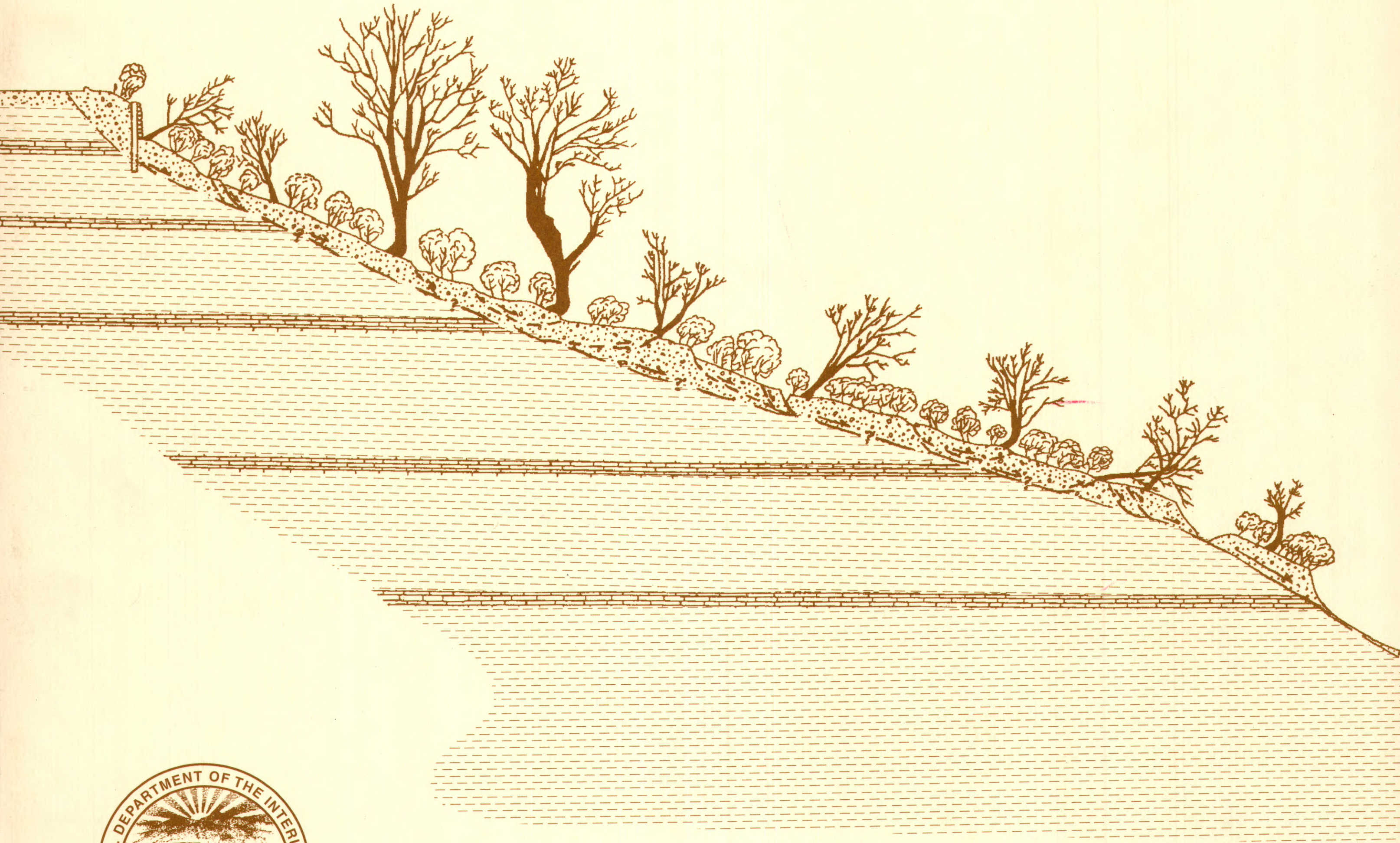
LANDSLIDES OF THE CINCINNATI, OHIO, AREA

Overview of Landslide Problems, Research, and Mitigation, Cincinnati, Ohio, Area



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Overview of Landslide Problems, Research, and Mitigation, Cincinnati, Ohio, Area

By REX L. BAUM *and* ARVID M. JOHNSON

LANDSLIDES OF THE CINCINNATI, OHIO, AREA

U.S. GEOLOGICAL SURVEY BULLETIN 2059–A

Description of landslide types in relation to local geology, history of research, and summary of efforts by citizens and local government to mitigate landslide hazards

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OVERVIEW OF LANDSLIDE PROBLEMS, RESEARCH, AND MITIGATION, CINCINNATI, OHIO, AREA

By Rex L. Baum *and* Arvid M. Johnson[1]

ABSTRACT

Landslides cause much damage to property throughout the metropolitan area of Cincinnati, Ohio. Most landslides occur in unconsolidated deposits, including colluvium, till, glacial lake clays, and man-made fill derived from colluvium and glacial deposits. Landslides in thin colluvium are widespread on steeper slopes that wall the valleys of the Ohio River and its tributaries. Abundant landslides also form in thick colluvium on flatter slopes, especially where the colluvium has been disturbed by earthwork. Unusual block glides and block-extrusion glides form where till rests on lake clay. Through the years, knowledge of the distribution and causes of landslides has increased as a result of many investigations. This knowledge became part of the basis for landslide mitigation programs adopted by the City of Cincinnati and Hamilton County, Ohio. In 1974 the Cincinnati City Council passed an excavation and fill ordinance to help reduce landslide damage in areas of new construction. In 1989 following much additional study, Cincinnati created a geotechnical office within its Department of Public Works. The office, which is staffed by a geotechnical engineer, an engineering geologist, and two technicians, carries out a mitigation program. Since 1989, members of the geotechnical staff have worked in several ways to reduce landslide damage in the city; their work includes engineering-geologic mapping of selected parts of the city, inspection of retaining walls that impact public right-of-way, review of proposed construction in hillside areas, inspecting and arranging for repair of landslide areas that affect city property, and compiling geologic and geotechnical data on landslide areas within the city. In 1990, Hamilton County also adopted an excavation and fill ordinance to help reduce the damage due to landslides in areas of new construction.

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INTRODUCTION

Landslides have been known in the Cincinnati area, southwestern Ohio (fig. 1), since before the 1850's, but the damage caused by landslides has become increasingly expensive as urban development has encroached more and more on the area's hillsides (Earth Movement Task Force, 1982). The City of Cincinnati spent an average of about $500,000 per year on emergency street repairs for damage due to landslides between 1983 and 1987 (Earth Surface Processes Group, 1987), and the cost of landslide damage in Hamilton County averaged about $5,170,000 per year between 1973 and 1978 (Fleming and Taylor, 1980).

Landslides occur in many kinds of surficial deposits of the Cincinnati area, but slides appear to be more common in colluvium than in any other deposits. Consequently, remaining chapters in this series (U.S. Geological Survey Bulletin 2059, chapters B, C, D, and E) report the results of several research projects on landslides in colluvium. Investigations by many people, particularly research conducted jointly by the U.S. Geological Survey and the University of Cincinnati, identified the causes and mechanisms of landslides in the Cincinnati area. Basic geologic data, the distribution of historic slides, and knowledge of the causes and mechanisms coupled with experience from other urban areas are the basis for mitigation strategies that the City of Cincinnati and Hamilton County have adopted in the last decade. This chapter briefly describes the geologic setting and landslide types of the area, traces the history of landslide investigations and efforts to remedy landslide problems, and reviews some of the questions and problems that prompted the research described in succeeding chapters.

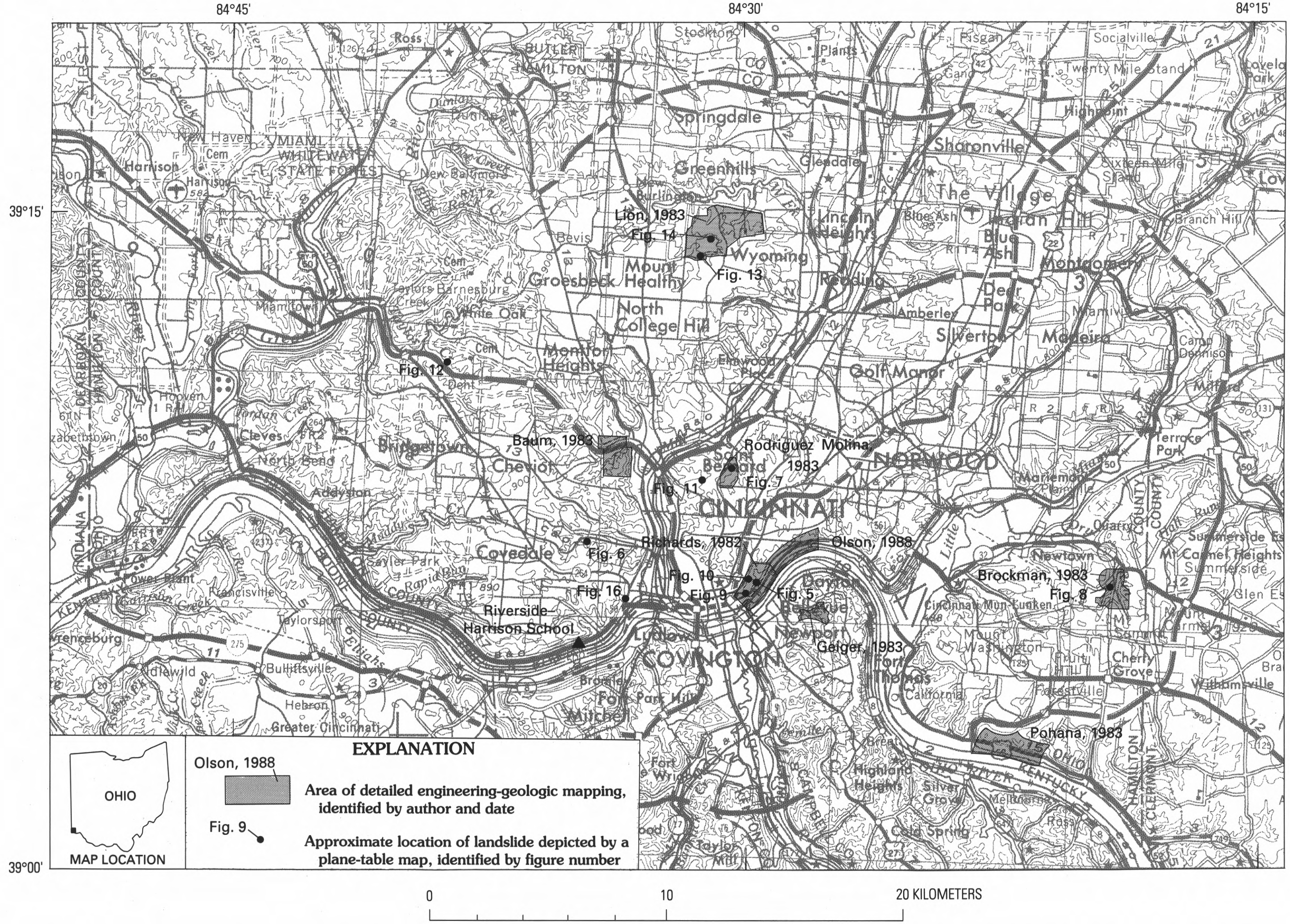


Figure 1. Map of Cincinnati and Hamilton County, Ohio, showing approximate outlines of areas of detailed engineering-geologic mapping by students at the University of Cincinnati and locations of landslides depicted by plane table maps. Base from U.S. Geological Survey 1:250,000 Cincinnati, Ohio; Indiana; Kentucky (1953, revised 1974). Contour interval 100 feet.

TOPOGRAPHY, GEOLOGY, AND LANDSLIDES OF THE CINCINNATI AREA

TOPOGRAPHY

The Cincinnati area is a rolling, gently sloping upland that has been dissected in a dendritic pattern by ancient drainage systems, as well as by the modern Ohio River and its tributaries (fig. 1). Many of the tributaries occupy broad, terraced valleys. Steep hillsides line the valleys. The area has about 120 m of relief between the Ohio River (139 m above mean sea level) and nearby hilltops. The highest point in Hamilton County is about 293 m above mean sea level at a point 11 km north-northwest of downtown Cincinnati, on a major north-trending drainage divide that bisects Hamilton County. Hillsides slope gently near the valley floor and gradually become steeper as elevation increases. Near the rounded hilltops, the slopes flatten again. About 20 percent of the area of Cincinnati and Hamilton County slopes more than 25 percent (about 14°) (Earth Movement Task Force, 1982). Thus, hillsides determine much of the character of the Cincinnati area by forming natural green belts between hilltop communities and neighboring valley communities.

GEOLOGY

Glacial deposits cover most of the upland areas and form terraces along the Ohio River and its tributaries. Outwash and alluvium occupy the valley floors; colluvium, locally derived from bedrock and glacial deposits, covers bedrock on most hillsides. Bedrock underlies the glacial deposits at various depths. Landslides occur in colluvium and in some glacial deposits. Brief descriptions of bedrock and glacial geology follow.

Ordovician bedrock underlying the area consists of almost horizontally layered shale with subordinate limestone (Ford, 1967). The Upper Ordovician Kope Formation (more than 60 m thick) is present between the level of the Ohio River and about midheight of hillsides along the Ohio and its major tributaries (fig. 2). The Kope Formation consists of about 70–80 percent blue-gray shale with discontinuous interbeds of gray, fossiliferous limestone. Shale of the Kope Formation slakes when exposed to water and weathers readily into a yellow-brown clay soil. The Upper Ordovician Fairview Formation, 20–30 m thick, rests conformably on and interfingers with the Kope Formation (Ford, 1967). The Fairview Formation consists of 60–75 percent blue-gray shale with continuous interbeds of fossiliferous limestone. Beds in the Fairview are less than 50 cm thick and average 8 cm. The Miamitown Shale, 0–11 m thick, interfingers with the Fairview Formation and may lie above or within the Fairview. Nodular, shale-rich (about 90 percent shale) lithology is typical of the Miamitown Shale. Bellevue Limestone, about 0–8 m thick, and unnamed Upper Ordovician beds cap the hilltops. The Bellevue Limestone consists of crenulated, shelly limestone with thin, clay-rich interbeds. Unnamed beds above the Bellevue Limestone contain variable amounts of shale and limestone.

Colluvium covers many hillsides in the area, especially those that were glaciated only in pre-Illinoian time (fig. 3). The colluvium is derived from weathered bedrock and consists of fragments of weathered limestone and siltstone in a matrix of yellow, silty clay. The colluvium forms a wedge-shaped deposit that is thin on the steeper, higher slopes and gradually becomes thicker (as much as 15 m thick) near the valley bottom.

The relatively simple geologic structure influences the movement of ground water in the bedrock. The area is on the west flank of the Cincinnati Arch, a broad anticline that occupies much of southwestern Ohio and northern Kentucky. Bedding in most of Hamilton County dips about 1.5–2.0 m/km toward the northwest. Limestone and siltstone beds contain near-vertical fractures that are spaced regularly. Two or three sets of fractures, each having a different orientation, exist at any given location. However, orientations of the fracture sets vary from place to place (Hoffman, 1966). The shale separates along bedding planes but it also contains steeply dipping fractures (Richards, 1982; Baum, 1983, p. 15). Fractures and, locally, small solution channels appear to be the main avenues of ground-water movement in the bedrock (Fenneman, 1916). Hoffman (1966) observed a few small, complex structures in bedrock exposed in stream valleys; the structures do not appear to have any relation to modern landslides.

Pre-Illinoian (Kansan?), Illinoian, and Wisconsinan glaciation changed the drainage pattern and left glacial deposits in valleys, on upland areas, and on hillsides (Durrell, 1961, 1977; Pavey and others, 1992) (fig. 3*A*). Before the advent of the first ice sheet in southwest Ohio, the area was a gently rolling plain and north-flowing streams occupied valleys that were about 45 m deep (Durrell, 1977). The pre-Illinoian glacier advanced into northern Hamilton County and dammed the north-flowing streams; eventually a deep, west-flowing river ("Deep Stage") formed that flowed west through Norwood, north up the valley of Mill Creek, and then south down the valley of the Great Miami River. Remnants of deeply weathered pre-Illinoian till, lake clay, and outwash are found on hilltops in Hamilton County (fig. 3*B*) and northern Kentucky, beyond the limits of later glaciers (Durrell, 1961,

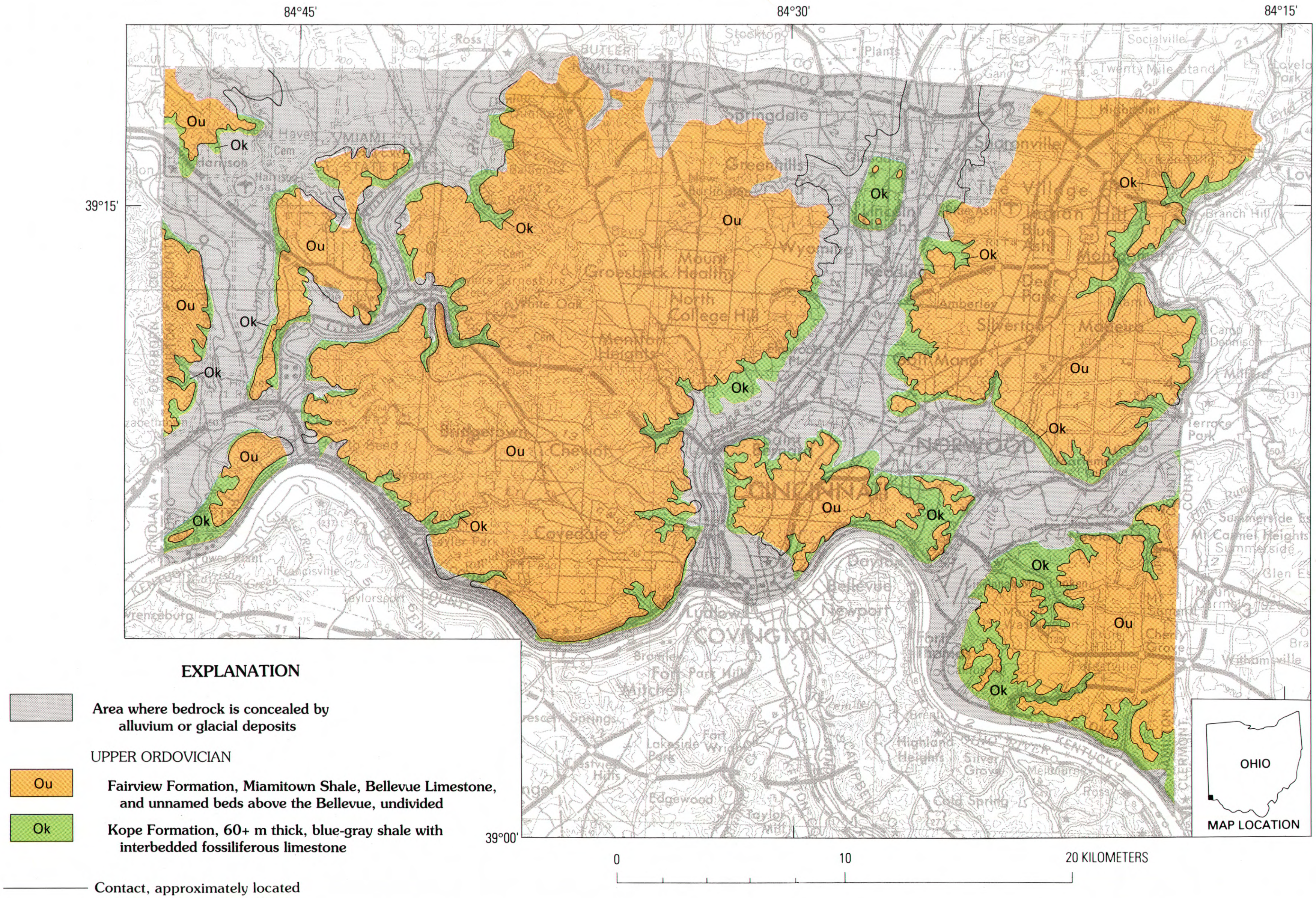


Figure 2. Bedrock geology of Hamilton County, Ohio (top of Kope Formation from Gray and others, 1972). Base from U.S. Geological Survey 1:250,000 Cincinnati, Ohio; Indiana; Kentucky (1953, revised 1974). Contour interval 100 feet.

p. 55). Two lobes of the Illinoian glacier advanced into Hamilton County, damming the Deep-Stage Ohio River. Eventually the water overflowed a divide at Anderson Ferry (fig. 3*A*, about 10 km east of downtown Cincinnati) and formed the channel of the modern Ohio River. Illinoian till and lake-clay deposits occur on the uplands and in the major tributary valleys (fig. 3*A*). In Hamilton County, Illinoian deposits appear to be absent only in a triangular area between the Great Miami River and the Ohio River. Wisconsinan till occupies only the northern part of Hamilton County, but coarse Wisconsinan outwash is found in valleys of the Ohio River and its major tributaries. The three episodes of glaciation left a complex array of glacial deposits (fig. 3*A*, *B*); many landslides have occurred in the deposits (Fleming and others, 1981; Lion, 1983; Rodriguez Molina, 1983).

LANDSLIDES

Landslides in the Cincinnati area generally occur in surficial materials; landslides in which bedrock failed have been extremely rare (Fleming, 1975, p. 5). Several kinds of landslides have been identified, including rapid earth flows, thin translational landslides, thick landslides that move by rotation or a combination of rotation and translation, and block-extrusion glides (table 1).

Many of the landslides that occurred in the 1970's and 1980's were studied by students of the University of Cincinnati. A part of the investigation was to make a detailed map of cracks and damage to such structures as roads and sidewalks. Several of these maps are reproduced here at a reduced scale to illustrate how the different kinds of landslides appear in the field. Detailed descriptions of most are contained in the reports and theses cited in the references.

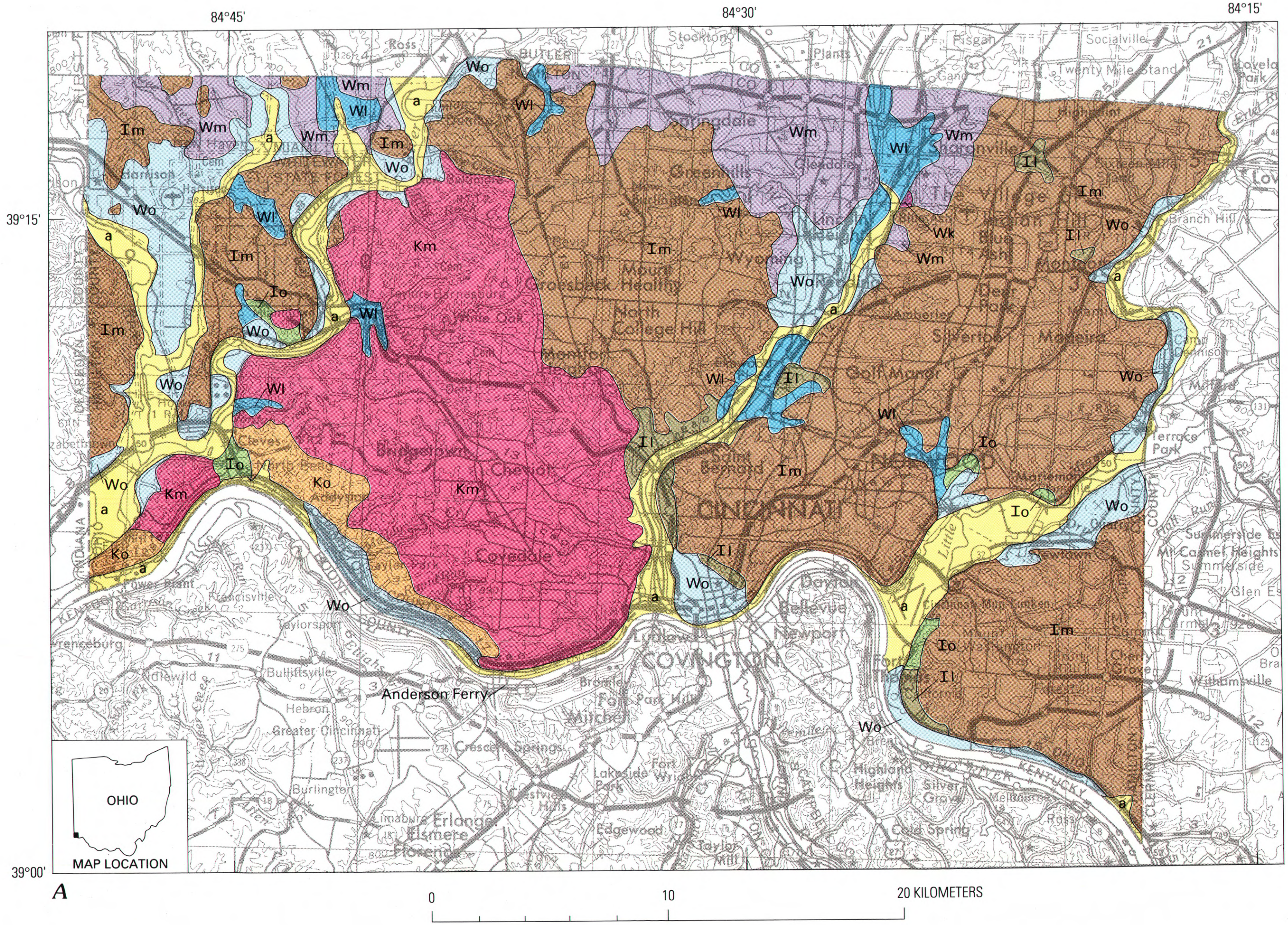
Rapid earth flows, known locally as "mudslides," are common on steeper slopes underlain by the Kope Formation in areas such as Columbia Parkway and Elberon Avenue (Fleming, 1975, p. 10). These failures are notorious for spilling onto Columbia Parkway and disrupting traffic. Rapid earth flows form during wet periods in thin colluvium (less than 2 m thick) overlying weathered bedrock and in clay derived from mechanically weathered bedrock exposed in steep cuts, mainly along highways (Pohana, 1983). Rapid earth flows involve the entire thickness of colluvium and leave exposed bedrock in their scars (fig. 4). Most rapid earth flows are small compared to other landslides of the Cincinnati area; the maximum dimension is usually less than 25 m (Fleming, 1975; Richards, 1982; Riestenberg and Sovonik-Dunford, 1983).

Slow-moving landslides also form in colluvium. Thin translational landslides form in thin colluvium on steep (27–47 percent or 15°–25°) slopes. Thick translational or rotational landslides form on flatter slopes in colluvium, artificial fill, and glacial deposits near the valley floors. In many places, thin and thick landslides join to form large landslide complexes (Fleming and others, 1981).

Translational landslides in thin colluvium are abundant on steep slopes underlain by the Kope and Fairview Formations (Richards, 1982). Commonly the slides are 10–150 m wide (parallel to the contours) and 30–150 m long, and they form on slopes between about 27 percent (15°) and 58 percent (30°). In plan view, the landslides can range in shape from long and narrow to short and wide (Richards, 1982, pl. 1). Thin landslides may occur singly or grouped in slide complexes; some complexes are several hundred meters long (Fleming and others, 1981). Springs and seeps occur within or near many thin landslides. Thin landslides are active only in the spring because the colluvium is nearly saturated between mid January and early May and dry the rest of the year (Haneberg, 1991). Longitudinal stretching is the dominant style of deformation in thin landslides. Features near the downslope end commonly appear more fully developed. Most thin slides have many downhill-facing scarps, 0.3–1 m high, consistent with longitudinal stretching (figs. 5–7). The well-developed flanks are indicated by troughs (0.3–1.2 m deep) or scarps roughly perpendicular to the contours. The slip surface, 0–2 m deep, is near the irregular contact between colluvium and weathered bedrock. Thin landslides have also been observed in till where it forms a veneer over bedrock (fig. 8).

Thick, rotational or rotational-translational landslides are common in till, thick colluvium, and fill derived from colluvium or till (figs. 9–12). Rotational landslides are commonly 2–15 m thick, 30–300 m wide, and 30–150 m long, and they occur on slopes between about 11 percent (6°) and 27 percent (15°). One of the largest of this type, near the Riverside-Harrison School (fig. 1), was about 600 m wide, 12 m deep, and 460 m long (Von Schlichten, 1935; Fleming and others, 1981). Some of these slides occur naturally, perhaps due to the action of subsurface water, but many occur in connection with earthwork in otherwise stable material (figs. 9–12). The landslide material appears to be only partially saturated most of the time. Although springs and locally marshy ground indicate that some areas are saturated (figs. 9 and 10), many open-tube piezometers remain dry

Figure 3 (following three pages). Surficial geology of Hamilton County, Ohio. *A*, Generalized map, simplified from a recent map of Quaternary deposits in Ohio (Pavey and others, 1992). Base from U.S. Geological Survey 1:250,000 Cincinnati, Ohio; Indiana; Kentucky (1953, revised 1974). Contour interval 100 feet. *B*, Part of a detailed map by Brockman (1986), showing complex distribution of glacial deposits. Base from U.S. Geological Survey 1:24,000 Shandon, Ohio (1965, photorevised 1981). Contour interval 10 feet.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A

EXPLANATION

HOLOCENE

a — Alluvium and alluvial terraces; silty clay in areas of fine-grained deposits; coarse sand, gravel, or cobbles in areas of shallow bedrock

LATE WISCONSINAN

Wo — Outwash, deposited by meltwater in front of glacial ice; valley terraces or low plains; well-sorted, stratified sand and gravel

Wl — Lacustrine silt, locally includes fine sand or clay, well laminated in distal parts of deltas, poorly laminated elsewhere

Wk — Kames and kame terraces, hummocks or high valley steps, sand and gravel, poorly sorted and stratified, locally contains boulders or masses of till

Wm — Moraine, flat to gently undulating, hummocks or hummocky ridges, sandy loam till with patchy loess cover

ILLINOIAN

Io — Outwash, small benches and high terraces, uniform sand beds, some coarse silts, 0.5–2 m loess cover

Il — Lacustrine deposits, clay and silts more than 1 m thick, massive silt or colluvial cover 0.25–0.5 m thick

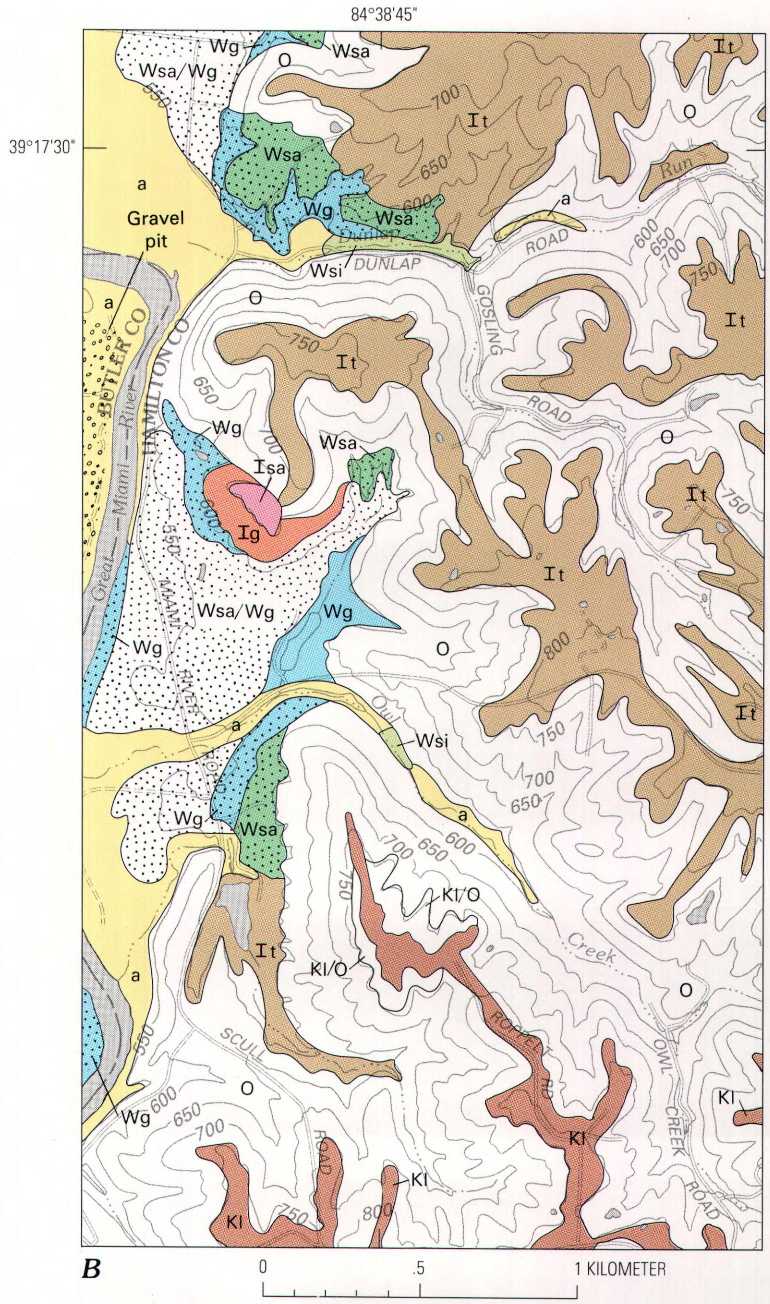
Im — Moraine, flat, relatively continuous in eastern Hamilton County; dissected, occurring on ridge tops and mixed with colluvium on hillslopes in western Hamilton County; silty loam till covered with 1–3 m loess

EARLY MIDDLE PLEISTOCENE

Ko — Outwash(?), "Gallia sands," high sandy areas with bright-red soil profiles

Km — Moraine, mainly on ridgetops, dissected, eroded, highly weathered remnants of pre-Illinoian (Kansan?) till

——— Contact, approximately located



EXPLANATION

a	Alluvium		HOLOCENE
Wsa	Sand	Wisconsinan	PLEISTOCENE
Wg	Gravel		
Wsi	Silt		
Isa	Sand	Illinoian	
Ig	Gravel		
It	Till		
Kl	Loess over till	Kansan(?)	
O	Bedrock (covered with thin layer of colluvium)		ORDOVICIAN

Note: Some units are "mixed," as, Wsa/Wg

Table 1. Characteristics of landslides in the Cincinnati, Ohio, area.

Type	Style of movement	Rate	Thickness (m)	Volume[1] (cubic meters)	Materials
Rapid earth flow (or "mudslide").	Translation and flow.	As much as several meters per second(?).	<2	<300	Colluvium.
Thin slide	Translation	Slow, probably a few centimeters per year with episodes of more rapid movement, 1–100 cm/day.	<2	300–50,000	Colluvium, artificial fill, till.
Thick slide	Rotation and translation.	0–50 cm/day([2])	2–15	200–500,000([3])	Colluvium, artificial fill, glacial deposits.
Block glide	Translation	0–25 cm/yr([4])	2–10	1,000–100,000	Till on glacial lake clay.
Block-extrusion glide ...	Translation and extrusion.	0–25 cm/yr([4])	10	1,000–100,000	Till on glacial lake clay.

[1] Estimated from typical dimensions.
[2] Von Schlichten (1935).
[3] The landslide near Riverside-Harrison School was one of the largest of its kind in the area; its volume was about 3,000,000 m^3 (Von Schlichten, 1935; Fleming and others, 1981).
[4] Fleming and others (1981, p. 561).

(Fleming and Johnson, 1994). Longitudinal shortening appears to be the dominant style of deformation in thick landslides because such slides commonly have many internal toes (fig. 11). The internal toes are analogous to thrust faults, which are known to result from shortening (Billings, 1972, p. 196). Many thick slides have only one major scarp (the head scarp) and a few minor internal scarps. The lateral margins are often poorly expressed.

Many complex slides consist of one or more thin slides, joined to a thick slide. In such complexes, the thin slides occupy the upper part of the hillside and contain many scarps; the thick slide occupies the lower part of the hillside and contains internal toes. Thus, the thin slide acts as the head and the thick slide acts as the toe of the landslide complex (Fleming and Johnson, 1994).

Unusual block glides (fig. 13) and block-extrusion glides (fig. 14) occurred in Illinoian glacial lake clay overlain by till at Huffman Court, McKelvey Road (Fleming and others, 1981; Gökce, 1989, 1992), at Glenwood Avenue in Avondale (Rodriguez Molina, 1983), near the southeast corner of Hamilton County (Pohana, 1983, pl. 4), and probably elsewhere. Gökce (1989, p. 108–204) described several examples and noted the following general characteristics. These slides typically occur where a stream has cut through till resting on soft, horizontally laminated lake clay; the lake clay rests on limestone and shale bedrock. The slides commonly are about 10 m thick, and the maximum dimension in plan view is about 100 m. Movement is slow, usually less than 25 cm/yr. The ground surface slopes gently, about 5°–15°, and the contact between the till and underlying lake clay slopes a few degrees toward the stream. The surface of the bedrock may be horizontal or gently sloping. Water pressures in the till are low or negative, but confined water occurs in the bedrock. Water levels of wells sealed into the bedrock are near the ground surface. Well-developed scarps or grabens form at the heads of these slides, weakly developed cracks mark lateral margins (flanks) of some landslides (the flanks cannot be located in others), and domes or ridges of clay that appear and disappear in the stream channels mark toes of these slides. Failure seems to occur by a combination of extrusion of the lake clay into the stream channel and sliding within the lake clay.

Several lines of evidence indicate that extrusion plays a significant role in movement of some of these block glides (Fleming and others, 1981; Gökce, 1989). Inclinometer measurements at the Huffman Court block-extrusion glide indicated a bulge in the velocity profile (that is, greater horizontal velocity) in the depth interval of the lake clay (fig. 14). Domes of laminated clay appeared in the stream beds during dry periods and apparently were eroded away during rainy periods. The laminations were disturbed and steeply dipping in the domes, but horizontal laminations were observed in samples from boreholes elsewhere in the landslide. Lake clay in the domes was also a few meters higher in elevation than the clay beneath the rest of the landslide. The ground surface of the landslides (except in the clay domes) settled, indicating that the slides were

Figure 4. Scar and deposits of rapid earth flow ("mudslide") along Columbia Parkway, by R.W. Fleming (reproduced from Fleming, 1975; Fleming and Johnson, 1994).

getting thinner. Shear strength of the laminated clay, measured in laboratory tests on samples from block extrusion glides at McKelvey Road and Huffman Court, were consistent with a model for extrusion (Gökce, 1989). However, the shear strength was not consistent with a model for simple sliding; back calculation by means of limit equilibrium stability analysis, using the observed water pressures and geometry, indicated much lower shear strengths than did the laboratory tests.

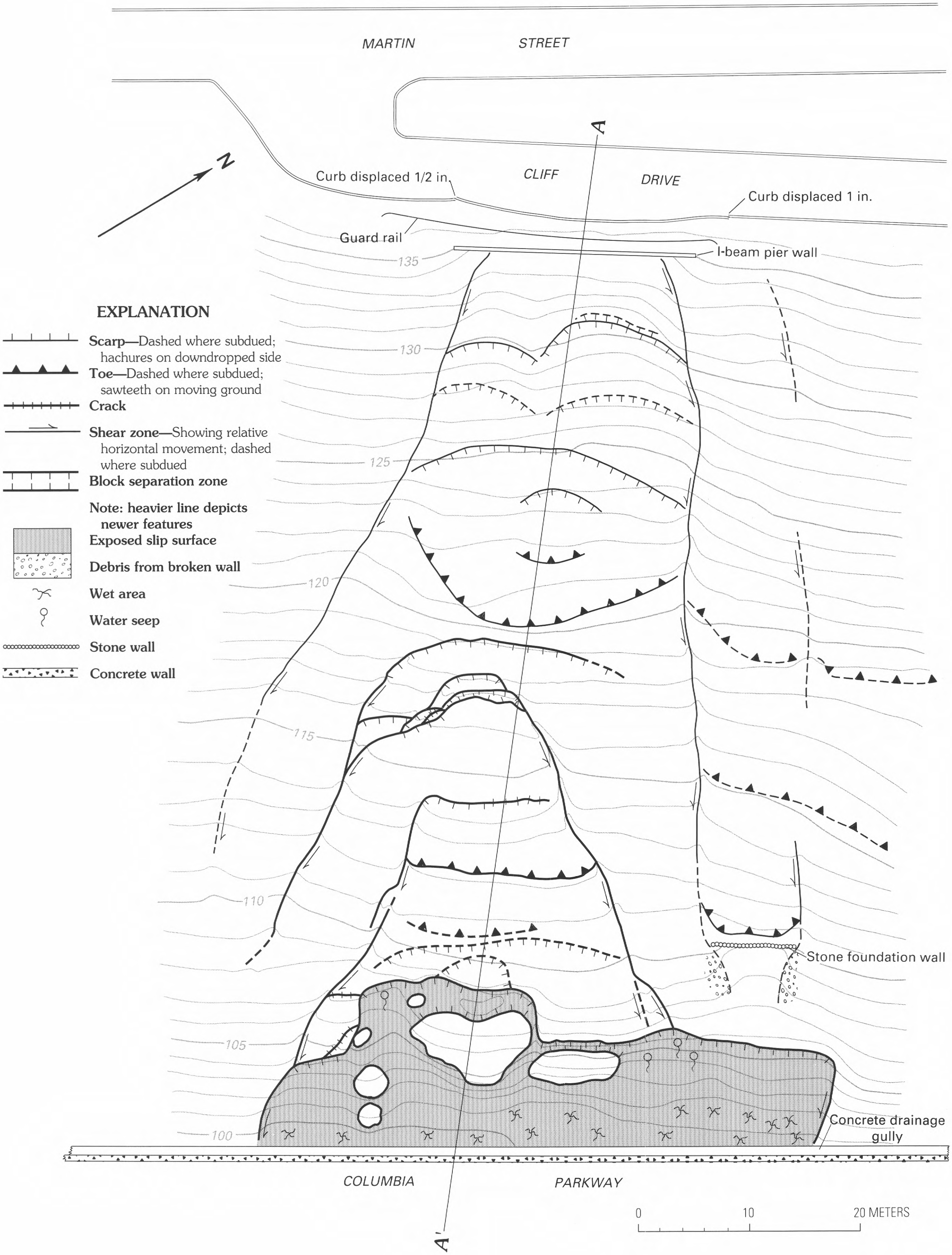
HISTORY OF LANDSLIDE INVESTIGATIONS IN CINCINNATI AND HAMILTON COUNTY

Reports of landslide investigations published before the 1970's are uncommon, and descriptions of the local geology mention landslides only briefly. Orton (1873, p. 423–424) mentioned landslide and foundation problems related to the Kope Formation (his Eden beds). Fenneman (1916, p. 76–77) in describing the geology of the Cincinnati area, noted that hillside soils creep downslope gradually, and that hillside soils sometimes fail during wet periods. Exon (1929) and Von Schlichten (1935) described in moderate detail a major landslide near the Riverside-Harrison School that was active from 1926 to 1930.

Landslides became more common after about 1960 when population growth and improvements in technology led to increased development of hillside areas. Hillsides served as natural barriers to urban development until about 1960 when heavy-duty earth-moving equipment became widely available and made it much easier to build on the hillsides (Hough, 1978). At about the same time, undeveloped level or gently sloping ground became scarce, so that urban development began to expand more and more into hillside areas.

Efforts to understand factors that contributed to landsliding and to delineate landslide-prone areas began in the late 1960's and early 1970's. H.C. Nutting and Co. (1967) compiled information on bedrock and glacial

Figure 5 (following two pages). Plane-table map of a landslide complex in thin colluvial soils above Columbia Parkway (modified from Richards, 1982, pl. 4). Contour interval 1 meter (arbitrary datum). Cross section vegetation is representational only.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EXPLANATION
Scarp—Dashed where subdued; hachures on downdropped side
Toe—Dashed where subdued; sawteeth on moving ground
Crack
Shear zone—Showing relative horizontal movement; dashed where subdued
Block separation zone
Note: heavier line depicts newer features
Exposed slip surface
Debris from broken wall
Wet area
Water seep
Stone wall
Concrete wall
Stone foundation wall
Concrete drainage gully
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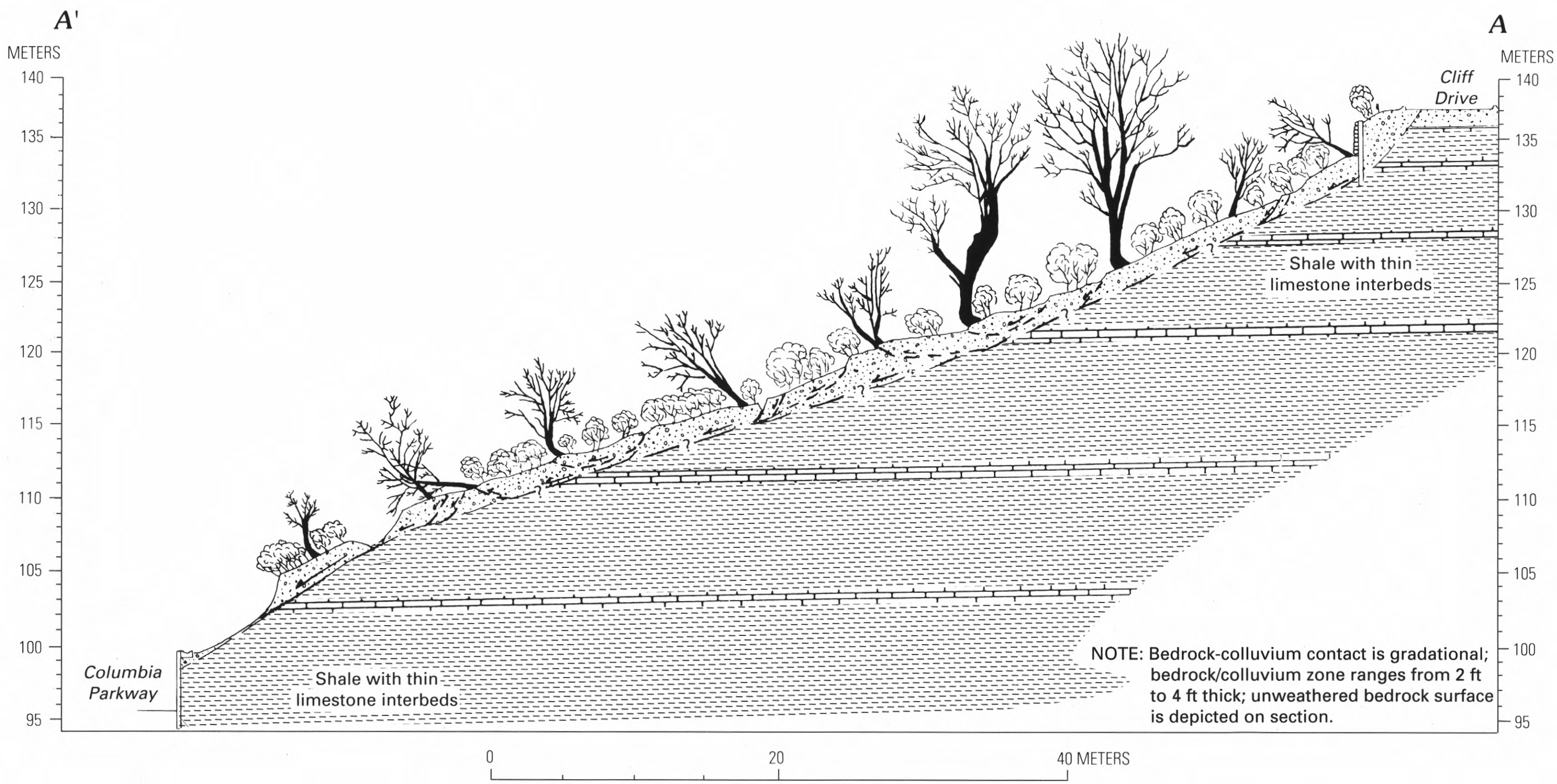
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Shale with thin limestone interbeds
Shale with thin limestone interbeds
NOTE: Bedrock-colluvium contact is gradational; bedrock/colluvium zone ranges from 2 ft to 4 ft thick; unweathered bedrock surface is depicted on section.
0
20
40 METERS

geology, soils, mineral and ground-water resources, and underground disposal for some of Hamilton County at a scale of 1:16,000. The Ohio Department of Natural Resources mapped the bedrock geology of about half of Hamilton County during this time (Ford, 1972, 1974; Osborne, 1970, 1974); bedrock geology is one of several factors considered in modern schemes of landslide hazard zonation. One of the first efforts to delineate areas of potential landslide hazard was a map of "landslide-prone bedrock" within the city limits. Using empirical observations, Hough and Fleming (1974) designated areas underlain by the Kope Formation and sloping 20 percent (11°) or more as landslide prone; areas sloping between 10 percent (6°) and 20 percent (11°) were considered susceptible to sliding if improperly graded. Merritt (1975) did a similar study for Hamilton County, but he classified ground sloping more than 15 percent (9°) as unstable.

Faculty and students at the University of Cincinnati began investigating landslides in the early 1970's. Scheper (1973) investigated the history of landslides in Illinoian till and lake clays at Huffman Court (fig. 14). Yahne (1974) described landslides in a 23-km^2 area north of downtown Cincinnati and found that landslides occurred in colluvium on the Kope Formation, in glacial till, and in man-made fill placed on till. McCandless (1976) measured the bulking of material in a few small landslides near the University of Cincinnati. Fleming (1975) described the observed relationship between geology and landslides. The most expensive landslide in the history of Cincinnati began moving in November 1973 when colluvium on the south side of Mount Adams (a 247-m hill that is on the north bank of the Ohio River and immediately east of downtown) failed during construction of ramps for Interstate Highway 471. Elaborate remedial measures completed in the early 1980's cost more than $22 million (Fleming and others, 1981).

From the mid 1970's through the 1980's, efforts to understand the causes and distribution of landslides increased. In an effort to reduce landslide damage in areas of new construction, the city instituted an excavation and fill ordinance in 1974. To help cope with the problem of landslides, the city commissioned a study of landslide susceptibility (Sowers and Dalrimple Consulting Engineers, 1980). The study compiled existing geologic, topographic, and engineering information along with an inventory of landslides visible on 1979 black-and-white aerial photographs. Composite data for 250-ft-square grid cells were analyzed statistically using a computer to determine what factors are common to landslide-prone areas. Generally, areas underlain by the Kope Formation or the Fairview Formation and having slopes greater than 20 percent (11°) were found to have the highest susceptibility. The Ohio Department of Natural Resources and the U.S. Department of Agriculture completed a soil survey for Hamilton County (Lerch and others, 1982); the survey shows the distribution of soils in the county and identifies several factors common to landslides. The soils are classified according to slope and parent material, as well as depth of weathering, texture, structure, and other properties.

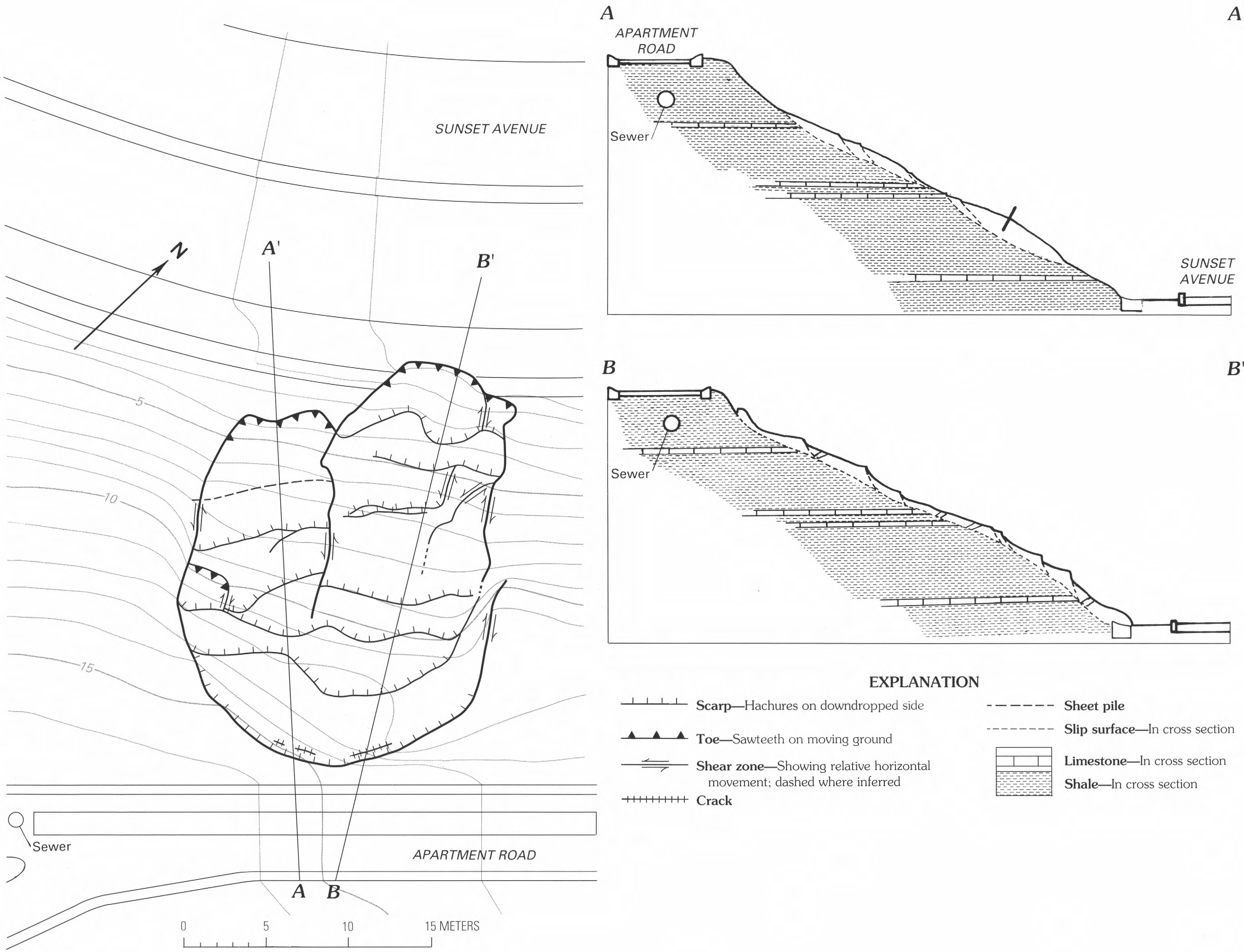
The severity of landslide problems in the Cincinnati area became widely known after Fleming and Taylor (1980) compiled and compared estimates of the cost of landslide damage in three large metropolitan areas. They determined that annual per-capita cost of damage in Hamilton County, Ohio, was $5.80 (not including the slide at Mount Adams), compared with $2.50 for Allegheny County, Pennsylvania, and $1.80 for the nine-county San Francisco Bay region, California.

Faculty and students at the University of Cincinnati together with the U.S. Geological Survey undertook detailed studies of landslides. Graduate students produced detailed engineering-geologic maps and relative stability maps (fig. 15*A*, *B*), most at a scale of 1:2400 or 1:4800, for several parts of the Cincinnati metropolitan area (fig. 1) (Richards, 1982; Baum, 1983; Brockman, 1983; Geiger, 1983; Lion, 1983; Pohana, 1983; Rodriguez-Molina, 1983; Olson, 1988). Riestenberg and Sovonik-Dunford (1983; also Riestenberg, 1981) began investigating the contribution of tree roots to stability of thin colluvium. Detailed field studies led to identification, description, and analysis of the main landslide mechanisms active on Cincinnati hillsides (Fleming and others, 1981; Gökce, 1989). Gökce (1989) described the variation of water levels in thin and thick colluvium and in bedrock beneath thick surficial deposits, described and analyzed block-extrusion glides, and investigated the contribution of cohesion and slip-surface roughness to the sliding resistance of thin colluvium. Efforts to map the distribution of glacial features and materials in Hamilton County also began (Weaver, 1983).

From about 1975 to 1981, Hamilton County undertook many plans, studies, and proposed earthwork regulations to mitigate landslide problems. In 1982, Hamilton County organized the Earth Movement Task Force to evaluate landslide problems in Hamilton County and to make recommendations for dealing with them. As part of their investigation, the Earth Movement Task Force (1982) compiled a landslide inventory showing where landslides had occurred in Hamilton County.

Investigations during the late 1980's and early 1990's built on previous work, in order to answer several questions related to mitigation. The Ohio Geological Survey started mapping bedrock of the remainder of Hamilton County in 1984 (Swinford and Schumacher, 1985; Swinford, 1986), and glacial deposits of all of Hamilton County in 1985 (Brockman, 1986; Vormelker, 1985a, 1985b). Murdoch

Figure 6 (overleaf). Plane-table map of the Sunset View landslide, by Michael J. Westerfield and Robert L. Olson, University of Cincinnati, 1987. All elevations are relative to an arbitrary station on Sunset Avenue. Contour interval 1 meter (arbitrary datum).



EXPLANATION

- **Scarp**—Hachures on downdropped side
- **Toe**—Sawteeth on moving ground
- **Shear zone**—Showing relative horizontal movement; dashed where inferred
- **Crack**
- **Sheet pile**
- **Slip surface**—In cross section
- **Limestone**—In cross section
- **Shale**—In cross section

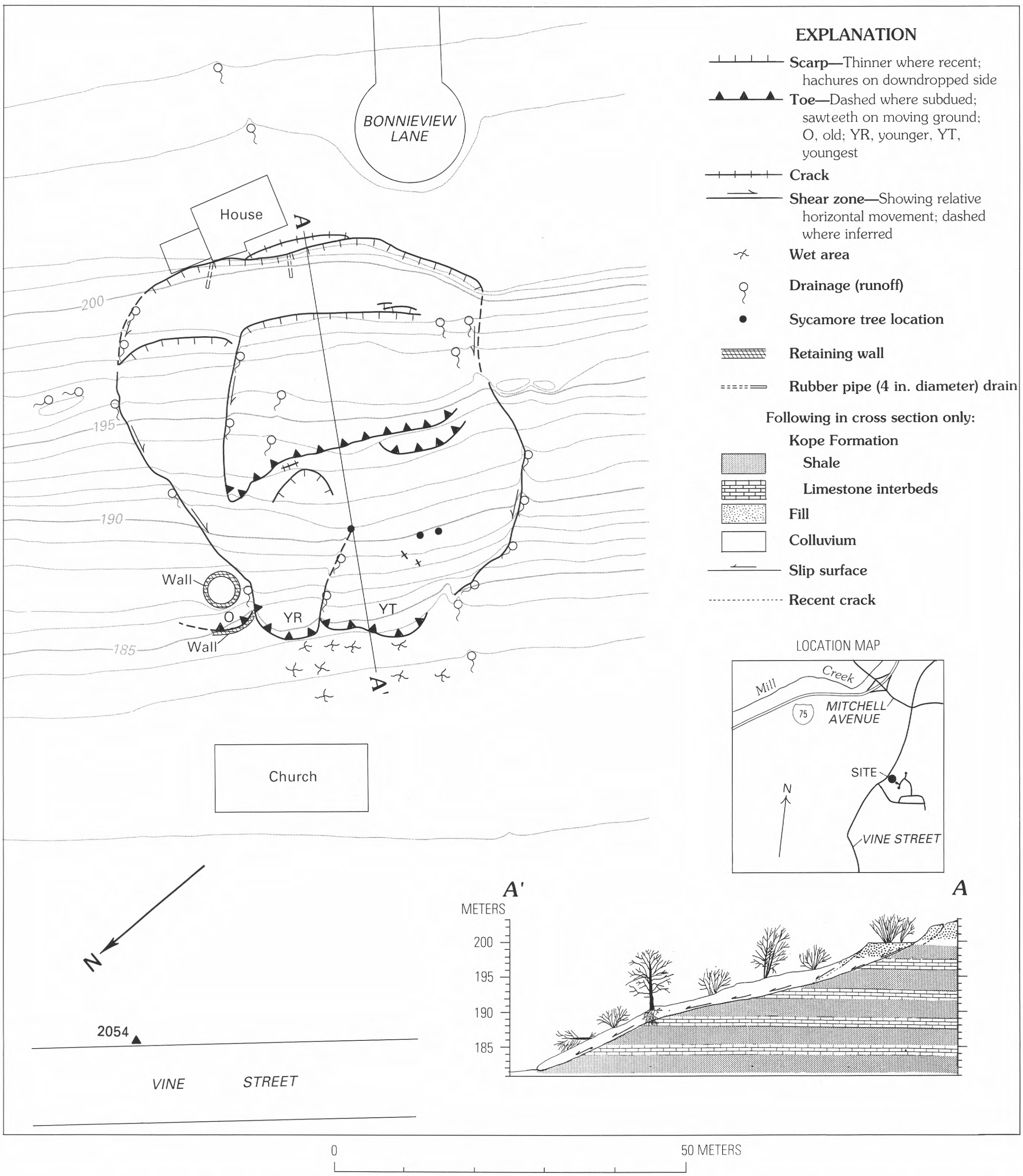
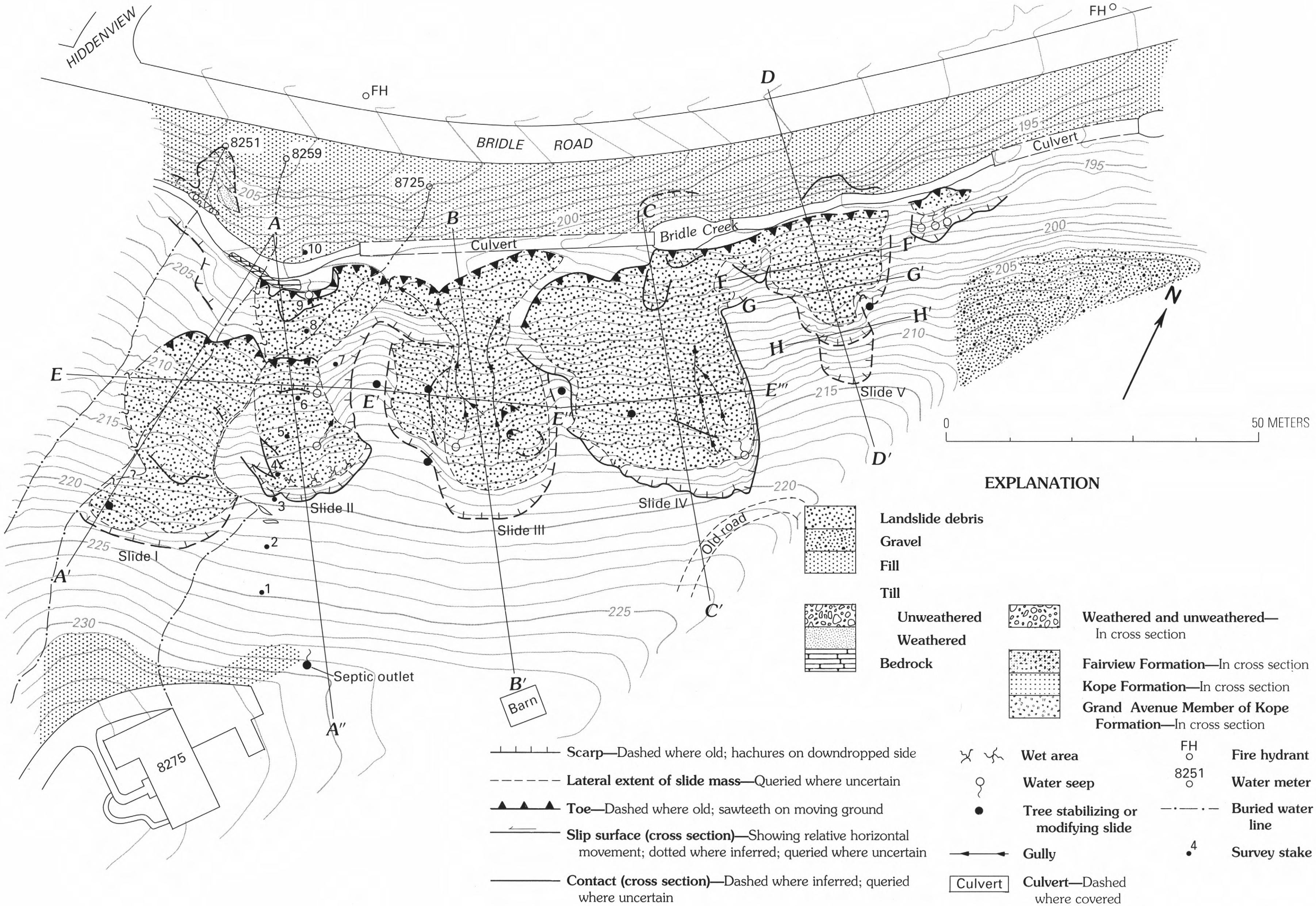


Figure 7. Plane-table map of a landslide between Bonnieview Lane and Vine Street by Carlos Rodriguez Molina and Paul Bates, Jr., University of Cincinnati, April 1982 (modified from Rodriguez Molina, 1983, pl. 4). Elevations on map and cross section are in relation to Benchmark 2054 (solid triangle) near Vine Street. City datum 167.7 meters; plane table datum, 181.5 meters. Contour interval 1 meter. Buildings are schematic. Cross section vegetation is representational only.


HIDDENVIEW
FH
BRIDLE ROAD
8251
8259
8725
Culvert
Bridle Creek
195
200
205
210
215
220
225
230
A
A′
A″
B
B′
C
C′
D
D′
E
E′
E″
E‴
F
F′
G
G′
H
H′
1
2
3
4
5
6
7
8
9
10
Slide I
Slide II
Slide III
Slide IV
Slide V
Old road
Septic outlet
Barn
8275
N
0
50 METERS
EXPLANATION
Landslide debris
Gravel
Fill
Till
Unweathered
Weathered
Bedrock
Weathered and unweathered—In cross section
Fairview Formation—In cross section
Kope Formation—In cross section
Grand Avenue Member of Kope Formation—In cross section
Scarp—Dashed where old; hachures on downdropped side
Lateral extent of slide mass—Queried where uncertain
Toe—Dashed where old; sawteeth on moving ground
Slip surface (cross section)—Showing relative horizontal movement; dotted where inferred; queried where uncertain
Contact (cross section)—Dashed where inferred; queried where uncertain
Wet area
Water seep
Tree stabilizing or modifying slide
Gully
Culvert—Dashed where covered
Fire hydrant
Water meter
Buried water line
Survey stake

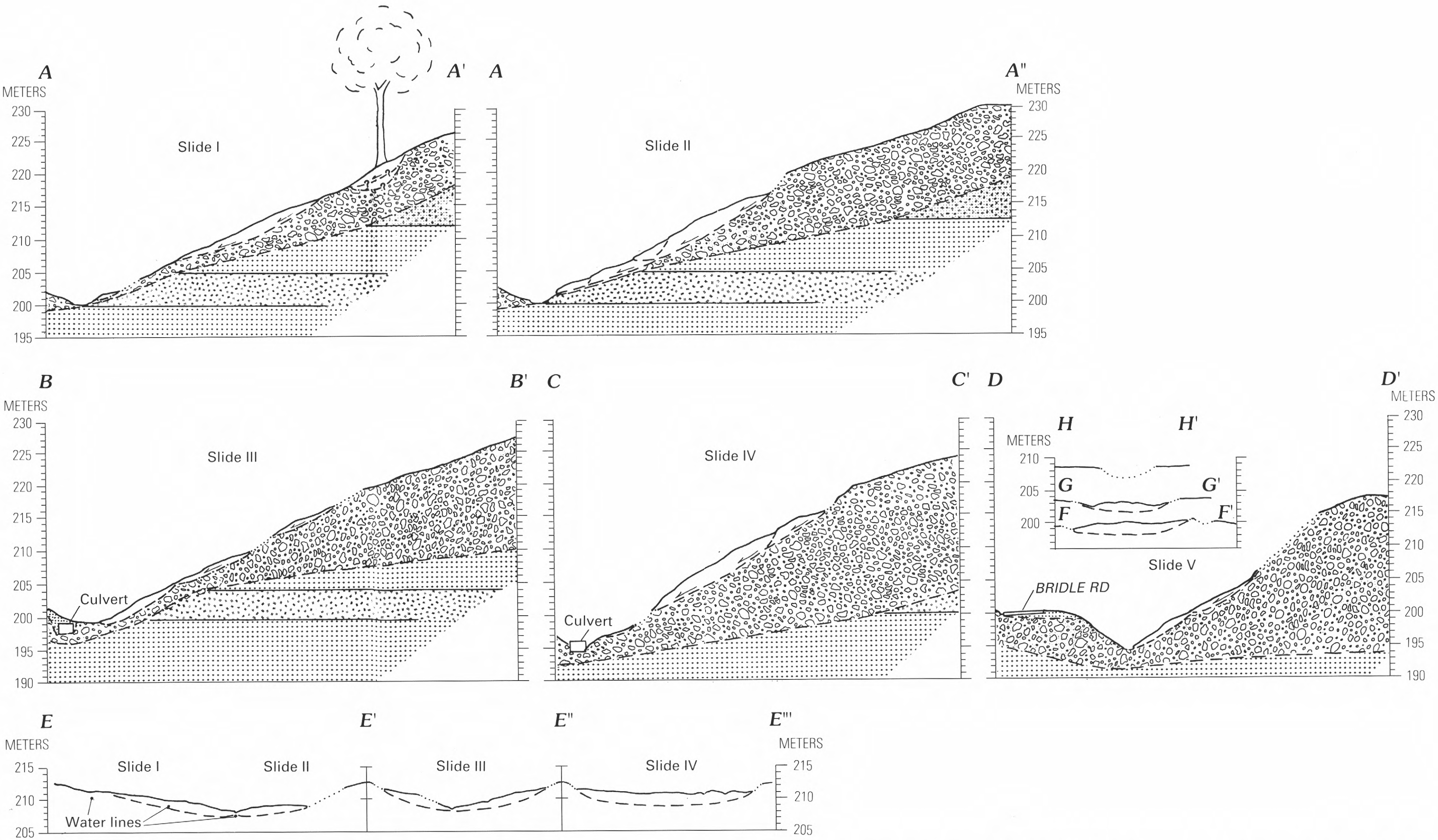


Figure 8. Plane-table map of the Bridle Road landslide complex (thin landslides in till) by C. Scott Brockman, University of Cincinnati, March 1982 (modified from Brockman, 1983, pl. 5). Base datum established from Hamilton County topographic map of the Dry Run Creek area, Anderson Township. Contour interval 1 meter.

(1987) and Haneberg (1989, 1991) investigated movement of soil moisture and rainfall infiltration in thin colluvium. Their work indicates that thin colluvium is uniformly moist and nearly tension saturated from mid January to early May and is nearly dry the remainder of the year. Haneberg (1989, 1991) observed that a sharp wetting front slowly moves downward from the surface toward the base of the colluvium during November and December; colluvium dries from the surface downward in May. Haneberg (1989) also investigated the effectiveness of subsurface drains in reducing destabilizing pore pressures in thin colluvium. A mass-balance model indicates that downslope discharge from thin colluvium barely exceeds the long-term recharge due to precipitation; the slow discharge enables destabilizing pore pressures to build during large storms (Haneberg, 1992). Riestenberg (1987, 1992) investigated the ability of tree roots to anchor thin colluvium to steep slopes. The Earth Surface Processes Group (1987) investigated the extent of landslide damage to streets and condition of retaining walls in the City of Cincinnati; they made several recommendations for improving methods of monitoring damage to and planning for repair of streets and retaining walls, as well as methods for avoiding landslide problems in areas of new development. Bernknopf and others (1988) used a geographic information system (GIS) to perform probabilistic landslide hazard mapping and estimate the costs and benefits of mitigation. They found that the cost of mitigation was significantly less than the prevented losses only if mitigation was applied only to areas having relatively high probability of landslide damage. Probability of damage was based on topographic slope and shear strength of the surficial materials. Thus, the work of Bernknopf and others (1988) pointed out the need for data that accurately portray landslide susceptibility for areas of planned development. Behringer and Shakoor (1992) concluded, at five different sites, that human modification of slopes has aggravated movement.

STEPS TOWARD MITIGATION

During the 1970's and continuing into the present, people from the private sector have become significantly and increasingly involved in the mitigation of landslide problems. Beyond the involvement of students and faculty from the Geology and Civil Engineering Departments of the University of Cincinnati, engineers and geologists from private consulting companies have donated services to prepare draft grading regulations and to recommend strategies for damage reduction. Private foundations, including the Cincinnati Institute of E. Pope Coleman during the 1970's, and currently the Hillside Trust under the leadership of Robin Corathers, have worked toward thoughtful use of hillsides, including support for research on causes and controls of landslides. Some of these activities are discussed in the next section.

As landslide problems became more severe and information about landslides accumulated, Cincinnati and Hamilton County began to take action to reduce losses due to landslides. Work began in 1967 to draft an excavation and fill ordinance, but the work soon halted (R.E. Pohana, City of Cincinnati, written commun., 1992). The work resumed in 1972, and an ordinance was passed by the Cincinnati City Council on October 30, 1974, providing for plan review prior to issuance of a building permit and for inspection during construction. The Department of Public Works of the City of Cincinnati administered the ordinance until 1979, but enforcement was ineffective because Public Works had no field personnel to perform the inspections. In 1979, the ordinance was amended to transfer administration of the inspection and enforcement functions to the Department of Buildings and Inspections. In 1983, the ordinance was incorporated into the Cincinnati, Ohio, Basic Building Code, and the plan review function was transferred to the Department of Buildings and Inspections.

Following Cincinnati's adoption of the excavation and fill ordinance, work by two committees, the Earth Movement Task Force (1982) and the Earth Surface Processes Group (1987), largely determined subsequent actions by the city and county governments to mitigate landslide problems. These committees drew their members from city, county, and Federal agencies and the University of Cincinnati.

COMMITTEE RECOMMENDATIONS

The Earth Movement Task Force (1982) recommended three approaches for mitigating landslide hazards in developed and undeveloped parts of Hamilton County. (1) Collect background geologic information for Hamilton County. (2) Adopt and enforce procedures for avoiding landslide problems during development of new properties. (3) Develop and use procedures for dealing with landslide damage in previously developed areas. A summary of specific tasks for each approach follows:

Geological Base Data and Mapping. Obtain geological base data, including 1:24,000 scale mapping of bedrock and surficial deposits, and detailed engineering-geologic mapping of selected areas. Obtain additional research on landslides, including effects of tree roots on stabilization of shallow landslides, what controls the rate of sliding, locations of landslides that pose hazards to life, and the value of drainage in the stabilization of active landslides.

Landslide mitigation for undeveloped land. Develop, fund, and staff an earthwork regulation to provide review, evaluation, and permit issuance on all earthwork in Hamilton County. In connection with this, the Board of County Commissioners would direct the Regional Planning Commission to designate hillside areas in the county for which geologic and geotechnical investigation is required prior to design of development, approval of zone changes, or approval of subdivision plats. A geotechnical engineer and an engineering geologist working for the county (either as employees or as contractors) would assist with enforcement of the regulation, review reports, and maintain a data bank of information relevant to geotechnical problems in Hamilton County.

Landslide mitigation for developed land. Implement a public-information program. Seek modification of requirements for State and Federal disaster relief to include "slow-death" slides (slides that gradually destroy property over an extended period, rather than suddenly). Work for creation of federally backed landslide insurance. Seek authority from the State legislature to designate landslide-prone areas. Improve Cincinnati's excavation and fill ordinance. As Hamilton County develops methods for dealing with landslides, all jurisdictions within the county should be encouraged to adopt the methods and review developmental regulations in order to promote orderly development. Establish a geographic information system (GIS) for Cincinnati and Hamilton County to aid research and make possible a broader approach to mitigation. Form a long-term action group to study mitigation.

The Earth Surface Processes Group (1987) made the following recommendations to the Smale Infrastructure Commission for the City of Cincinnati: (1) The city should hire a geotechnical engineer and an engineering geologist to serve as consultants to other city agencies and to work to mitigate hazards in undeveloped areas by helping enforce the excavation and fill ordinance, reviewing engineering geologic and geotechnical engineering reports submitted to any city agency or department, and developing and maintaining a data base of geotechnical information relevant to problems likely to be encountered in undeveloped areas. The engineer and the geologist would also work in previously developed areas by (a) making and maintaining engineering-geologic maps and repair-priority maps (fig. 15*A*; table 2), (b) monitoring landslide problem areas and notifying appropriate city agencies about need for emergency repairs, (c) monitoring damage to utilities in landslide areas and notifying utility companies about impending damage, and (d) studying records of utility repairs, if feasible, to determine whether landslide damage can be forecast (fig. 16). (2) Make annual contributions to landslide emergency repair fund; the amount is to be based on the current average cost of emergency repairs. (3) Provide for one-time inspection, by trained personnel, of all city-owned retaining walls and follow-up yearly inspections on a 5-yr cycle. (4) Establish a geotechnical advisory committee to aid in the search for a competent geotechnical engineer and an engineering geologist, recommend how the geotechnical group should be placed in the city, advise the geotechnical group and help it clarify its duties, annually review the work of geotechnical staff for 5 yr, help the geotechnical group to recommend changes to the excavation and fill ordinance. (5) Require geotechnical investigation prior to development of hillside areas.

IMPLEMENTATION

Cincinnati and Hamilton County have implemented a number of these recommendations. In particular, Cincinnati adopted most of the recommendations of the Earth Surface Processes Group (1987). The City of Cincinnati created its Geotechnical Office within the Department of Public Works and hired a geotechnical engineer, an engineering geologist, and two technicians in August 1989. Pohana (1992a) outlined the six major responsibilities of the Geotechnical Office: (1) To provide geotechnical expertise for prevention and stabilization of landslides on property controlled by the city, (2) To compile geological information in a computerized data base, (3) To make detailed engineering-geologic maps and relative stability maps of selected parts of the city and add that information to the city's data base, (4) To inspect and inventory all retaining walls in the city that impact the public right-of-way, (5) To provide technical assistance to other departments and divisions of the city government (including review of proposed development within the city's Environmental Quality Hillside Districts), (6) To respond to questions from the public about slope stability. By the spring of 1992, the geotechnical staff had inspected sites of known slope movement and selected 40 of them for monitoring and repairs over a period of 6 yr. Nine of the sites were repaired soon after selection. The staff had also started compiling an automated data base; by reviewing city files they had identified nearly 500 areas of suspected landslide activity for eventual inspection and inclusion in the data base. They had completed engineering-geologic maps and relative-stability maps for one area and part of another area of the city and directed inspection of retaining walls throughout the city. Also, they had reviewed many proposed construction projects and provided other services to the city (Pohana, 1992a). The increased attention to landslides is evident in the city's expenditures: Cincinnati spent $1.3 million for landslide repairs from 1983 to 1987, $7.5 million from 1988 to 1992, and projected spending from 1993 to 1997 is $8.5 million (Pohana, 1992b).

To reduce the damage from landslides caused by new construction, Hamilton County adopted earthwork regulations (an excavation and fill ordinance) November 1, 1992. The Hamilton County Department of Public Works administers the regulations, which require plan review and periodic inspections during the progress of earthwork operations. The Hamilton County Division of Engineering has been responsible since 1960 (or perhaps earlier) for landslide repairs in the public right-of-way; the county spends about $0.5–$1 million to repair an average of four landslides annually (Steve Mary, Hamilton County Division of Engineering,

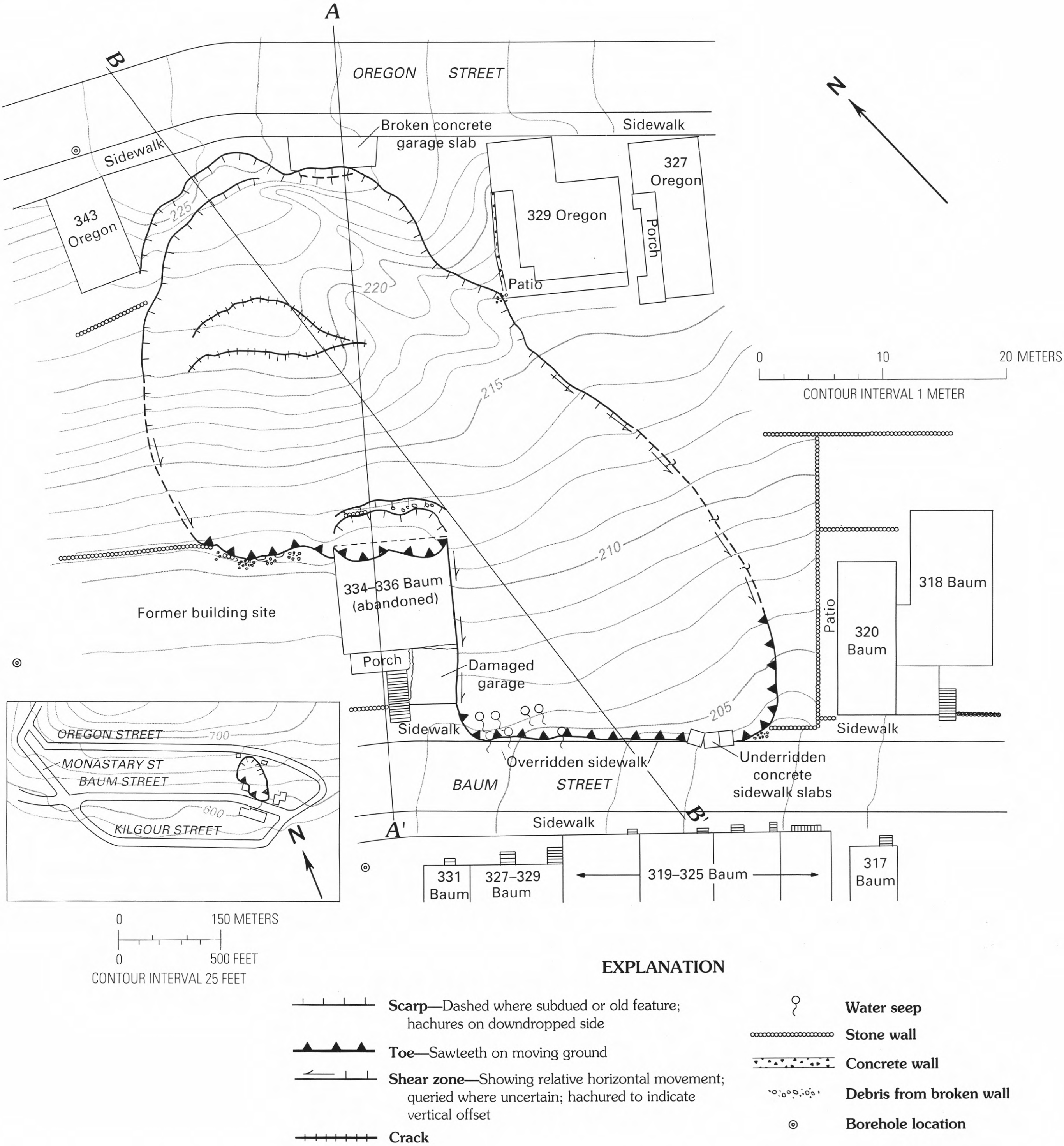
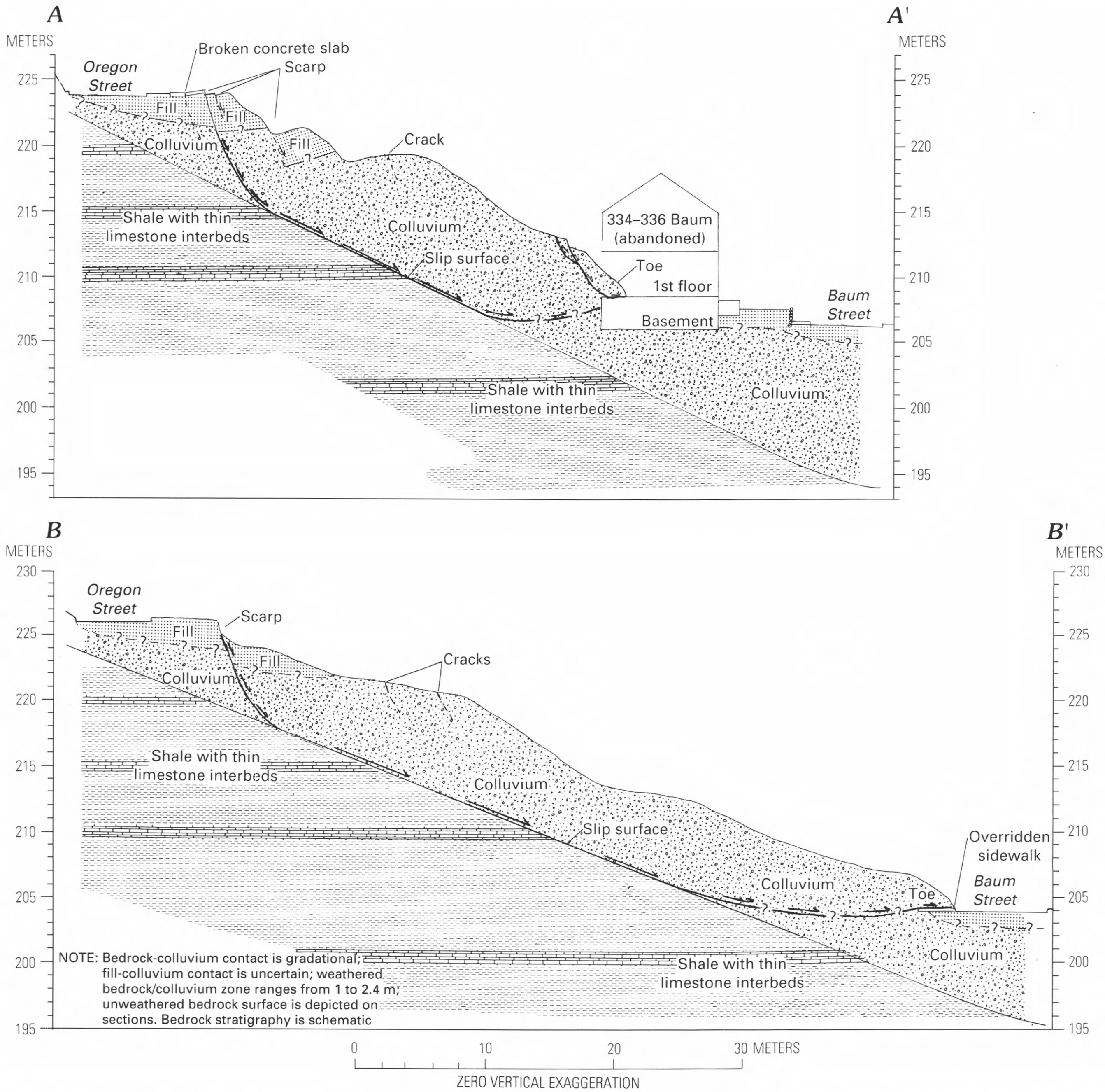


Figure 9 (above and facing page). Plane-table map of the Oregon Street and Baum Street landslide in Mount Adams, by N.B. Patterson and K.A. Richards, University of Cincinnati, spring 1981 (modified from Richards, 1982, pl. 3). Map contours defined by arbitrary datum on Baum Street; index map datum is mean sea level. Buildings, steps, sidewalks, and walls are schematic.

oral commun., 1993). The Division of Engineering relies on the street department, maintenance crews, and the general public to report landslides needing correction and uses local consultants to perform geotechnical investigations of individual landslides needing repair.

Work has also proceeded on other recommendations of the Earth Movement Task Force. The background geologic data became available toward the end of the 1980's as the Ohio Geological Survey completed bedrock and glacial geologic mapping of Hamilton County (Swinford, 1986;



Brockman, 1986, and oral commun., 1993) and some of the proposed research projects have been completed (Riestenberg, 1987; Haneberg, 1989). By 1990, work was started to create a geographic information system covering all of Hamilton County; aerial photographs for topographic data were made in the spring of 1990 (R. E. Pohana, City of Cincinnati, written commun., 1992).

Overall the city of Cincinnati and Hamilton County, in conjunction with the general public and the geotechnical community, have combined in a major effort to reduce the damages from landslides. Experience in other areas, notably the City of Los Angeles (Fleming and Taylor, 1980) reveals that these efforts will be successful. The most visible successes should be in the quality of new construction where grading is performed under strong regulations with inspection of plans and grading by the technical staff from the city and county. The pieces are in place with the enthusiastic involvement of both the public and private sectors to achieve major gains in landslide-damage reduction.

OVERVIEW OF CHAPTERS IN THIS SERIES

This bulletin series contains four chapters in addition to this overview and introduction. Fleming and Johnson (1994)

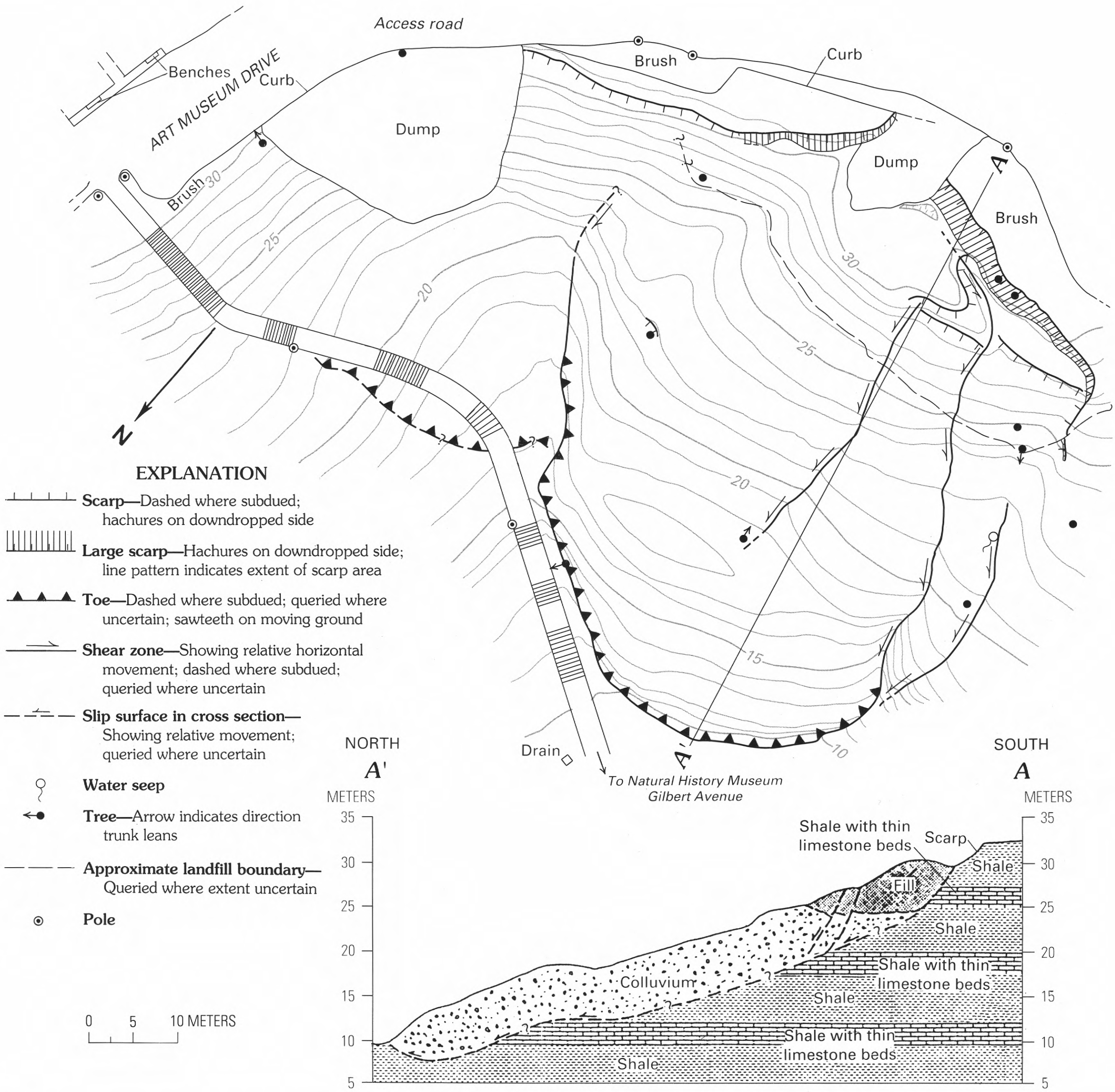


Figure 10. Plane-table map of the Eden Park landslide, by R.G. Hummeldorf and E.F. Robinson, University of Cincinnati, spring 1982 (after Richards, 1982, pl. 5). Contour interval 1 meter (arbitrary datum). Cross section scale in meters. Bedrock stratigraphy in cross section is schematic.

described typical landslides in thin and thick colluvium, the most common types in the Cincinnati area. Their field investigation focused primarily on the causes of the landslides. Detailed trench logs depict the internal structure of one of these landslides, which consists of several blocks that rest on an irregular slip surface; the blocks are bounded by listric faults. Observations of movement and ground water indicate differing behavior of water in thin and thick colluvium. Water levels appear to rise rapidly as rainfall soaks into thin colluvium following spring storms. Water levels in thick colluvium and in bedrock beneath thick colluvium or glacial deposits seem to vary on an annual cycle. Thick colluvium appears to be capable of sliding even when only partially saturated, and some water may enter thick colluvium by lateral flow from bedrock. Measured properties and residual shear strength of colluvium seem consistent with failure of the thick landslides, but appear to be too low to explain how thin colluvium remains on steeper slopes. Observations indicate that tree roots, residual cohesion, soil suction (negative pore pressure), and roughness of the potential slip surfaces are possible sources of additional sliding resistance needed to keep the thin colluvium on the slopes.

Fleming and Johnson's (1994) observations raised several questions about the mechanics of landslides in thin colluvium, and students from the University of Cincinnati investigated some of these questions. The rapid water-level fluctuations observed in thin colluvium following rain storms required explanation. Haneberg and Gökce (1994) have analyzed this problem to determine the relationship between rainfall infiltration and the fluctuations. The presence of confined ground water in limestone layers of bedrock seemed to indicate that pressurized ground water might exert significant buoyant pressure at the base of the colluvium (Fleming and others, 1981; Fleming and Johnson, 1994). Baum's (1994) analysis indicates that the limestone layers determine the distribution of pressure at the base of the colluvium but the factor of safety is almost the same as if water flowed parallel to the slope. Artesian pressure in a limestone bed disperses within a short distance after flowing from the bed into the colluvium. Residual shear strength of the colluvium appears inadequate to explain how colluvium remains on steep slopes. Riestenberg (1994) investigated the ability of tree roots to anchor thin colluvium on slopes. She found that roots can effectively anchor thin colluvium on steep slopes and that anchoring ability of a tree species depends on its root system. White ash has a dominant tap root that can anchor colluvium as thick as 1 m, but sugar maple has shallow roots that can anchor colluvium only 0.5 m thick.

Several subjects still need detailed investigation. An inventory of landslides, achieved by mapping the entire metropolitan area at a scale of 1:24,000, would constitute a rational starting point for studying landslide susceptibility. An inventory is in progress within the Cincinnati city limits (Pohana, 1992a). By combining inventory data with geologic, topographic, and other data, a study of susceptibility in the context of surficial materials, slope, and other parameters significant to slope stability would be possible. Results of such study could be used to identify areas needing detailed investigation prior to development. Monitoring of ground movement and subsurface water on a short time interval (15–30 minutes) at different levels in thick and thin colluvium could clarify the details of ground-water movement in Cincinnati hillsides and the role of water in failure of the colluvium. The actual subsurface water conditions at the time of movement of existing slides has yet to be documented. Monitoring in progress by the City of Cincinnati is aimed at determining whether landslides can be stabilized economically by dewatering (Pohana, 1992b). Additional trenching and detailed subsurface investigation of landslides in thin colluvium combined with the movement and water data would form a basis for determining the relative amounts of sliding resistance contributed by various sources, including shear strength of the soil, roots, and roughness of the slip surface. Ultimately, information from studies such as these will lead to improved construction practices in sloping areas and better methods of landslide repair. A field study of rapid earth flow ("mudslides") might aid in design of measures to contain or divert these slope failures away from major roads to areas where they pose no serious threat. Although the formation of small earth flows on cut slopes seems fairly well understood (Pohana, 1983), study is needed to determine what causes some landslides in thin colluvium to become rapid earth flows.

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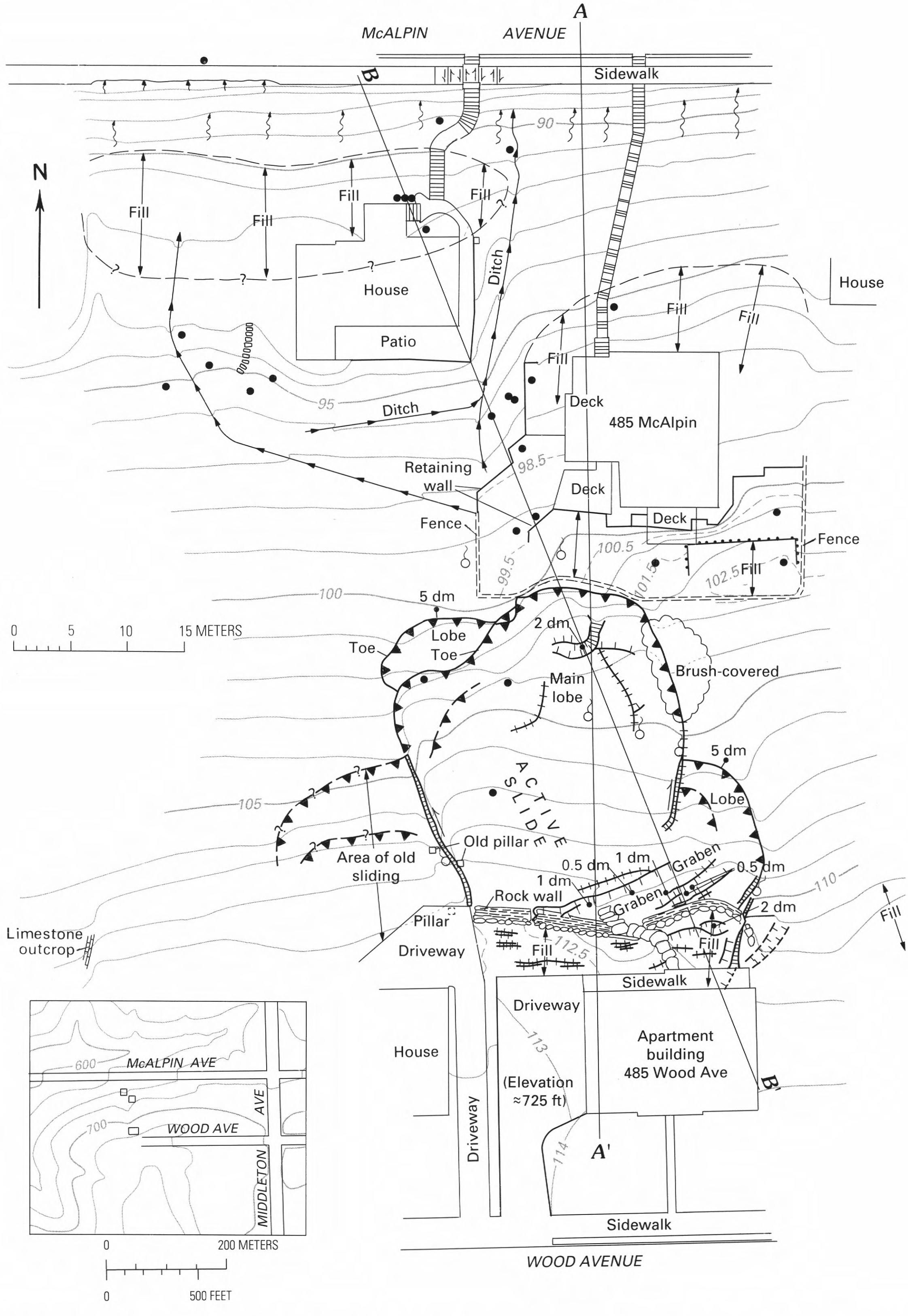
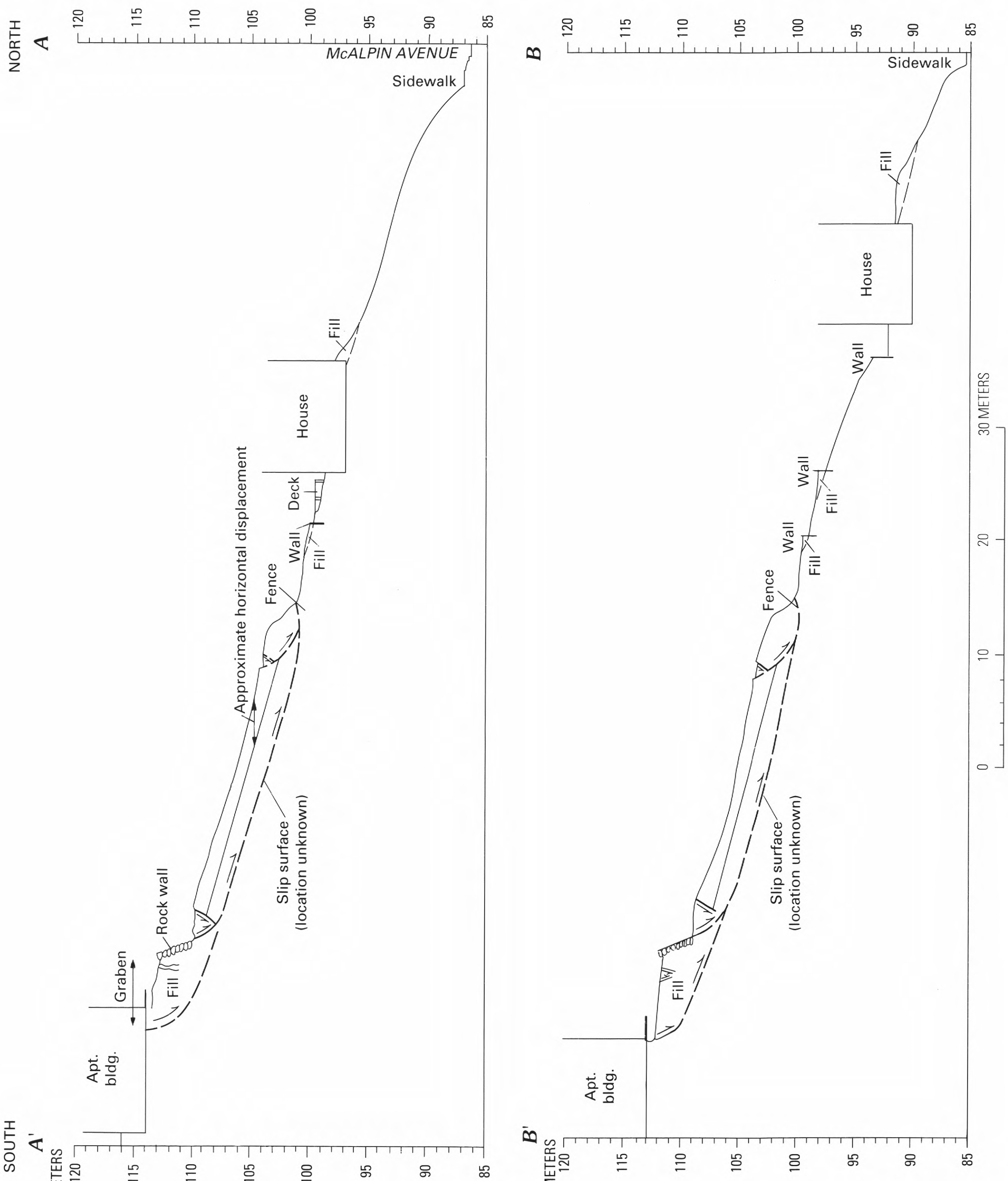


Figure 11 (above and facing page). Plane-table map of a landslide between Wood Avenue and McAlpin Avenue, by Arvid Johnson, University of Cincinnati, April 1980. Contour interval 1 meter (arbitrary datum); intermediate contours dashed; approximate contours dotted. Dashed outline for fill, queried where extent uncertain. Buildings, steps, rock wall, and sidewalks are schematic. Inset map contour interval 25 feet (datum is mean sea level).



EXPLANATION

2 dm

Scarp—Dashed where subdued or old; hachures on downdropped side; bar and ball show and locate amount of vertical offset, in decimeters

Toe—Dashed where subdued or old; queried where uncertain; sawteeth on moving ground; bar and ball show and locate height of toe, in decimeters

Shear zone—Showing relative horizontal movement

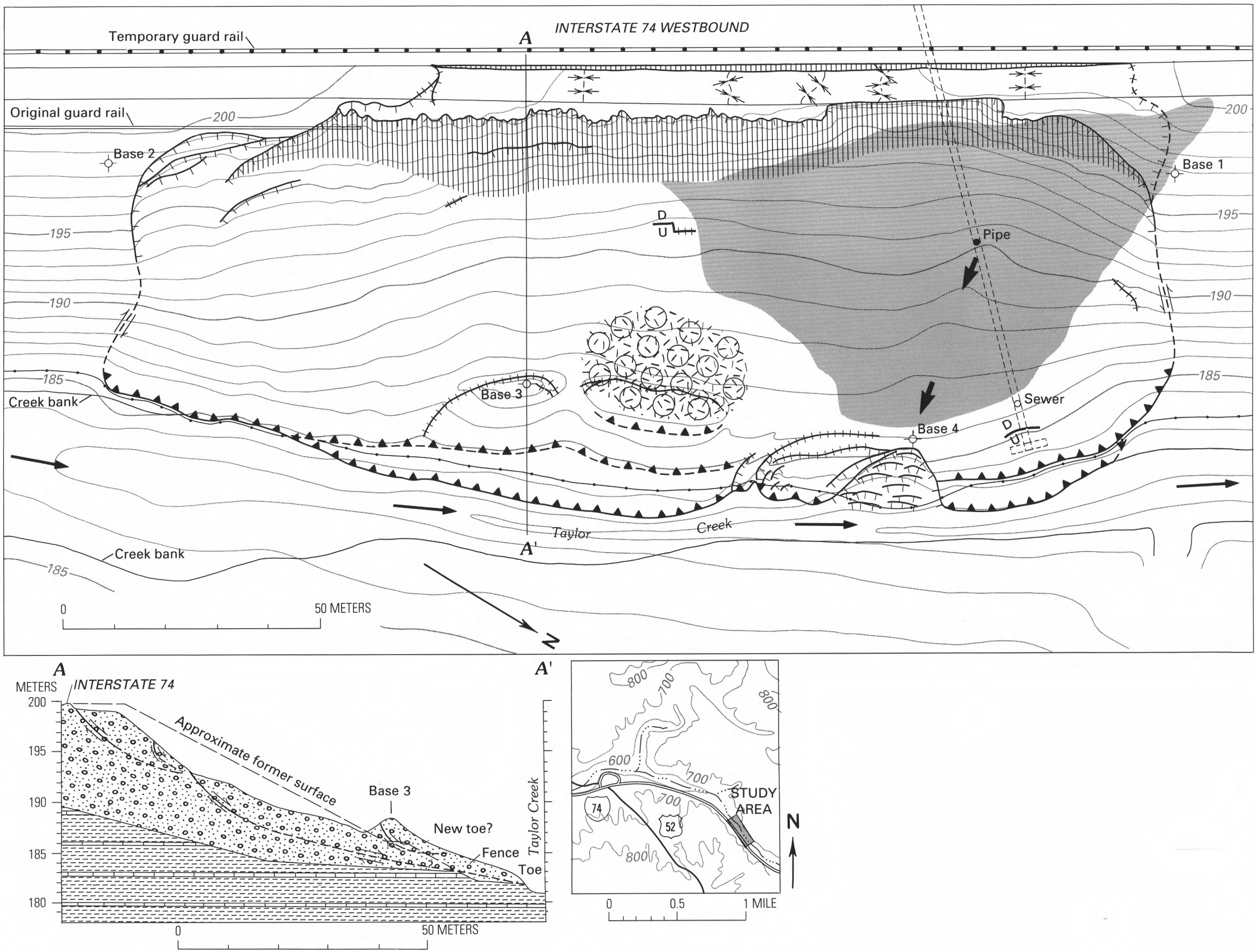
Wide crack or graben

Narrow crack

Area of soil creep or incipient sliding

Water seep

Tree


INTERSTATE 74 WESTBOUND
Temporary guard rail
A
Original guard rail
200
Base 2
Base 1
195
D
U
Pipe
190
185
Creek bank
Base 3
Sewer
Base 4
Taylor
Creek
A'
Creek bank
185
0
50 METERS
N
A
A'
METERS
INTERSTATE 74
200
195
190
185
180
Approximate former surface
Base 3
New toe?
Fence
Toe
Taylor Creek
0
50 METERS
800
700
800
600
700
700
STUDY AREA
74
52
800
N
0
0.5
1 MILE

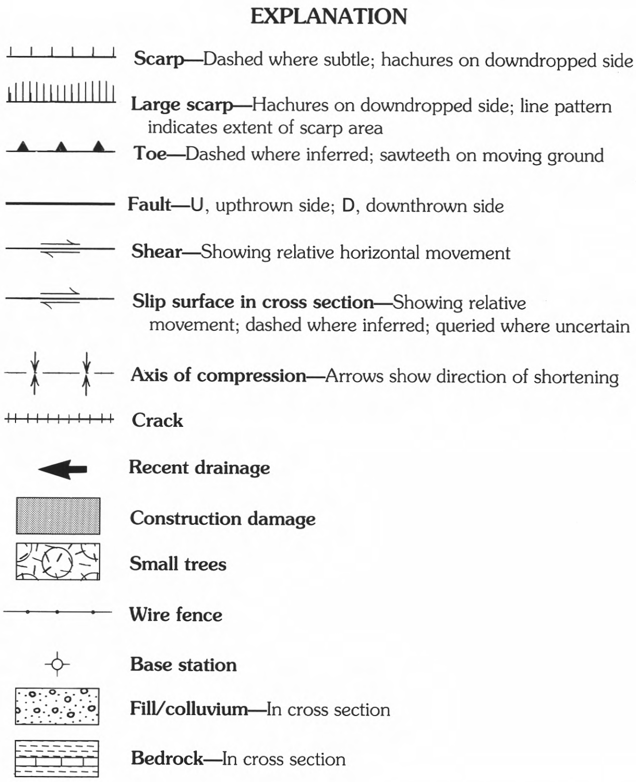


Figure 12 (above and facing page). Plane-table map of the Taylor Creek landslide next to I-74 by Reginald Victor, Jr., Jonathan Woods, and David Lubinski, University of Cincinnati, spring 1987. Contour interval 1 meter (arbitrary datum). Cross section vertical scale in meters; vertical exaggeration ×2. Bedrock stratigraphy in cross section is schematic. Index map contour interval 100 feet.

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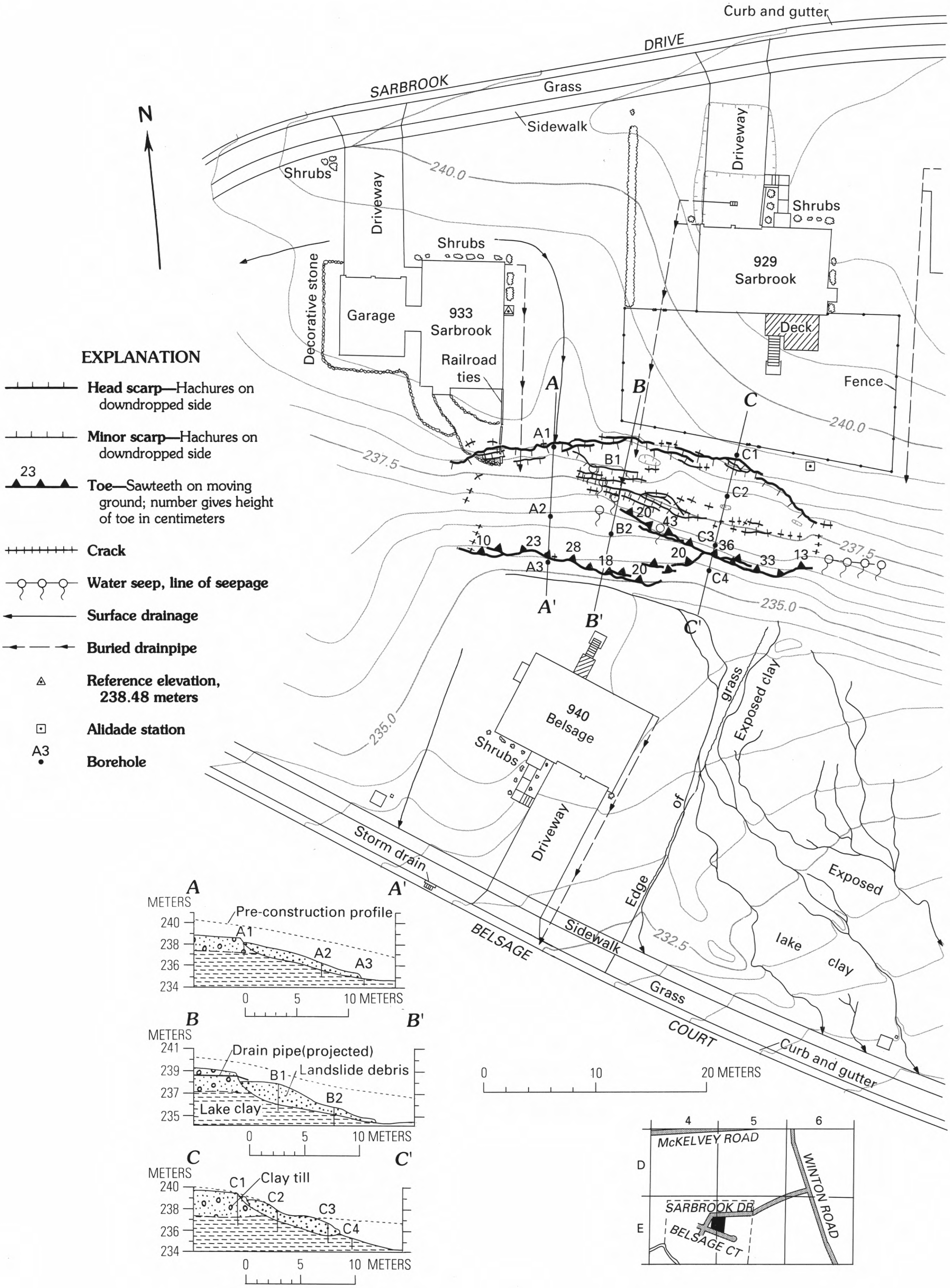
Figure 13 (overleaf). Plane-table map of the Partridge Hills landslide, a block glide in till and lake clay, by Thomas Lion and Paul Rauf, University of Cincinnati, spring 1981 (modified from Lion, 1983, p. 112). Contour interval 0.5 meter (arbitrary datum); contours hachured in closed depression. Cross section vertical scale in meters.


Curb and gutter
SARBROOK
DRIVE
Grass
Sidewalk
N
Shrubs
240.0
Driveway
Shrubs
Driveway
Shrubs
929
Sarbrook
Decorative stone
Garage
933
Sarbrook
Deck
Railroad
ties
Fence
A
B
C
240.0
A1
B1
C1
237.5
C2
A2
20
43
B2
C3
36
237.5
10
23
28
20
33
13
18
A3
20
C4
A'
B'
C'
235.0
grass
Exposed clay
940
Belsage
235.0
Shrubs
of
Driveway
Storm drain
Edge
Exposed
lake
clay
Sidewalk
232.5
BELSAGE
Grass
COURT
Curb and gutter
0
10
20 METERS
EXPLANATION
Head scarp—Hachures on downdropped side
Minor scarp—Hachures on downdropped side
23
Toe—Sawteeth on moving ground; number gives height of toe in centimeters
Crack
Water seep, line of seepage
Surface drainage
Buried drainpipe
Reference elevation, 238.48 meters
Alidade station
A3
Borehole
A
A'
METERS
Pre-construction profile
240
238
236
234
A1
A2
A3
0
5
10 METERS
B
B'
METERS
241
239
237
235
Drain pipe(projected)
B1
Landslide debris
Lake clay
B2
0
5
10 METERS
C
C'
METERS
240
238
236
234
C1
Clay till
C2
C3
C4
0
5
10 METERS
4
5
6
McKELVEY ROAD
D
E
SARBROOK DR
BELSAGE CT
WINTON ROAD

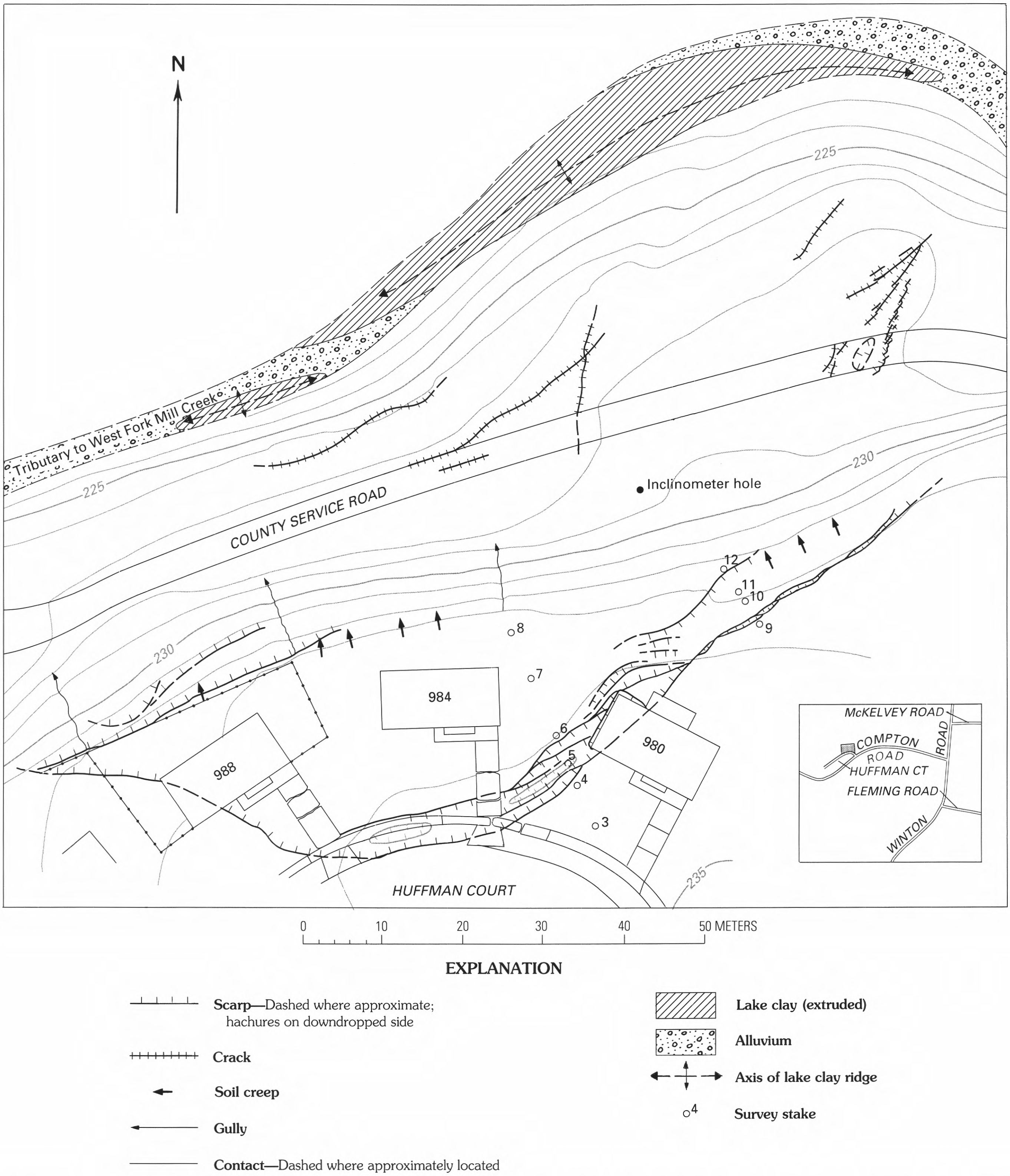


Figure 14. Plane-table map of a block-extrusion glide in till and lake clay at 980, 984, and 988 Huffman Court, by A. Önder Gökce, University of Cincinnati, spring 1980. Contour interval 1 meter (arbitrary datum); contours hachured in closed depression.

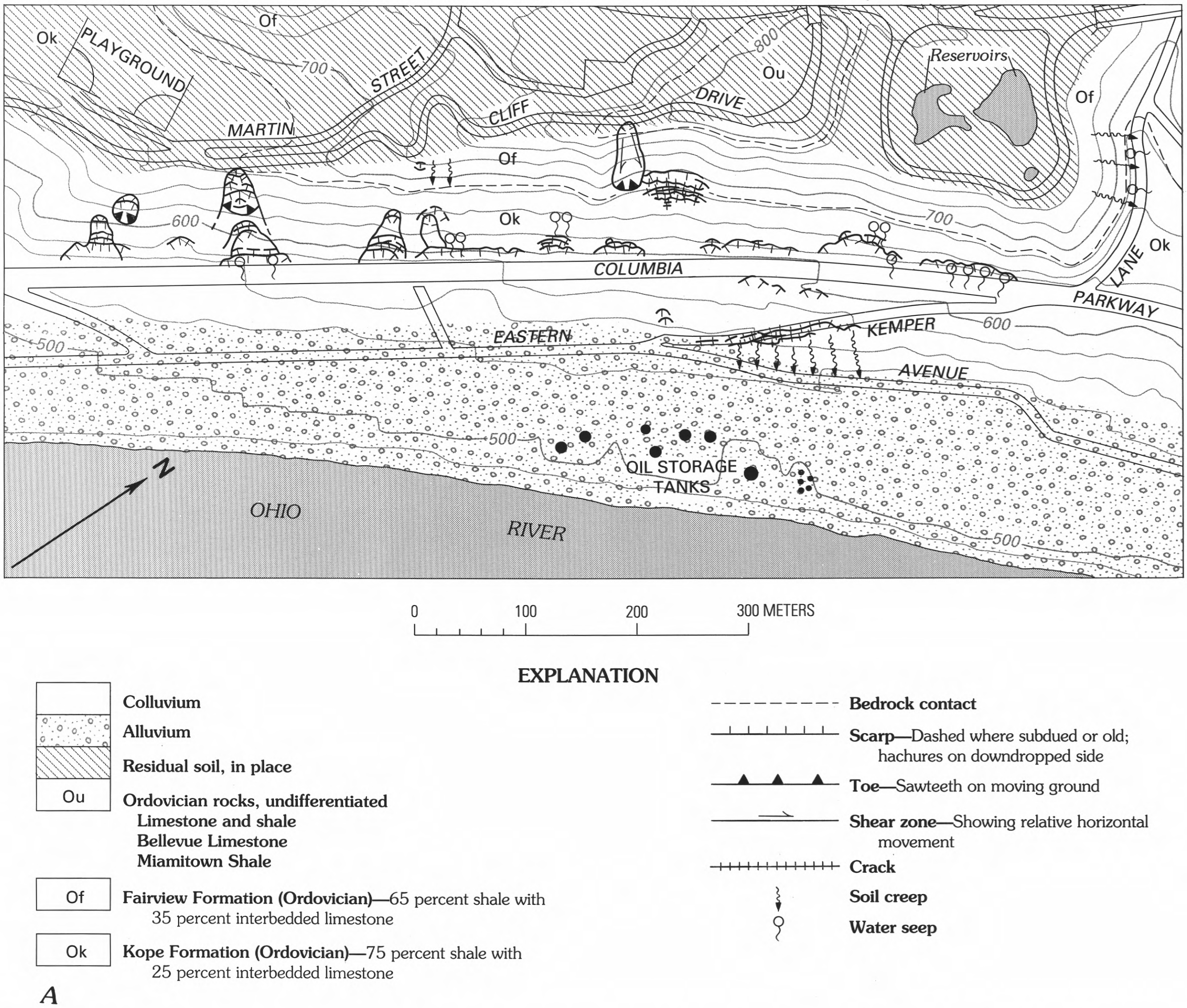


Figure 15 (above and facing page). Example of maps produced by students at the University of Cincinnati. Contour interval 25 feet (about 7.6 meters; datum is mean sea level). Base from City of Cincinnati topographic map series. *A*, Engineering geologic map of part of Mount Adams (modified from Richards, 1982, pl. 1). All fresh and subdued landslide features are depicted (as of 1982). Some areas of active and past movement, however, exhibited no mappable features; such areas are shown on the relative stability map (*B*). *B*, Relative stability map of part of Mount Adams (modified from Richards, 1982, pl. 2). Active deep-seated landsliding not shown on this part of map view but retained in explanation for completeness.

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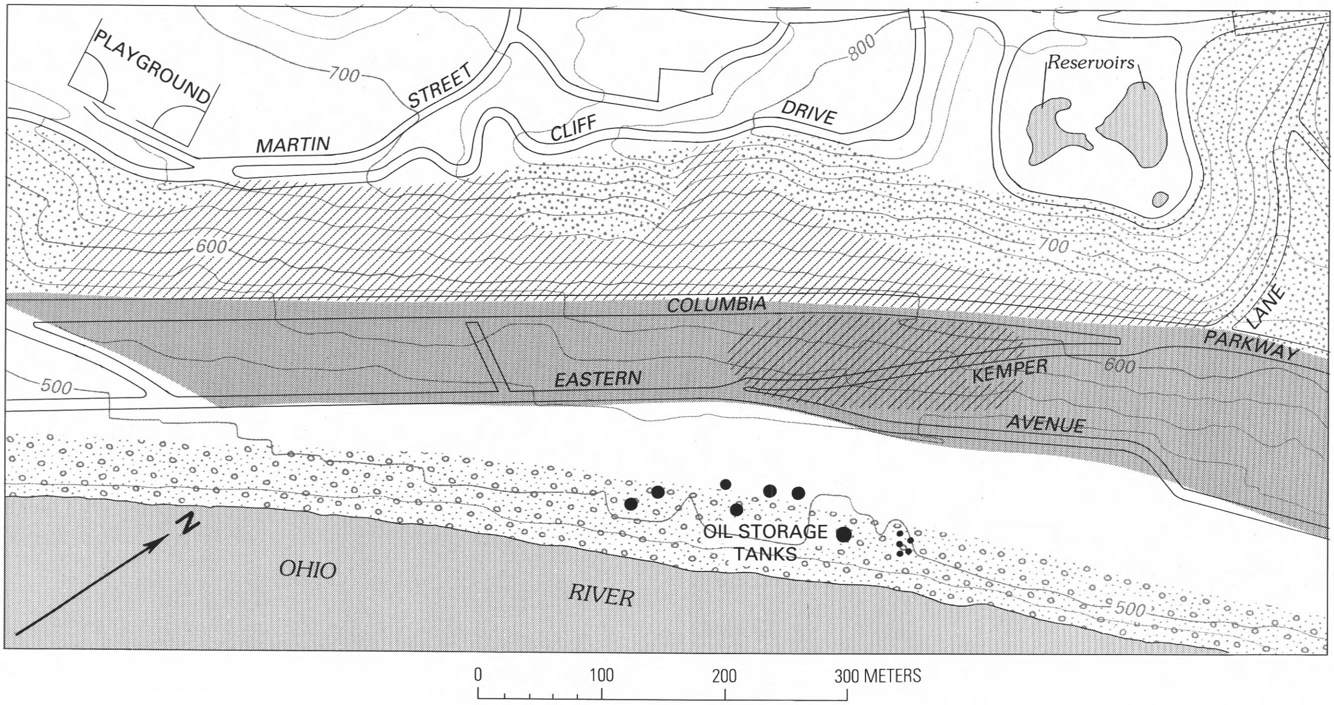

EXPLANATION

TYPE OF MOVEMENT, MATERIAL, OR SLOPE	FURTHER INVESTIGATION REQUIRED OR RESTRICTION OF LAND USE
STABLE GROUND	
Stable gentle hillside	Place entire weight of structure on bedrock or have geotechnical engineer determine type of foundation.
Stable steep hillside	Geotechnical engineer should design foundation and slope modifications.
POTENTIALLY UNSTABLE GROUND	
Potential for shallow-seated landsliding	Geotechnical engineer in cooperation with engineering geologist should be consulted concerning location and design of structures and slope modification.
Potential for deep-seated landsliding	Extreme caution should be exercised–develop *only* with guidance of engineering geologist and geotechnical engineer.
Artificial fill of questionable stability	Engineering geologist and geotechnical engineer should investigate and evaluate potential instability.
MOVING GROUND	
Active shallow-seated landsliding	Moving material must be removed or stabilized prior to development. Geotechnical engineer in cooperation with engineering geologist should be consulted concerning stabilization, and location and design of structures.
Active deep-seated landsliding (none shown in this view)	Develop with extreme care with guidance of engineering geologist and geotechnical engineer. Development should be allowed *only* if ground is stabilized prior to construction.

NOTE: Shallow-seated is defined as slip surface 5 feet or less from ground surface. Similarly, deep-seated is defined as slip surface greater than 5 feet from ground surface.

B

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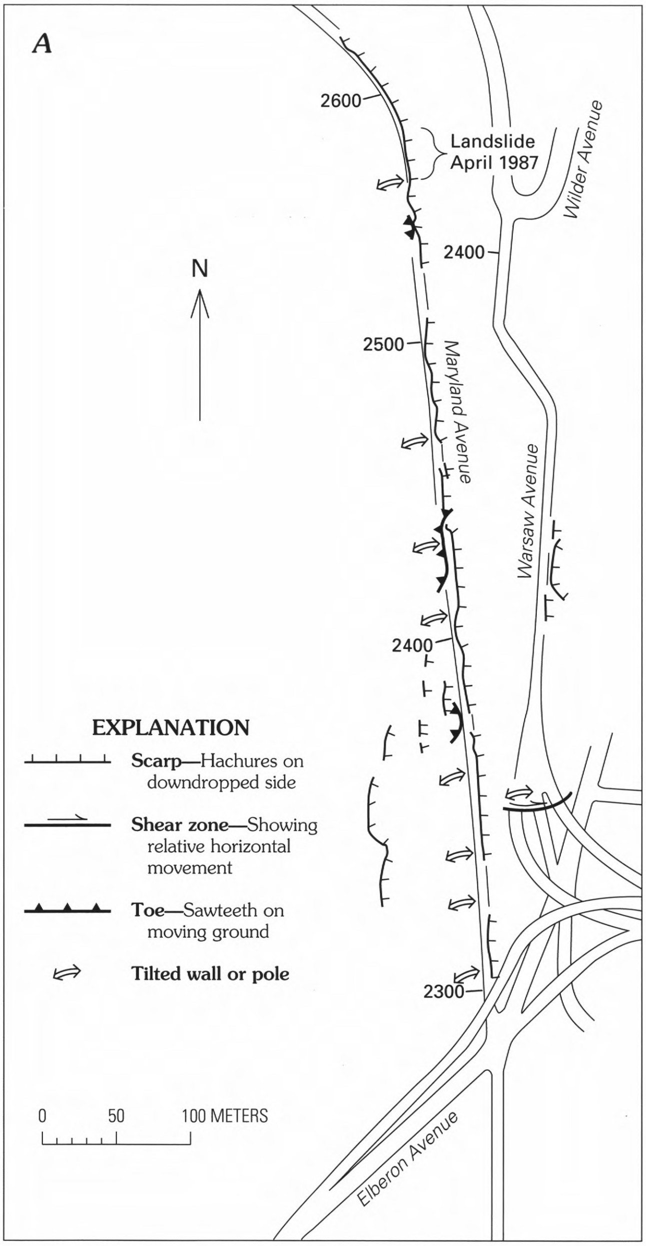

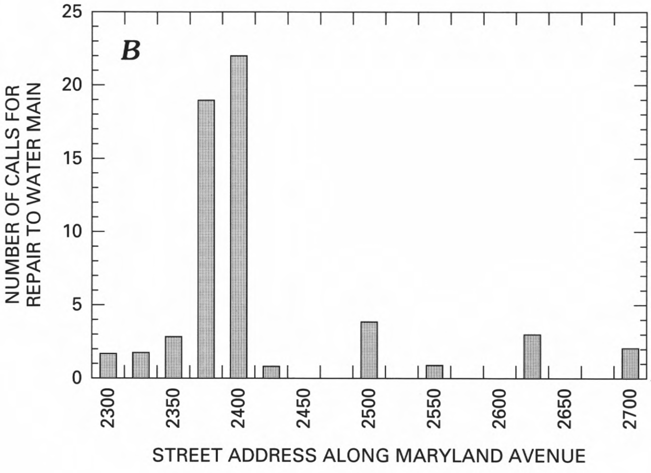

Table 2. Characteristics of maps proposed for mitigation of landslide damage in developed areas of Cincinnati, Ohio (Earth Surface Processes Group, 1987).

Map	Map units
ENGINEERING GEOLOGIC MAP (product of field investigation, scale about 1:2,400).	Surficial deposits of man-made fill. Man-made excavations. Bedrock units. Glacial deposits. Colluvium. Landslide deposits. Landslide features (scarps, toes, cracks, lateral shears). Boundaries of individual landslides. Boreholes.
LANDSLIDE INTERSECTION MAP (product resulting from overlay of engineering geologic map and maps of water and sewer lines).	Locations where lateral shears, heads, and toes cross alignments of water mains, sewer lines, and other sources of subsurface water.
REPAIR PRIORITY MAP (product of interpreting engineering geologic map, landslide intersection map, and potential economic/social impact of damage from individual landslides).	**Priority one**: Emergency repairs required. Landslide damage is so severe or is developing so rapidly that it must be repaired to protect the public health or safety. **Priority two**: Geotechnical study needed now. Emergency repairs probably required within a few years. Shallow[1] landslides that will disrupt water or sewer lines. Deep landslides that will disrupt water or sewer lines or that are damaging critical facilities. **Priority three**: Geotechnical study required within a few years. Emergency repaires probably required within a few tens of years. Shallow landslides that involve no man-made water sources. Deep landslides that do not intersect man-made water sources and are not damaging critical facilities. **Priority four**: Stable ground. No evidence of sliding of the street.

[1]Shallow landslides are less than 2 m thick.

Figure 16. Landslide damage and number of calls for repair of water mains by address along Maryland Avenue (modified from Earth Surface Processes Group, 1987). *A*, Landslide features along Maryland Avenue on March 28, 1987, mapped by faculty and students of the University of Cincinnati Department of Geology. Numbers are street addresses. A landslide that moved abruptly and caused the street to be closed occurred in April 1987 near 2600 Maryland Avenue. A large landslide that is damaging the ramps to the Sixth Street Viaduct appears to be between 2350 and 2400 Maryland Avenue. *B*, Total number of calls for repair of water main by address from 1931 to 1987. Many breaks between 2350 and 2400 Maryland Avenue appear to coincide with the landslide damaging the ramps to the Sixth Street Viaduct. No breaks occurred near 2600 before the abrupt movement in April 1987.

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Baum and Johnson—OVERVIEW OF LANDSLIDE PROBLEMS, RESEARCH, AND MITIGATION, CINCINNATI, OHIO, AREA—U.S. Geological Survey Bulletin 2059–A