—Figure 31 shows the potential consequences when a sensitive slope is excavated at its base. Similar results could occur anywhere along a slope wherever a bench or flat area is desired. Because valleys are generally narrow throughout the Appalachian Plateau, excavation at the foot of a slope to make more flat land is a common practice. If the cut is in the toe of an unidentified old or prehistoric landslide deposit, then a slope movement could result. However, slope failures can occur anywhere along the slope if unstable soil is disturbed.
3. *Drainage changes.*—Figure 32 shows a slope excessively wetted by an inadequate drainage system and its potential consequence. Inadequate disposal of downspout water can affect the stability of slopes and indirectly has caused slope failures in the Marietta area. Modification of a ridgetop for housing or a new road can cause drastic changes in surface- and groundwater flow along the slope below the alteration. Complete removal of vegetation may increase or decrease soil moisture because water that ordinarily would be lost by evapotranspiration may either infiltrate or run off as overland flow, depending on soil conditions.

Remedial Actions

Design procedures on unstable soil slopes were discussed by Gedney and Weber (1978) and Záruba and Mencl (1982). Field and laboratory investigations are necessary in any corrective studies conducted by a geotechnical engineer. Maximum flexibility in the application of remedial

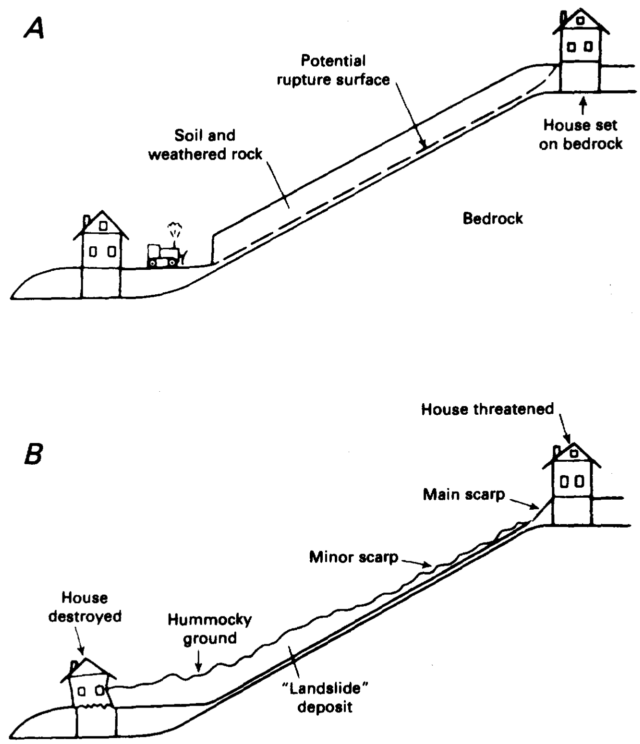


Figure 31. Possible effects of lower slope excavation. *A*, Sensitive slope excavated at bottom. *B*, Potential consequences thereof.

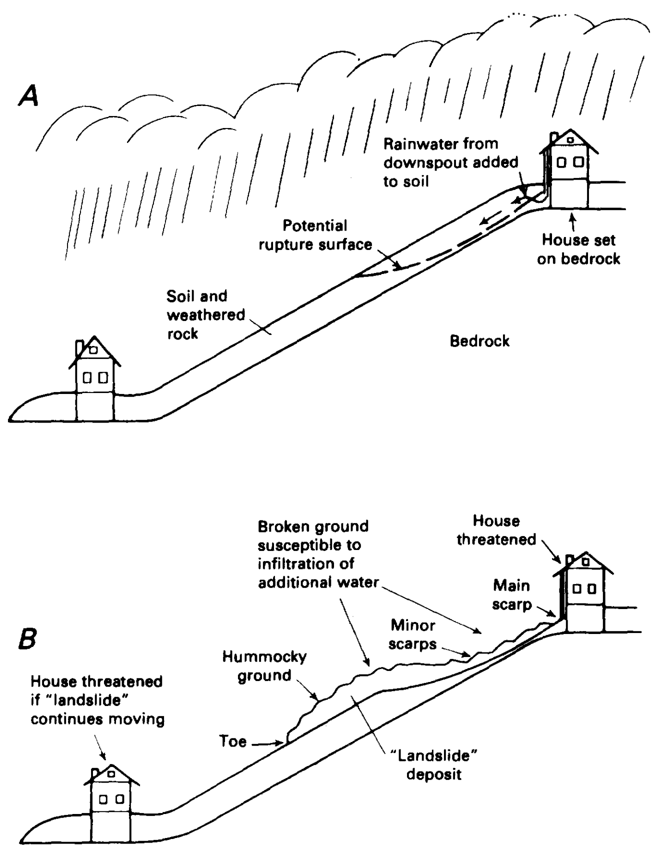


Figure 32. Possible effects of downspout water on slope. *A*, Water added to soil on sensitive slope by poor drainage system; here, a downspout. *B*, Potential consequences thereof.

measures is mandatory as each problem area poses different approaches.

Several options should be considered by landowners in the Marietta area. They are (1) to avoid or eliminate the problem by abandoning the site, (2) to build retaining walls in an attempt to prevent further slope movement, or (3) to control surface- and ground-water movement by installing trench drains.

Depending upon the circumstances and present slope use, the first option might not only be the least expensive but the only feasible approach. An on-site investigation by an experienced geologist or geotechnical engineer will be critical to most decisions.

Option 2 involves the construction of a retaining wall(s) above the head and (or) at the toe of the movement. Construction of any one of a number of devices such as a concrete crib wall, gabion-wall retaining structure, timber bulkhead, reinforced concrete retaining wall, or various types of anchor systems can be effective but costly. However, poor drainage should not be ignored in a retaining wall design.

Option 3 may be effective alone or in addition to option 2 in many problem areas. A backhoe can be utilized effectively in the construction of trench drains through the slide area parallel to the direction of movement. Care must be exercised especially during the wetter part of the year because trench walls will rapidly close in and fall. The effect of drain emplacement will be to lower the ground-water table along the problem slope. Drains must come to the surface near the base of the slope to ensure the expedient movement of water.

As in most slide-prone areas anywhere in the country, the most successful methods for remedial work on slopes in the Marietta area generally deal almost entirely with ground-water control. Controls should include the following:

1. Diversion of surface water from any area of the slide, especially the head area. Downspout water from adjacent housing must not enter the landslide body. Ditches above and parallel to the head scarp should have an impervious pavement. Water emanating from springs, commonly within the head area, should be directed away from the slide area.
2. Filling and compaction of open cracks in the crown area of the landslide (fig. 2*A*). These cracks may extend to the failure plane of the slide.

SUMMARY

Shallow-seated and planar slope movements, largely earth flows, in the regolith (mostly colluvium) are widespread throughout the Appalachian Plateau region of southeastern Ohio and adjacent States. Field investigations in the Marietta area showed that the slopes most susceptible to movement are those overlying relatively thick intervals of shale-mudstone with thinner beds of coarser grained clastic rock. Slope movements are less common where sandstone is more dominant than the less competent shale-mudstone. Seeps are common at the contact of permeable sandstone and underlying less permeable, poorly exposed shale and mudstone that form more moderate slopes. Movements in the colluvium and at the colluvium-bedrock interface originate below the seeps. No relation exists between the direction of dip of strata and the distribution of the slope movements. The density of movements is uniform throughout the Monongahela and Dunkard Groups.

Over 60 percent of the slope movements occur on eastward- or northward-facing slopes; a greater percentage of large (greater than 100 m in maximum dimension) failures face north or east. Well-drained slopes with channels about every 30 m (across slope) show few movements. More than 45 percent of the channeled slopes face southwest, and an additional 26 percent face west or south. A more deeply weathered and thicker regolith seems to be typical of north- and east-facing slopes; outcrops are more common on south-facing slopes. Because of generally higher antecedent moisture levels, north- and east-facing slopes tend to be more unstable than those facing the opposite direction.

Slope movements have an affinity for concave slopes (in contour and profile). Areas adjacent to recent failures have slope angles varying from 8° to 28°, with most being from 12° to 20°. Possibly, because of valley stress release, slopes facing major drainages particularly are subject to movement. Extensive slope movements are as likely to occur in forested areas as on grassland slopes.

Precipitation, the most important factor in the frequency of slope failures, has been largely above normal since 1970. The resultant high level of ground water in the regolith has caused pore-water pressures to be especially high during and following rainy periods. The rise in ground-water levels is accompanied by a reduction in shear strength of the regolith. The inventory suggests that most recent slope failures in the Marietta area are caused by precipitation rather than by construction and other slope modifications. A striking example is a 4.5-km^2 forested area with nearly 90 recent slope movements at least 10 m in maximum dimension and as large as 50,000 m^2. This area is largely undeveloped; most of the movements probably have been caused by above normal rainfall since 1970.

Similar suites of clay minerals were identified in basal shear surfaces of landslides, in other parts of landslides, and from areas unrelated to any slope failure. No distinctions could be made in the clay mineralogy between the slickensided shear plane and nonshear plane material. The illite is potassium deficient, which is a condition also prevalent in the unstable regolith areas of western Pennsylvania.

Determining where slope movements will occur is hampered by poor exposures, thinness of lithologic units, and rapid facies changes within short distances.

REFERENCES CITED

Berryhill, H. L., Jr. Schweinfurth, S. P., and Kent, B. H., 1971, Coal-bearing Upper Pennsylvanian and Lower Permian rocks, Washington area, Pennsylvania, pt. 1, Lithofacies, pt. 2, Economic and engineering geology: U.S. Geological Survey Professional Paper 621, 47 p.

Briggs, R. P., Pomeroy, J. S., and Davies, W. E., 1975, Landsliding in Allegheny County Pennsylvania: U.S. Geological Survey Circular 728, 18 p.

Burns, G. W., 1958, Wisconsin age forests in western Ohio: Ohio Journal of Science, v. 58, no. 4, p. 220–230.

Campbell, R. H., 1975, Soil slips, debris flows, and rainstorms in the Santa Monica Mountains and vicinity, southern California: U.S. Geological Survey Professional Paper 851, 51 p.

Collins, H. R., and Smith, B. E., 1977, Geology and mineral resources of Washington County, Ohio: Ohio Geological Survey Bulletin 66, 134 p., map scale 1:62,500.

D'Appolonia, E., Alperstein, R., and D'Appolonia, D. J., 1967, Behavior of a colluvial slope: American Society of Civil Engineers, Proceedings, v. 93, Paper 5326, Soil Mechanics and Foundation Division Journal, no. SM4, p. 447–473.

Everett, K. R., 1963, Slope movement, Neotoma Valley, southern Ohio: Ohio State University Research Foundation, Institute of Polar Studies Report, no. 6, 50 p.

Ferguson, H. F., 1967, Valley stress release in the Allegheny Plateau: Association of Engineering Geologists Bulletin, v. 4, no. 1, p. 63–71.

Ferguson, H. F., and Hamel, J. V., 1981, Valley stress relief in flat-lying sedimentary rocks: Proceedings of International Symposium on Weak Rock, Tokyo, v. 2, p. 1235–1240.

Finney, H. R., Holowaychuk, N., and Heddleson, M. R., 1962, The influence of microclimate on the morphology of certain soils of the Allegheny Plateau of Ohio: Soil Science of America Proceedings, v. 26, p. 287–292.

Fisher, S. P. 1969, The geology of eastern Ohio with relation to slope movements: Ohio University Research Institute Proceedings—A symposium on landslides, February 26, 1969, Athens, p. 1–20.

———1978, Geological aspects of the environment in southeastern Ohio (abs.): Ohio Academy of Science, 87th Annual Meeting, Wright State University, Dayton, Ohio, 1978, v. 78, p. 36

Fisher, S. P., Fanaff, A. S., and Picking, L. W., 1968, Landslides of southeastern Ohio: Ohio Journal of Science, v. 68, no. 2, p. 65–80.

Fleming, R. W., and Taylor, F. A., 1980, Estimating the costs of landslide damage in the United States: U.S. Geological Survey Circular 832, 21 p.

Gary, Margaret, McAfee, Robert, Jr., and Wolf, C. L., eds., 1972, Glossary of geology: Washington, D.C., American Geological Institute, 805 p.

Gedney, D. S., and Weber, W. G., Jr., 1978, Design and construction of soil slopes, chap. 8, *in* Shuster, R. L., and Krizek, R. J., eds., Landslides—Analysis and control: National Academy of Sciences Transportation Research Board Special Report 176, p. 11–33.

Gray, R. E., Ferguson, H. E., and Hamel, J. V., 1979, Slope stability in the Appalachian Plateaus of Pennsylvania and West Virginia: Rock slides and avalanches, pt. 2, Engineering sites, *in* Voight, Barry, ed., Developments in geotechnical engineering, v. 14B: New York, Elsevier, p. 447–471.

Gray, R. E., and Gardner, G. D., 1977, Processes of colluvial slope development at McMechen, West Virginia: International Association of Engineering Geology Bulletin 16, p. 29–32.

Hackman, R. J., and Thomas, R. E., 1978, Landslides and related features (Ohio, Pennsylvania, West Virginia)—Clarksburg 1 x 2 sheet: U.S. Geological Survey Open-File Report 78–1056, 128 pls.

Harstine, L. J. (compiler), 1975–85, Monthly water inventory report for Ohio: Ohio Department of Natural Resources Division of Water, 4 p. summary for each month.

Hooper, J. R., 1969a, Slope movements of residual clays in southeastern Ohio: Ohio University Research Institute Proceedings—A symposium on landslides, February 26, 1969, p. 33–57.

———1969b, Slope stability investigation of residual clay soils of southeastern Ohio: Ohio State University, Transportation Research Center Research Project EES 312 Final Report, 91 p.

Hubbard, G. D., 1908, Two notable landslides (near Waverly and in Monroe County, Ohio): Ohio Naturalist, v. 8, p. 287–289.

Keefer, D. K., and Johnson, A. M., 1983, Earth flows—Morphology, moblization, and movement: U.S. Geological Survey Professional Paper 1264, 56 p.

Lanyon, L. E., and Hall, G. F., 1983, Land-surface morphology, pt. 2, Predicting potential landscape instability in eastern Ohio: Soil Science, v. 136, no. 6, p. 382–386.

Lessig, H. D., 1966, Landslide along highway in Vinton County, Ohio: Journal of Soil and Water Conservation, v. 21, p. 234–236.

Lessig, H. D., Rubel, T. N., Brown, D. L., and Hole, Thornton J. F., 1977, Soil Survey of Washington County, Ohio: U.S. Soil Conservation Service (in cooperation with Ohio Department of Natural Resources and Ohio Agricultural Research and Development Center), 206 p.

Lessing, Peter, Kulander, B. R., Wilson, B. D., Dean, S. L., and Woodring, S. M., 1976, West Virginia landslides and slide-prone areas: West Virginia Geological and Economic Survey, Environmental Geology Bulletin 15, 64 p.

Lessing, Peter, Messina, C. P., and Fonner, R. F., 1983, Landslide risk assessment: Environmental Geology v. 5, no. 2, p. 93–99.

Marshall, H. E., 1969, Landslide recognition and control on Ohio highways: Ohio University Research Institute Proceedings—A symposium on landslides, February 26, 1969, p. 64–97.

Mast, V. A., 1980, Distribution and engineering properties of landslide susceptible soils in southeast Ohio: Ph.D. dissert., Columbus, Ohio State University, 204 p.

Mitchell, R. H., 1941, An unusual landslide (Ohio): Journal Geology, v. 49, 382–391.

National Oceanic and Atmospheric Administration, 1963–84, Climatological data—Annual Summary, Ohio: National Climatic Data Center, Asheville, N.C., v. 67–89, no. 13, p.194, 185, 188, 186, 173, 187, 191, 192, 198, 195, 5, 5, 5, 6, 6, 6, 6, 6, 6, 6, 8.

Ohio State University Engineering Experiment Station News, 1950, Rockfall (Marietta, Ohio): v. 22, no. 2, p. 1.

Philbrick, S. S., 1962, Old landslides in the Upper Ohio valley (abs.): Geological Society of America Special Paper 68, p. 245–246.

Phipps, R. L., 1974, The soil creep—Curved tree fallacy: U.S. Geological Survey Journal of Research, v. 2, no. 3, p. 371–377.

Pomeroy, J. S., 1978, Map showing landslides and areas most susceptible to sliding in Butler County, Pennsylvania: U.S. Geological Survey Miscellaneous Field Studies Map MF–1024, 2 sheets, scale 1:50,000.

———1979, Map showing landslides and areas most susceptible to sliding in Beaver County, Pennsylvania: U.S. Geological Survey Miscellaneous Geologic Investigation Map I–1160, scale 1:50,000.

———1982a, Landslides in the Greater Pittsburgh region, Pennsylvania: U.S. Geological Survey Professional Paper 1229, 48 p.

———1982b, Mass movement in two selected areas of western Washington County, Pennsylvania: U.S. Geological Survey Professional Paper 1170–B, 17 p.

———1984a, Slope failure hazards in the Marietta area, Washington County, southeastern Ohio: Geological Society of America Abstracts with Programs 1984, Southeastern and North-central Sections, Lexington, Ky., April 4–6,1984, v. 16, no. 3, p. 187.

———1984b, Preliminary map showing recently active landslides in the Marietta area, Washington County, southeastern Ohio: U.S. Geological Survey Open-File Report 85–84, scale 1:24,000 with text.

———1984c, Storm-induced slope movements at East Brady, northwestern Pennsylvania: U.S. Geological Survey Bulletin 1618, 16 p.

———1985, Preliminary slope stability map showing relative susceptibility to landsliding in the Marietta area, Washington County, southeastern Ohio: U.S. Geological Survey Open-File Report 85–352, scale 1:24,000 with text.

———1986, Map showing slope movements in the Oak Forest quadrangle, Greene County, southwestern Pennsylvania: U.S. Geological Survey Miscellaneous Field Investigation Map, MF–1794, scale 1:24,000, with text.

Radbruch-Hall, D. H., and others, 1982, Landslide overview map of the conterminous United States: U.S. Geological Survey Professional Paper 1183, 25 p.

Riestenberg, M. M., and Sovonick-Dunford, Susan, 1982, The role of woody vegetation in stabilizing slopes in the Cincinnati area, Ohio: Geological Society of America Bulletin, v. 94, p. 506–518.

Sangrey, D. A., Harrop-Williams, K. O., and Klaiber, J. A., 1984, Predicting ground-water response to precipitation: Journal of Geotechnical Engineering, v. 110, no. 7, p. 957–975.

Savage, C. N., 1950, Earthflow associated with strip mining (Macksburg, Ohio): Mining Engineering, v. 187, p. 337–339.

———1951, Mass-wasting, classification, and damage in Ohio: Ohio Journal of Science, v. 51, no. 2, p. 299–308.

Sharpe, C. F. S., and Dosch, E. F., 1942, Relation of soil creep to earthflow in the Appalachian Plateaus (Ohio): Journal of Geomorphology, v. 5, no. 4, p. 313–324.

Sheley, C. T., 1969, Contractors experience-slips in eastern Ohio: Ohio University Research Institute Proceedings—A symposium on landslides, February 26, 1969, Athens, p. 58–63.

U.S. Geological Survey, 1965, Ground-water levels in the United States, 1958–1962, Northeastern States: U.S. Geological Survey Water-Supply Paper 1782, p. 178.

———1970, Ground-water levels in the United States, 1958–62, Northeastern States: U.S. Geological Survey Water-Supply Paper 1977, p. 192–193.

———1971–85, Water resources data, Ohio, 1970-1984, Volume 1, Ohio River Basin, prepared in cooperation with State of Ohio and other agencies.

———1974, Ground-water levels in the United States, 1968–72, Northeastern States: U.S. Geological Survey Water-Supply Paper 2140, p. 149.

———1977, Ground-water levels in the United States, 1973–74, Northeastern States: U.S. Geological Survey Water-Supply Paper 2164, p. 89–90.

———1982, Goals and tasks of the landslide part of a ground-failure hazards reduction program: U.S. Geological Survey Circular 880, 49 p.

Van Buskirk, D. R., 1977, The relationship between aspect and slope condition in northeastern Ohio: Geological Society of America Abstracts with Programs, Northeastern Section, 12th Annual Meeting, v. 9, no. 3, p. 327.

Varnes, D. J., 1978, Slope movement types and processes, *in* Schuster, R. L., and Krizek, R. J., eds., Landslides—Analysis and control: National Academy of Sciences Transportation Research Board Special Report 176, p. 11–33.

Waltz, D. P., and Fisher, S. P., 1978, Suburban landslides in Gallipolis, Ohio: Ohio Academy of Science, 87th Annual Meeting, Wright State University, Dayton, Ohio, 1978, p. 35, v. 78.

Webb, D. K., and Collins, H. R., 1967, Geologic aspects of a recent landslide in Vinton County, Ohio: Ohio Journal of Science, v. 67, no. 2, p. 65–74.

Wieczorek, G. F., 1981, Ground water level and precipitation data for slopes near La Honda, California: U.S. Geological Survey Open-File Report 81–367, 25 p.

Wolfe, J. N., Wareham, R. T., and Scofield, H. T., 1943, The microclimates of a small valley in central Ohio: American Geophysical Union Transaction, v. 24, p. 154–166.

Wyrick, G. G., and Borchers, J. W., 1981, Hydrologic effects of stress-relief fracturing in an Appalachian Valley (W.Va.): U.S. Geological Survey Water-Supply Paper 2177, 51 p.

Záruba, Quido, and Mencl, Vojtěch, 1982, Landslides and their control: Amsterdam, Elsevier Publishing Company, 315 p.

APPENDIX

Figure 4

Locality (either representative specific site or more extensive area)	Landslide type	Aspect	Average angle (and grade) of adjacent slope (to landslide head)[1]	Slope configuration	Vegetation	Trigger—Natural (N) or construction activity (C)	Notes
A	Earth flows	NE	14° (26 percent)	Planar to concave.	Forest (eastern part); brush (western part).	N	Red clay is basal shear surface. Occasional sandstone ledges above landslide head.
B	No landslides	SW	SEE TEXT				
C	Earth flows	N components	17° (30 percent)	Mostly concave	Forest	N	Largely red shale-mudstone makes up slide-prone slope.
D	Debris avalanche	E	33° (65 percent)	Concave	do	N	30-m-wide at head; 24-m-wide at toe. Highest head scarp at base of 6 m high sandstone cliff; younger (1983) head scarp 6 m below highest scarp; up to 1.2 m of regolith from head area.
E	Slump-earth flow	NE to E	15° (27 percent)	Planar	do	N	160-m-wide head scarp.
F	do	SW	18° (33 percent)	Planar to concave	do	C?	45-m-wide head scarp; drainage alteration from new house above landslide.
G	Slump-earth flow and earth flow.	NE to E	15° (27 percent) to 23° (42 percent).	do	do	C cutting of lowermost slope for access road.	1.5 m of colluvium removed from head area of slump-earth flow; basal shear surface is 1 m below land surface.
H	Earth flows and slump-earth flows (coalescing).	N to NE	15° (27 percent) to 17° (31 percent).	Mostly planar, some concave.	do	N	Discontinuous sandstone ledges 1.5 to 4.5-m-thick lie above landslides.
I	Debris avalanche	SW	22° (40 percent)	Mostly planar	do	N	3-m-thick sandstone above head scarp; 1.0–1.5 m of regolith removed from head area.
J	Slump-earth flow	NE	18° (33 percent)	Planar	Grass	C widening of highway at base of slope.	9-m-thick sandstone above head scarp of 100-m-wide failure; seepage at base of ledge.
K	Debris avalanches (2).	do	22° (41 percent)	do	Forest	N mostly	17–18 m wide; colluvium is less than 1.5 m thick; seeps below sandstone ledge.

[1]See figure 27 of Appendix.

Figure 6

Locality (either representative specific site or more extensive area)	Landslide type	Aspect	Average angle (and grade) of adjacent slope (to landslide head)[1]	Slope configuration	Vegetation	Trigger—Natural (N) or construction activity (C)	Notes
A–B-----	Earth flows (coalescing).	E ----------	23° (42 percent) to 33° (65 percent).	Planar -------	Mostly forest---	N and C road widening?	Poor exposures of red mudstone-shale beneath 6.0- to 9.0-m-thick sandstone ledge.
C -------	Rockfall (not a landslide).	SE ---------	SEE TEXT				
D -------	Slump-earth flows (coalescing).	---- do ----	18° (33 percent) to 22° (41 percent).	Planar to concave.	Forest---------	Largely C unstable fill placed on red shale-mudstone slope.	Widest and most continuous area of sliding in Marietta area.
E -------	Earth flows -------	Mostly NE---	17° (31 percent) to 24° (45 percent).	Concave and planar.	Grass-brush-forest.	Mostly N also, storm-water runoff from subdivision along ridge crest on northeast side of tributary drainage.	Large concentration of springs below sandstone ledge feed slide-prone slopes.
F -------	Slump-earth flow --	S ----------	19° (34 percent) ---	Concave------	Grass ---------	N and C storm-water pipe breakage induced by heavy rain.	2.5-m-high (>average) head scarp of 40-m-wide failure; crown cracks extend 6 m behind head scarp.
G -------	Debris slide-------	---- do ----	33° (65 percent) ---	Planar -------	Cut slope; no vegetation.	N and C--------	8.2-m-wide head scarp is 18 m above Ohio 550; red mudstone-shale cut slope below sandstone ledge; seep at contact. Red clayey slickensided basal shear surface is within 0.3 m of land surface in the head area.
H -------	Earth flows, slump-earth-flows, and slumps.	N components	13° (23 percent) to 17° (31 percent).	Mostly concave	Forest---------	N -------------	Most earth flows have basal shear planar within 1 m of surface.
I--------	Debris slide, debris avalanche, earth flow.	S, SE, NE---	15° (27 percent) to 28° (54 percent).	Planar and concave.	----- do -----	------ do -----	Basal shear plane is within 1.0–1.5 m of surface.
J--------	Earth flows -------	Mostly NW to E.	15° (27 percent) to 21° (38 percent).	Mostly concave	Mostly forest---	------ do -----	Wet slopes below 1.0- to 4.5-m-thick sandstone ledge at 860- to 870-ft elevation.

[1]See figure 27 of Appendix.

Figure 10

Locality (either representative specific site or more extensive area)	Landslide type	Aspect	Average angle (and grade) of adjacent slope (to landslide head)[1]	Slope configuration	Vegetation	Trigger—Natural (N) or construction activity (C)	Notes
A–B	Earth flows (2)	NW and W	17° (31 percent)	Planar to concave	Brush to grass	C surcharging of slope by highway cut fill.	350-m and 100-m-wide failures in fill and subjacent slope.
C	Earth flows	NW, SE	21° (38 percent)	Concave and planar.	Forest to brush	N	Wet slope beneath sandstone ledge above head scarp.
D	Earth flow	NW	23° (42 percent)	Sightly concave to planar.	Brush	do	Fresh 18 m wide; uppermost sliding plane is 0.6–0.9 m below surface. Basal shear surface striations lose identity and diffuse into soil near head of movement. Digging revealed two other equally fresh striated surfaces below the topmost one.
E	do	ESE	Renovated slope is 11° (20 percent).	Planar	Grass	C	160-m-wide multiple backyard (largely fill) failure; south lateral edge preserved.
F	Earth flows	E, SW	16° (28 percent)	Concave to planar.	Grass to brush	C drainage uncontrolled?	No outcrops but lithologic control is evident with head scarps at similar elevations.
G	Earth slump or rock slump.	W	19° (34 percent) to 25° (45 percent).	Planar to slightly concave.	Forest	Mostly N; cutting into hill for house construction probably caused at least part of north section of failure.	340-m-wide failure irregular in shape; 1.0- to 2.0-m-thick sandstone lies above head area.
H	Slump-earth flow	S	24° (45 percent)	Planar to convex	Forest to grass	N?	200-m-wide, 50-m-long; small house in head area at eastern end destroyed; larger residence at base of slope threatened at west end.

[1]See figure 27 of Appendix.

Figure 16

Locality (either representative specific site or more extensive area)	Landslide type	Aspect	Average angle (and grade) of adjacent slope (to landslide head)[1]	Slope configuration	Vegetation	Trigger—Natural (N) or construction activity (C)	Notes
A	Slump-earth flow	N	----------------	Concave	Grass	Mostly C	Fill and subjacent colluvium are in an ancient landslide.
B	Earth flows	NW	18° (33 percent) to 22° (40 percent).	Concave to planar.	Forest to grass	Mostly N	Scant outcrop indicative of weak mudstone-shale underlying colluvium.
C	NO DATA	EXACT LOCATION NOT KNOWN					
D	Earth flow	S	9° (15 percent)	Slightly concave to planar.	Grass	Not known what caused earth flow which broke waterline.	Failure appears to be in crown area of an ancient landslide.
E	do	E	13° (23 percent)	Concave to planar.	do	Probably N	Extremely slow moving earth flow; part of movement is due to creep.
F	Slump-earth flow	S	14° (25 percent)	Concave	Brush to forest	N	Unique slope failure in that essentially all of ancient landslide has been reactivated. Landslide (350 m wide) is largest within town limits.

[1]See figure 27 of Appendix.

Figure 19

Locality (either representative specific site or more extensive area)	Landslide type	Aspect	Average angle (and grade) of adjacent slope (to landslide head)[1]	Slope configuration	Vegetation	Trigger—Natural (N) or construction activity (C)	Notes
A	Earth flows (2)	N	18° (32 percent)	Concave	Grass	N?	Seepage in head areas that lie below sand stone ledge.
B	Earth flow	SE	13° (23 percent)	do	Grass to brush	N	>100 m in width seepage at base of 1-m-high head scarp.
C	do	W	17° (30 percent)	do	Forest	do	24-m-wide movement, basal shear plane is 1 m below surface.
D	Earth slump	SW	13° (23 percent)	Planar	do	C? drainage from road "funnels" into head area.	50-m-wide rotational movements extends to foot at drainage; sandstone ledge above head scarp.
E	Slump-earth flow	do	29° (55 percent)	do	do	C pipeline emplacement above head scarp; drainage changes.	Sandstone capping of top of ridge, red mudstone below; very fresh 25-m-wide landslide.
F	Earth flows	Multidirectional.	17° (30 percent)	Mostly concave	do	N	Clearly shows affinity of large slope movements to hollows or coves.

[1]See figure 27 of Appendix.

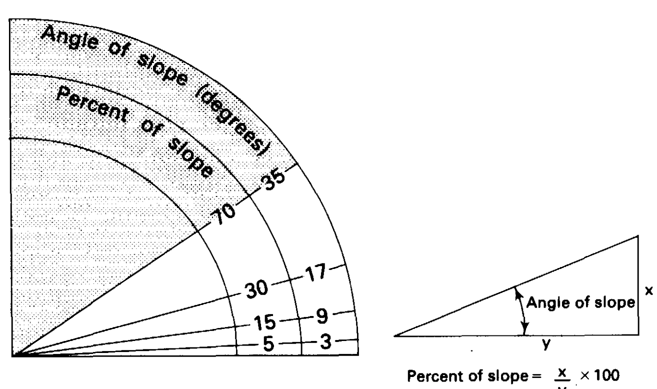
Figure 23

Locality (either representative specific site or more extensive area)	Landslide type	Aspect	Average angle (and grade) of adjacent slope (to landslide head)[1]	Slope configuration	Vegetation	Trigger—Natural (N) or construction activity (C)	Notes
A	Earth flow	N to NW	22° (40 percent)	Planar	Forest	N	24-m-wide head area; regolith has been displaced 3.0—3.5 m.
B	do	NE	16° (28 percent)	Concave	Grass	do	Seepage in head scarp and below steeper slope.
C	Earth slump	E	horizontal (0°)	-------------	do	do	14-m-wide, 6-m-long with 1-m-high head scarp; basal shear surface lies beneath creek channel.
D	Earth flow	N to NE	21° (38 percent)	Concave	do	do	Widest farmland earth flow (400 m wide) in Marietta area.
E	Mostly earth flows, some slump-earth flows.	Multidirectional; largest failures face N.	17° (30 percent)	Concave and planar.	Mostly forest	N except for garbage dump.	Smaller movements along south-facing slope have not been caused by any slope modification; slippage of garbage and soil discernible on 1968 aerial photographs.
F	SLOPE MOVEMENTS ARE SCARCE TO NONEXISTENT (SEE TEXT)						
G	Mostly earth flows, some slump-earth flows.	Mostly N or NE-facing.	23° (47 percent)	Mostly concave	Forest	N	Seepages at base of sandstone ledge, area underlain by weaker rock than that at locality F.

[1]See figure 27 of Appendix.

Figure 27

Locality (either representative specific site or more extensive area)	Landslide type	Aspect	Average angle (and grade) of adjacent slope (to landslide head)[1]	Slope configuration	Vegetation	Trigger—Natural (N) or construction activity (C)	Notes
A	Earth flow (upper part). Earth slump (lower part).	SW	25° (47 percent)	Planar	Forest to brush	N	Seepage at base of 9-m-thick sandstone cliff lies above head scarp.
B	Slump-earth flow	W	16° (29 percent)	do	Forest	Probably C	Pipeline and access road possibly triggered movement.
C	Earth flow	SW	14° (26 percent)	Planar to slightly concave.	do	Probably C slight slope modification for golf course fairway.	Head scarp lies at base of sandstone ledge; toe of earth flow has been recontoured.
D	do	do	18° (33 percent)	Concave	do	N	Nearby lithologic section (10, fig. 3) indicates that 85 percent of interval along slope is mudstone-shale; 15 percent is sandstone.
E	Earth flows and slump-earth flows.	E to NE	17° (31 percent) to 24° (46 percent).	Mostly concave	do	do	Largest movement is in 150-m-wide cove and consists of several overlapping earthflows.
F	Earth flows	SW	15° (28 percent) to 19° (35 percent).	Mostly planar	do	do	Opposing (northeast-facing) slope is hummocky but without any recent landsliding.



☆ U.S. GOVERNMENT PRINTING OFFICE: 1987 - 201-933 - 226/60058

, OHIO, AREA—U.S. Geological Survey Bulletin 1[illegible]