GUIDEBOOK NO. 9

CINCINNATI'S GEOLOGIC ENVIRONMENT: A TRIP FOR SECONDARY-SCHOOL SCIENCE TEACHERS

by

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and
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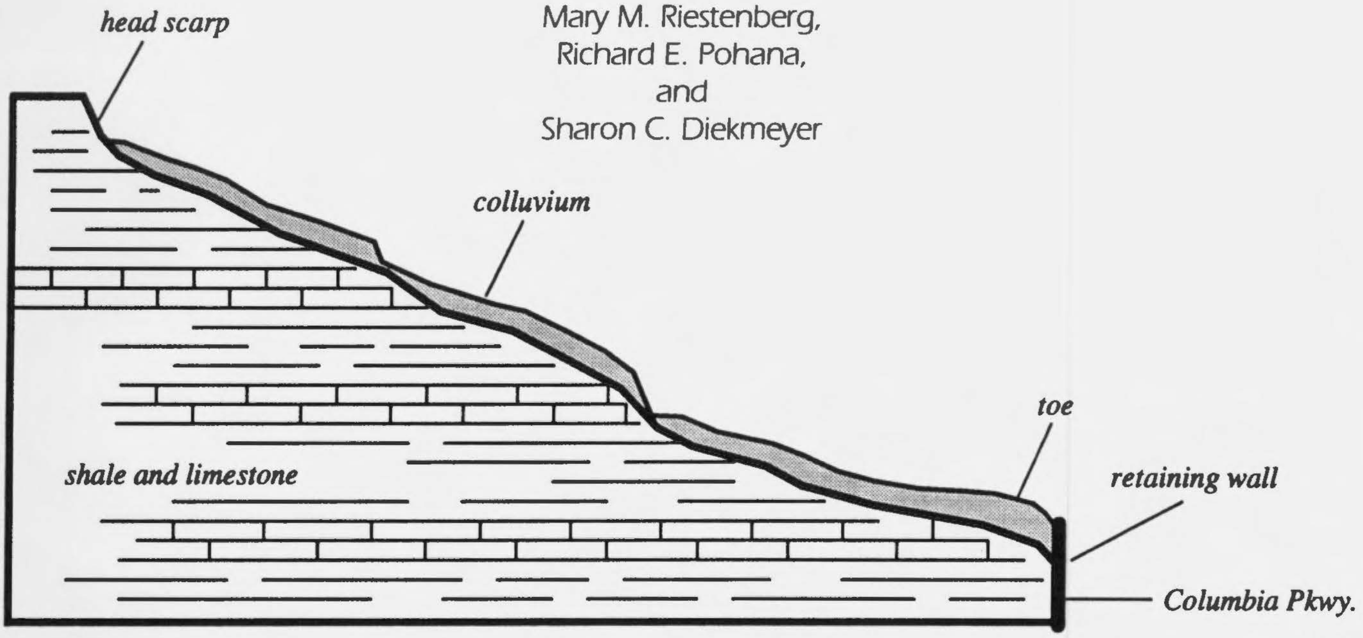

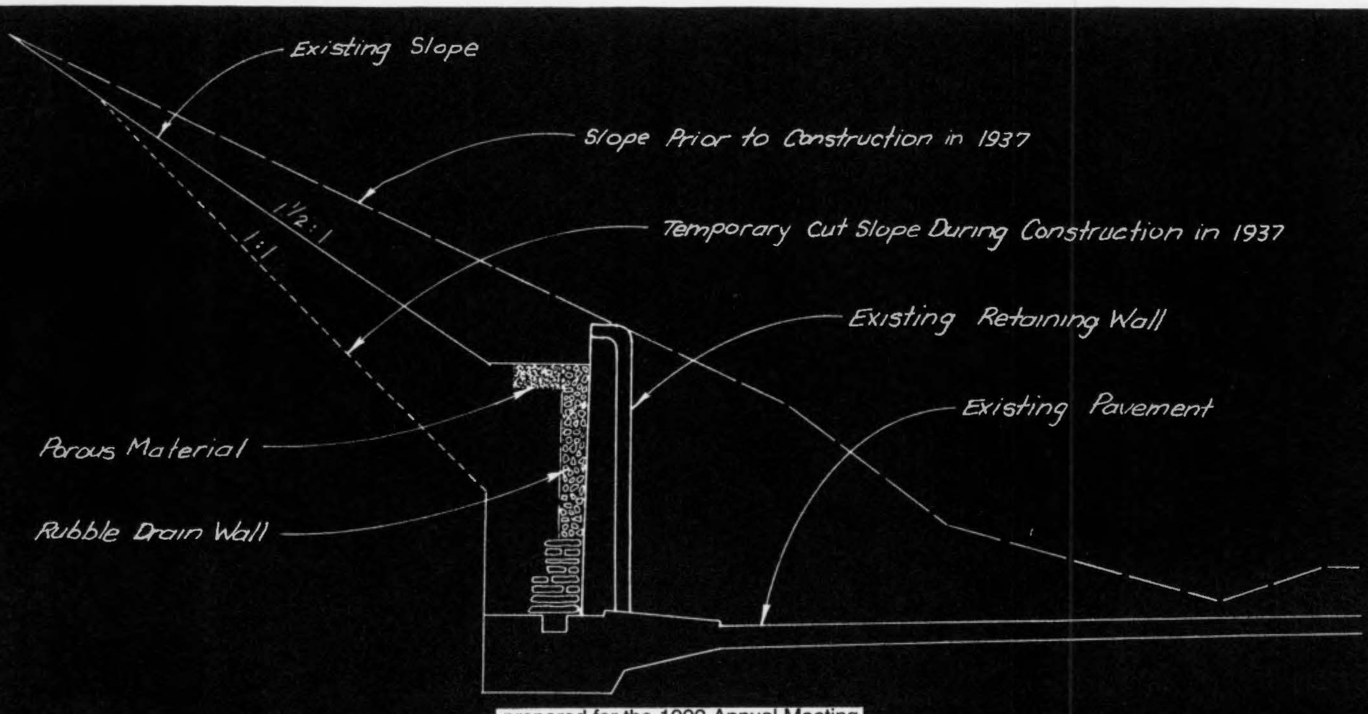

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INTRODUCTION

The influence of geology on everyday life is inescapable. Roads and buildings are constructed on rock and soil, water is pumped from the ground, and trash is buried beneath the Earth's surface. The development of soils, some of which are more suitable for agriculture than are others, is controlled in large part by geologic factors. Mineral and energy resources, essential to modern civilization, lie beneath the surface of the Earth.

In order to emphasize the impact of geology on human activities, the Engineering Geology Division of the Geological Society of America is sponsoring a one-day field excursion for secondary-school science teachers as part of the Society's 1992 annual meeting in Cincinnati. This trip is designed to give teachers an introduction to the impacts of geologic factors on people living and working in the Cincinnati area. Although little or no previous exposure to geology is presumed, a list of professional-level references is included for those who wish to pursue any of the topics in depth.

Engineering geology is the use of geologic principles to understand and predict the the occurrence of surface and subsurface geologic conditions that affect human activities. In recent years, the term "environmental geology" has come into vogue to describe much of the work traditionally done by engineering geologists. Engineering geologists are involved in many kinds of projects, including the siting of landfills and hazardous-waste facilities; studies of ground-water and soil contamination; foundation investigations; geologic hazards investigations (for example, landslides, debris flows, floods, earthquakes, and land subsidence); and the discovery of construction materials such as sand, gravel, and clay.

A person could spend a lifetime studying the geology of Cincinnati, and many have. We can devote only one day to the subject. The stops described in this guidebook were chosen to provide a broad overview of Cincinnati's geologic history and the effects of modern-day geologic processes on human activity. We will dedicate several stops to Cincinnati's geologic past. Although the study of ancient seas and glaciers is fascinating in and of itself, the rock and soil formed as the result of ancient processes also has an effect on the way Cincinnatians live and work. Other stops will focus on ground-water resources, as well as the costly combination of landslides and human ignorance.

This guidebook was written by four geologists with different interests and expertise, so you will find the tone and scope of each section a little different. Some sections concentrate on the pragmatic and economic aspects of geology, whereas others are devoted to more academic topics. We hope that this diversity will help to illustrate the breadth of geological research and practice. Much of the trip involves landslides, for two reasons. First, three of us are interested in slope instability in general and the landslides of Cincinnati in particular. Second, landsliding is a significant geological process and an economic headache throughout the area.

The field-trip route is illustrated in figure 1 and also on the back cover. After leaving downtown Cincinnati, we will follow Columbia Parkway along the Ohio River valley east of the city, where stops will focus on landslides, ground-water resources, and geologically young deposits. Then, we will cross the Ohio River into Kentucky via I-275 on the way to a well-exposed outcrop of fossiliferous limestone and shale. Finally, we will cross the Ohio River back into Ohio to examine an intensively studied landslide complex along Delhi Pike, in the far western part of Cincinnati. This loop can be easily completed in one day, including time for photography, fossil collecting, and questions.

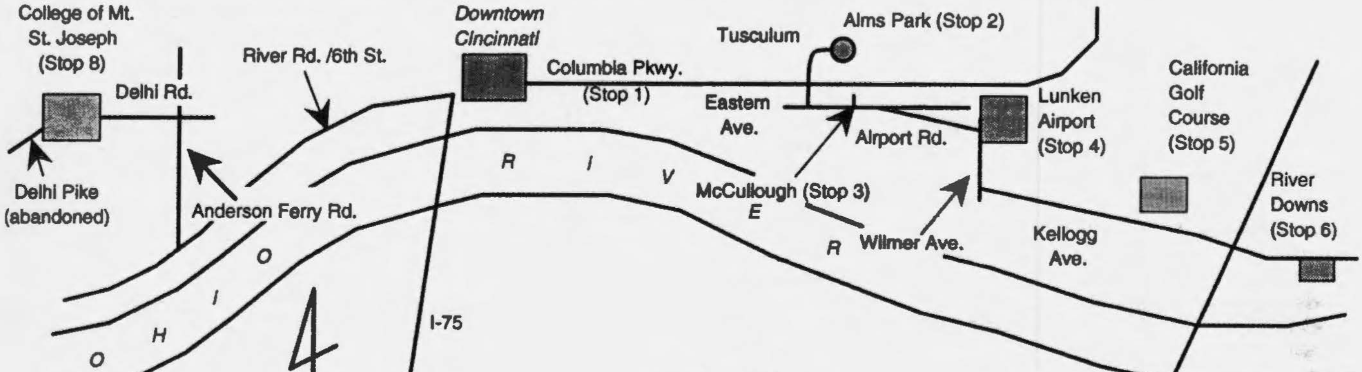

FIGURE 1.—Map of field-trip route, showing scheduled stops (not to scale).

The field-trip stops are listed below. Geologic descriptions of the eight stops are provided in a series of five short papers that follow (two of the papers pertain to more than one stop each).

STOP #1. Columbia Parkway at Tusculum Avenue. Examine a pier wall constructed to stabilize the sliding hillside.

STOP #2. Alms Park overlook of Little Miami and Ohio River valleys. Observe the course of the pre-Illinoian Deep Stage River and physiographic setting of the Little Miami valley-fill aquifer.

STOP #3. McCullough Avenue at Columbia Parkway. Examine a pier wall constructed to stabilize the sliding hillside.

STOP #4. Lunken Airport. Discuss flow and occurrence of ground water, as well as subsurface stratigraphy of the Little Miami alluvial aquifer.

STOP #5. California Golf Course. Examine a Pleistocene depositional terrace.

STOP #6. River Downs. Inspect exposures of Pleistocene terrace sands and gravels.

STOP #7. Riedlin Road/Mason Road (Kentucky). Examine Upper Ordovician shale and limestone sequences, discuss paleontology and paleoenvironmental interpretations, and collect fossils.

STOP #8. Abandoned Delhi Pike at College of Mt. St. Joseph. Examine both thin and thick colluvium landslide complexes, the destructive effects of landsliding, and the relationship between vegetation and slope stability. If weather and time permit, we may take a short cross-country hike to examine landslides associated with undercutting of colluvium hillslopes along Rapid Run.

LANDSLIDES ALONG COLUMBIA PARKWAY (STOPS #1, 3)

by Richard E. Pohana

Although many people envision landsliding as a problem limited to steep mountain valleys, a study by the U.S. Geological Survey (Fleming and Taylor, 1980) concluded that Hamilton County, Ohio, probably has the highest annual per capita landslide damage costs in the country. The City of Cincinnati alone has about 25 miles of retaining walls (about 20 percent of which are in poor shape), spends about $500,000 per year on emergency landslide repairs, and has deferred about $15 million in repairs to roads and streets damaged by landslides (Smale, 1987). Of course, the total damage costs from landslides in some areas, such as the San Francisco Bay region, may be greater. Hamilton County's smaller population, however, means that the cost to each taxpayer is proportionally greater than in other areas. A recent economic study (Bernknopf and others, 1988) has shown that enforcement of rudimetary zoning and grading provisions throughout Hamilton County, taking into account only slope and bedrock type, would save more than twice the cost of enforcement.

Columbia Parkway (U.S. Route 50) is a limited access roadway connecting eastern Cincinnati, its suburbs, and eastern Hamilton County with downtown Cincinnati. The western terminus of Columbia Parkway is located on the edge of the central business district of downtown Cincinnati. The parkway extends 6.4 miles to the east, becoming Wooster Road at the Cincinnati-Fairfax corporation line.

Columbia Parkway was constructed in 1937 and 1938 and followed the alignment of pre-1937 Columbia Avenue. The latter was a two-lane roadway with a total width of 35 to 40 feet, measured from the ditch line on the uphill side to the top of the downhill slope. Columbia Avenue was constructed by cutting on the uphill side, and placing fill on the downhill side. The angle of the cut slope varied, but was generally about 1.5 horizontal to 1 vertical (1.5:1, or about 34 degrees), and the depth of cut ranged from 5 to 10 feet.

Columbia Parkway was created by widening Columbia Avenue, which was accomplished by cutting into the hillside on the northern, uphill side and constructing retaining walls. The cut section was about 20 feet wide, and the retaining-wall cuts were on a slope of approximately 1:1. The wall was constructed, and then backfilled at a slope of 1.5:1 to the intersection with the existing grade. The height of the wall ranged from 6 to 12 feet. Figure 2 shows the configuration of the pre-1937 ground line, the temporary cut for construction of the retaining wall, the retaining wall itself, and the ground slope behind the retaining wall.

The rebuilt roadway had a total width of 57 feet from the face of the retaining wall to the top of the downhill slope. Construction included a 44-foot-wide roadway, a 4-foot sidewalk along the north side, and a 9-foot berm along the south side, which included a second 4-foot-wide sidewalk.

GEOLOGY

The hillside above Columbia Parkway rises as much as 200 feet in a horizontal distance of 400 feet, which is a slope of 2:1 (about 27 degrees). Natural slopes beneath the parkway are generally about 3:1 (about 19 degrees). The hillside is underlain by Upper Ordovician shales and limestones of the Kope and Fairview Formations. The contact between the Kope and Fairview occurs at an elevation of about 700 feet above sea level, which is 75 to 100 feet above the parkway. The bedrock is covered with a clayey residual soil known as colluvium. Each of these is described below.

The Kope Formation is primarily shale, but thin limestone layers, typically 2 to 6 inches thick, constitute 20 to 30 percent of the Kope. Shale in the Kope Formation is not tightly cemented and is therefore susceptible to physical disintegration. The large amount of easily disintegrated shale results in accumulations of colluvium, which range from 3 to 50 feet thick, atop the Kope. Within the uppermost 50 feet of the Kope Formation is the 11-foot-thick Grand Avenue Member, which contains a higher percentage of limestone than does most of the Kope. Shale beds in the Grand Avenue Member are less than 2 feet thick, and limestone layers are as thick as 1 foot.

The Fairview Formation lies above the Kope Formation and has an average limestone-to-shale ratio ranging from 1:1 to 3:1. The limestone layers are typically thickly bedded and tabular. Many of the limestone layers are more than 4 inches thick, and some are 7 to 10 inches thick. Because of the higher percentage of limestone, the Fairview Formation supports steeper slopes and thinner soils than does the Kope Formation. Natural slopes developed on the Kope Formation can be as gentle as 6:1 (about 10 degrees), whereas slopes developed on the Fairview Formation can be steeper than 2.5:1 (about 22 degrees). Hence, there is in

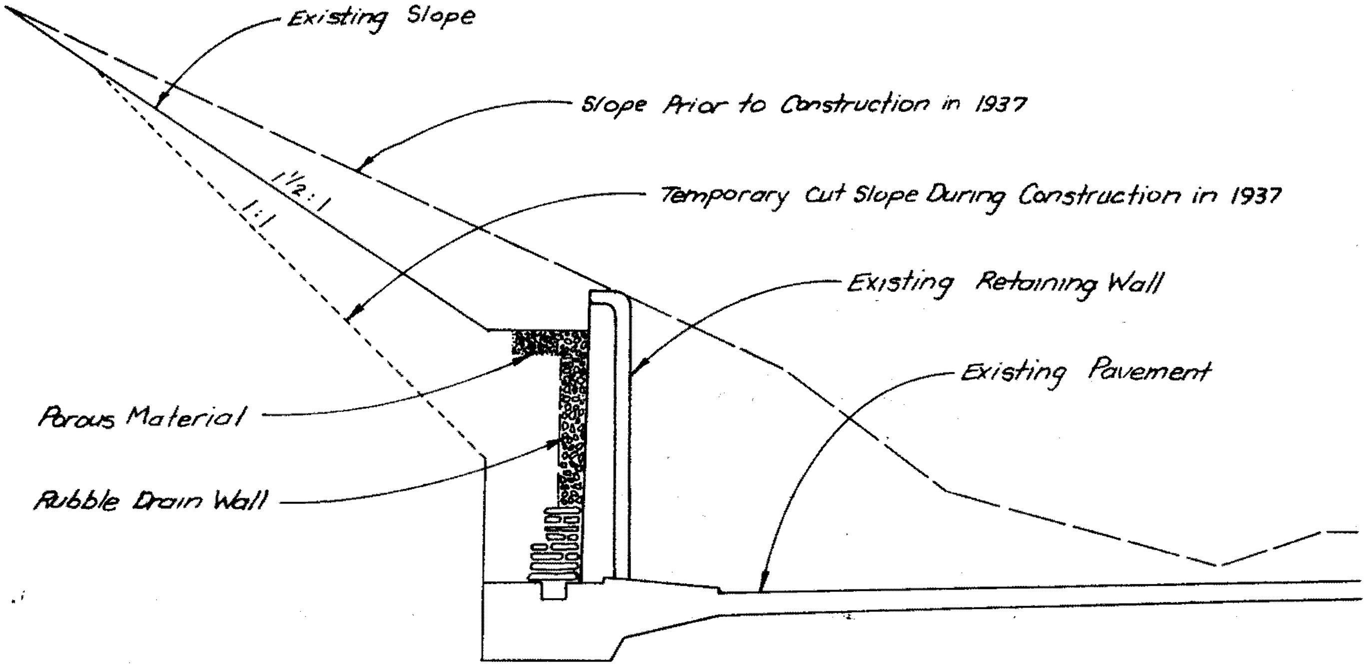

FIGURE 2.—Typical pre- and post-construction (1937) topography along the Columbia Parkway retaining wall.

many cases a noticeable change in topography at the Kope-Fairview contact. Colluvium thickness above the Fairview Formation ranges from zero to 6 feet.

Foundations for some of Cincinnati's early buildings were constructed with local limestone. Practically all of the commercial quarrying was done in the Fairview Formation, mostly in the upper Fairmont Member (also known as the Hill Quarry Beds). Steep slopes, terraces, and exposed bedrock suggest that limestone was quarried from the top of the hillside above Columbia Parkway. During quarrying, shale was often dumped over the slope across from the exposed quarry wall. In 1975, waste from 19th-century quarrying operations slid onto Columbia Parkway near Foster Avenue.

Colluvium in the Cincinnati area is weathered shale and limestone that has been transported downslope by soil creep. Colluvium derived from the Kope and Fairview Formations is typically a very stiff to hard, medium-plastic clay containing pieces of embedded shale and limestone. During dry periods, colluvium near the ground surface is dry and hard; however, it is softened and becomes plastic during rainy periods. Colluvium occurs along the entire length of Columbia Parkway and can be as much as 50 feet thick. When wet, Cincinnati colluvium is highly susceptible to landsliding. Landslide problems above the parkway are limited primarily to shallow, creeping movement that accumulates debris behind retaining walls. Deep-seated landslides below the roadway have severely damaged its pavement.

LANDSLIDES ABOVE COLUMBIA PARKWAY

Movement of colluvium on the hillside above Columbia Parkway has been a continuing problem, presumably, since its construction. In many cases, landslides have caused colluvium to slide over retaining walls and onto the parkway itself. Retaining wall maintenance is a yearly task in some places along Columbia Parkway. The slides block surface drainage behind retaining walls and cause trees to lean out over the roadway. During heavy rains, much material is washed over the wall and, in some cases, through the joints of the walls. Maintenance includes the cutting of trees leaning over the walls, as well as removal of soil and vegetation along the tops of the walls. Landslides above the wall occur in colluvium derived from the Kope Formation. Slip surfaces are probably located along the bedrock-colluvium interface. The slip surfaces are typically shallow, from 3 to 5 feet deep. The areas in which soil encroaches upon the retaining walls are slide blocks which have separated from the lower portions of much larger landslides, which extend much higher up the slope (fig. 3). The slide blocks eventually reach the foot of the slope, where they are removed by city maintenance crews or slide over the walls. The lower portion of the landslide remains dormant and marginally stable until another block separates, causing repeated landslides in the same location.

The original cause of landsliding along Columbia Parkway was road construction, which oversteepened the lower portions of the slope and removed lateral support for the colluvium. Other important factors are ground-water flow and precipitation, as well as continued oversteepening of the slope during maintenance. From time to time, large landslides occur above the retaining wall, bringing large amounts of debris over the wall and onto the parkway.

Several landslides occurred on the slopes above Columbia Parkway during the spring of 1992, requiring the city to close the road and remove about 950 cubic yards of debris at a cost of $19,000. Areas in which sliding occurred are between Bains and Kemper, just east of Kemper Lane, and just west of the intersection of William Howard Taft Road. During March 1981, accumulated landslide debris behind the retaining wall across from Audubon Avenue created a public hazard. Trees were reportedly resting on power lines, and were in danger of falling onto the parkway. Some mud was washed over the wall. City records do not indicate the amount of soil removed or the cost involved. In 1975, a large landslide, involving as much as 10,000 cubic yards of soil, occurred about 800 feet west of Audubon. The weight of the slide mass caused about 160 feet of retaining wall to fail. Apparently, most of the slide

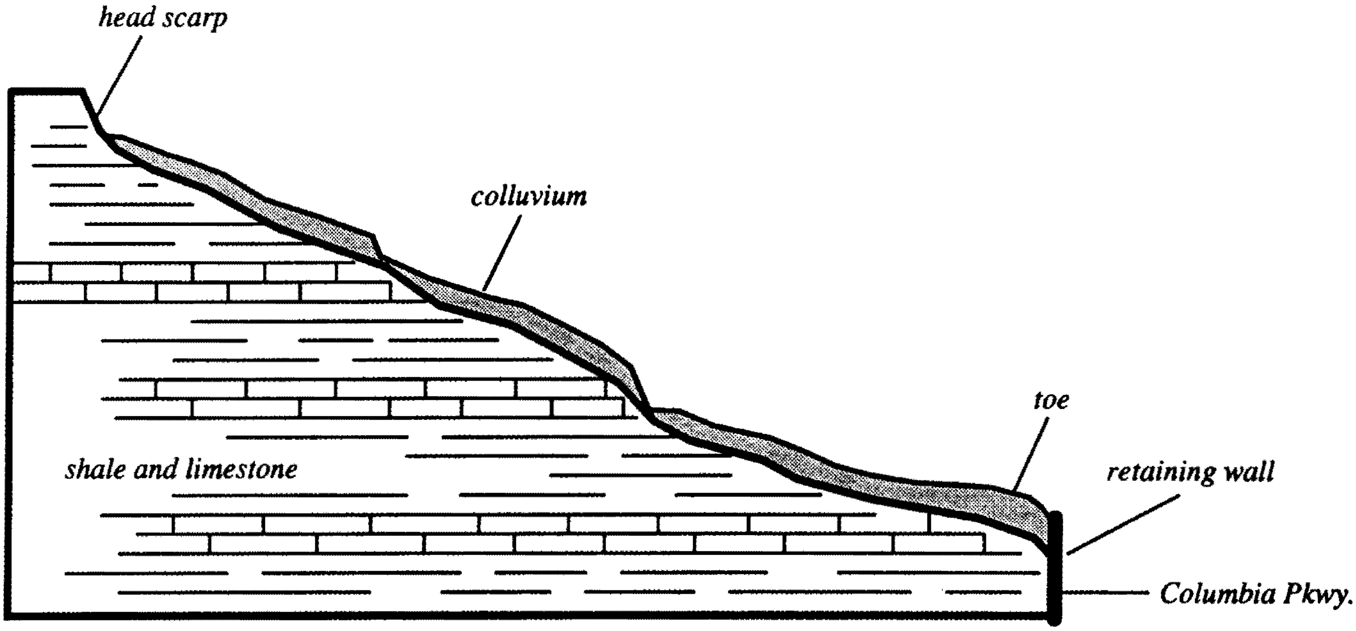

FIGURE 3.—Cross section through a typical thin colluvium landslide along the Ohio River valley. Bedrock is predominantly shale with limestone interbeds, and the landslide slip surface coincides with the bedrock-colluvium contact.

material was shale and clay dumped along the slope during 19th-century quarrying operations. Cost of removal was $31,000. Also in 1975, six landslides occurred along the hillside east of Kemper Lane. About 5,000 cubic yards of soil was removed from behind the retaining wall, at a cost of $19,000. A review of files revealed that in 1973 a large amount of soil slid over the retaining wall, blocking the westbound lane of Columbia Parkway in several places. Sliding was caused by heavy rains that occurred between February and May 1973. The costs to remove the debris along the parkway were:

Bains to Kemper	$8,325
Kemper to Taft	$1,930
East of Torrence Pkwy.	$2,352
At Wortman	$4,754

Landslides above Columbia Parkway will continue to occur, and the rate of sliding at any given time will be related to rainfall. The conditions most conducive to landsliding will be heavy rain storms during early spring, after the spring thaw but before trees had leafed out.

MASS MOVEMENT BELOW THE PARKWAY

The entire hillside below Columbia Parkway is actively creeping downslope. When the rate of movement within a given area differs sufficiently from the adjacent area, scarps, cracks, and other landslide features develop and the area is referred to as a landslide. Sidewalks and curbs may be offset, and buried utility lines may rupture due to the effects of landsliding. Deep-seated active and inactive landslides occur on the hillside below Columbia Parkway and are almost continuous from Bains to Torrence Parkway. The landslides are elongated, with their long dimension running perpendicular to the hillsides. The head scarps of the landslides occur within 6 to 10 feet of the roadway, in some places cutting through several feet of roadway if not through the roadway entirely. Within the pavement, the head scarps are easily distinguished by extensive cracking, settlement, and warping of the pavement. Head scarps on the downhill side of the pavement are not as easily distinguished because of vegetation and the effects of weathering. The slip surfaces of the landslides presumably occur along the soil-rock interface, which is typically more than 15 feet deep. The toes of landslides occur along the north side of the Conrail tracks and in some instances extend downhill as far as Eastern Avenue.

Maintaining the integrity of the eastbound lanes of Columbia Parkway has been a long-term problem. The rate of movement, as determined by the amount of vertical displacement within the pavement, is on the order of several inches per year. In order to insure a smooth ride, asphalt overlays must be placed at least twice a year in areas most affected by landsliding. As is the case for landslides above the parkway, the rate of sliding at any given time is directly related to precipitation.

IMPROVING COLUMBIA PARKWAY

Columbia Parkway is currently being widened and improved between Bains and Beechmont Avenue. The improvement is being performed in three sections: Bains to Torrence Parkway, Torrence to Tusculum, and Tusculum to Beechmont.

In 1976, the section of Columbia Parkway between Torrence Parkway and Delta was widened by adding approximately 8 feet onto the south side of the roadway. Retaining walls consisting of 36-inch-diameter concrete piers, socketed into bedrock, were required in several places. Sections of the roadway between Torrence and Delta that are not supported by a pier wall are affected by soil creep. This movement has caused up to 5 inches of settlement along the southern curb line and opening of joints in the eastbound lane. The City of Cincinnati will improve this section in the fall of 1992 by rehabilitating and resurfacing the existing pavement, installing pier walls, and underpinning sections of the existing barrier walls.

In October 1990, the State of Ohio began construction on the improvement of Columbia Parkway from Tusculum to

Beechmont Avenue. This project was completed in the spring of 1992. In October 1991, the State began construction on the improvement of Columbia Parkway from Bains to Torrence; this project is expected to be completed by the spring of 1993. The Tusculum to Beechmont and the Bains to Torrence projects involve widening the existing traffic lanes, rehabilitation and resurfacing of the existing pavement, resurfacing and strengthening or replacement of uphill retaining walls, and other safety upgrades. The existing reinforced concrete retaining walls along the uphill side of Columbia Parkway between Tusculum and Beechmont were resurfaced with 8 inches of reinforced concrete. The top of the wall was raised slightly and a safety barrier was incorporated into the wall along the roadway. The retaining walls were also strengthened using tiebacks to prevent the kind of sudden wall failures that have occurred in the past. All existing uphill retaining walls between Bains and Kemper will be strengthened, refaced, and tied back with grouted rock anchors. Existing uphill walls between Kemper Lane and Torrence Court will also be strengthened or replaced. Several new walls will be built in areas where there are none.

Because of continuing sliding beneath the parkway and the need to further widen the roadway, the downhill side of the pavement along 5.2 miles of Columbia Parkway will be stabilized using 3.2 miles of drilled pier walls. A pier wall is an earth-retaining structure consisting of a row of individually drilled piers socketed into stable bedrock. The piers are constructed so that they penetrate the unstable soils and develop resistance to the lateral loads in the underlying bedrock. In many cases, the depth to bedrock is such that tiebacks with grouted rock anchors are necessary to support

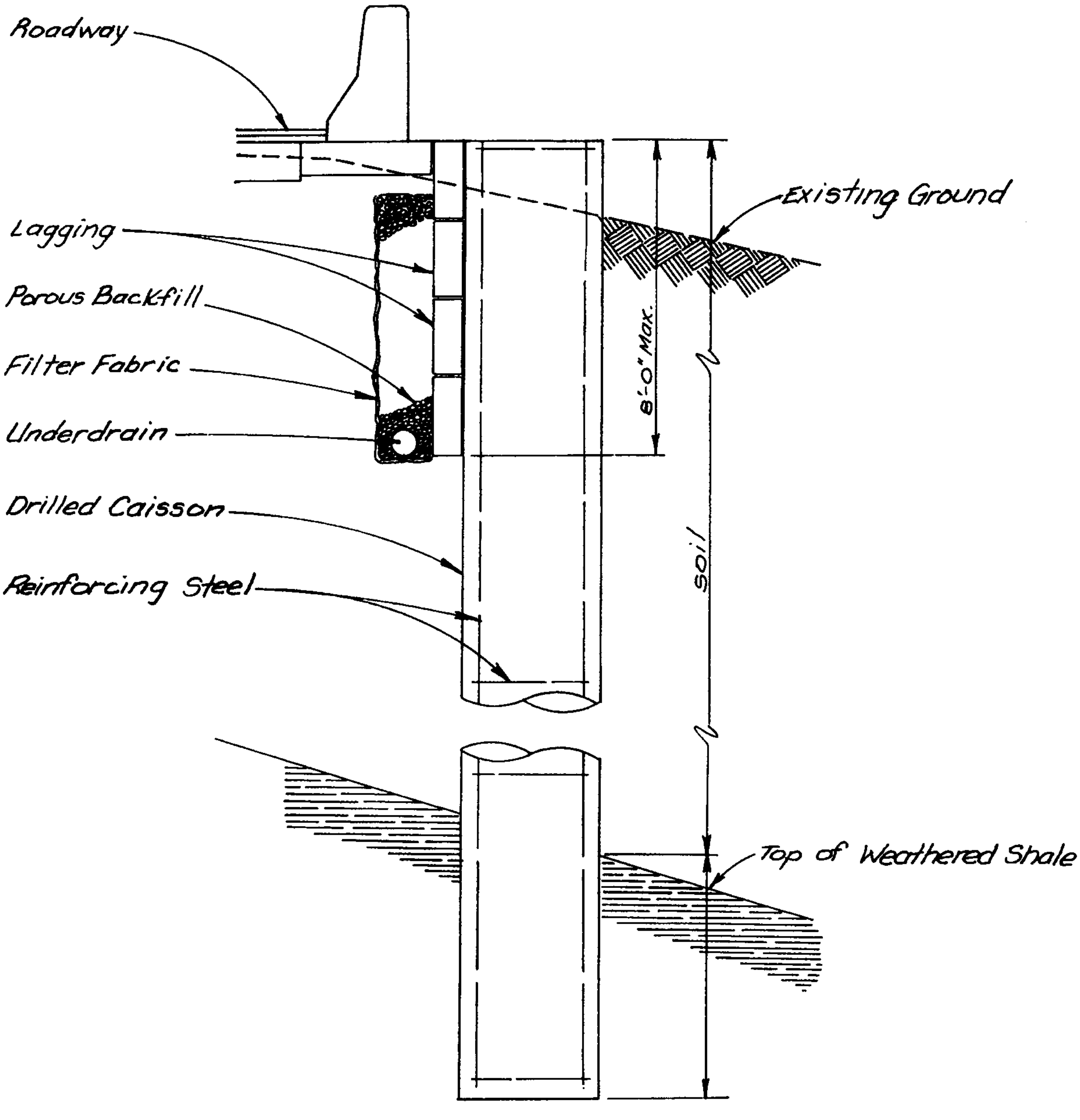

FIGURE 4.—Design of a typical cantilevered pier wall used to support potentially unstable slopes in the Cincinnati area. Pier walls are constructed by drilling large diameter holes into bedrock, which are in turn filled with reinforced concrete. When completed, each pier acts as a lever to prevent the colluvium from moving downslope.

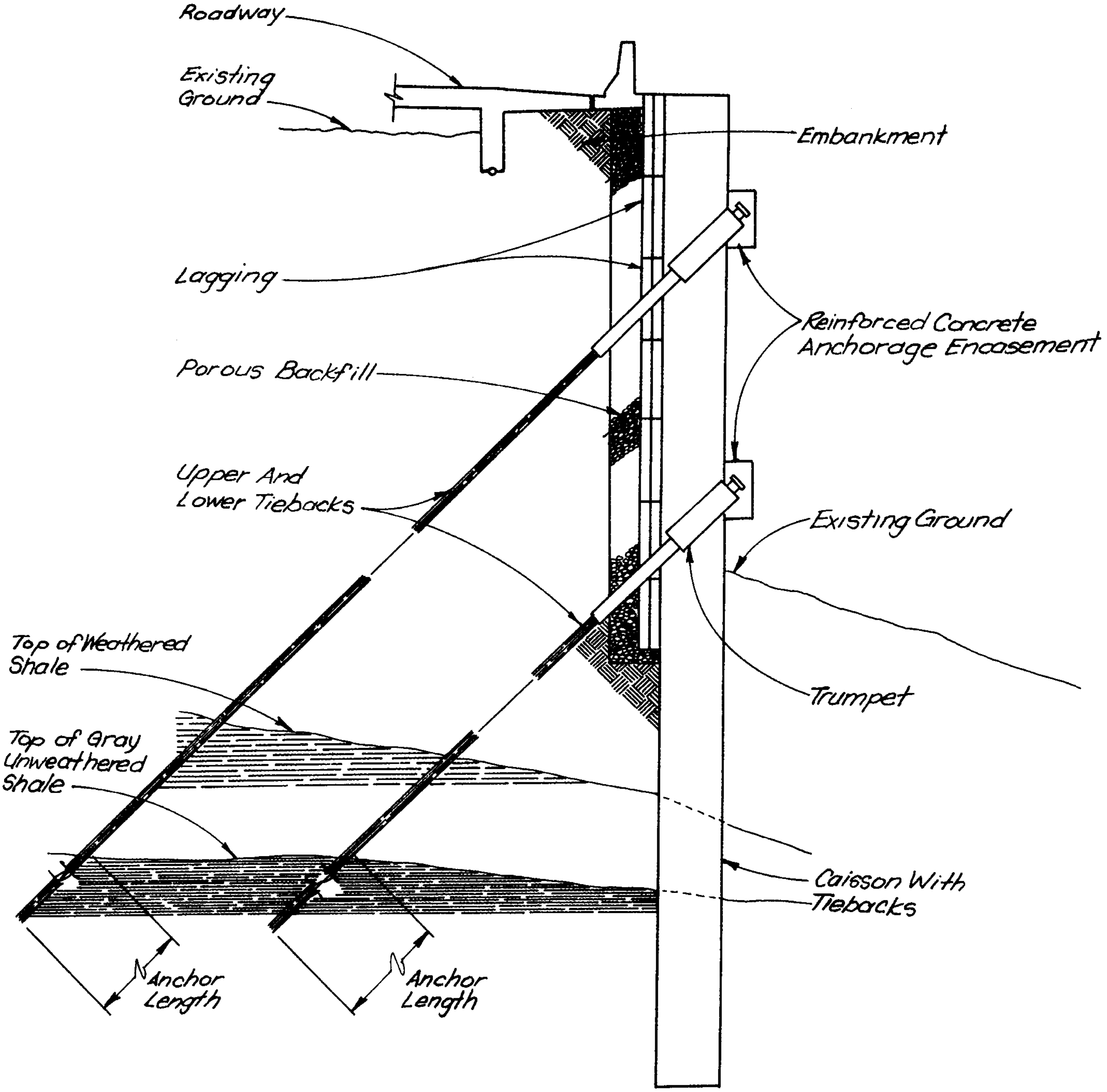

FIGURE 5.—Design of a typical tied-back pier wall. Tied-back pier walls are similar to cantilevered pier walls, but resistance to sliding is increased by adding steel tiebacks anchored in stable shale bedrock.

the tops of the piers. Figures 4 and 5 show typical details of a cantilevered and tied-back drilled pier. The diameter of the piers on Columbia Parkway projects ranges from 30 to 48 inches, and the length ranges from 15 to 55 feet. The bedrock sockets range from 5 to 18 feet deep, and the total number of individual piers to be installed is 2,526. Estimated cost of the project is $25 million, or about $5 million per mile. While these projects will stabilize the parkway, they will neither eliminate landsliding below the pier walls nor reduce the occurrence of landslides above the parkway.

As we travel east along Columbia Parkway, observe the barren areas along the uphill side of the roadway, where soil has slid over the wall. Along the downhill side of the roadway, pier-wall construction should still be in progress. It may be possible to pull off the road to inspect and discuss the construction of pier walls (Stop #1). If not, we will stop at McCollough Avenue off Eastern Avenue to inspect an existing pier wall (Stop #3).

GROUND WATER AND THE LITTLE MIAMI VALLEY (STOP #4)

by William C. Haneberg

Although much of Cincinnati's public water supply is drawn from the Ohio River, a surprising amount is pumped out of the ground. In addition, industrial processes consume a great deal of ground water. Stop #2 is atop the Little Miami aquifer, near Lunken Airport. Before discussing site-specific details, we will take some time to discuss the occurrence, movement, and pollution of water beneath the Earth's surface.

PRINCIPLES OF GROUND-WATER FLOW

Ground water does not exist in underground lakes and rivers. Instead, it is distributed throughout a network of small open spaces, known as pores, in rock and soil. Although ground water flows through porous soil and rock, it does so very slowly. The ability of soil or rock to transmit water is known as hydraulic conductivity, which has units of length/time, for example meters per second or feet per day. Sand, gravel, and highly fractured bedrock generally are highly conductive, whereas silt, clay, and intact bedrock generally have low values of hydraulic conductivity. The exact values of hydraulic conductivity need not concern us, because they have little intuitive value. It is, however, important to realize that they can differ by factors of tens, hundreds, or even thousands among different types of soil and rock. (Soil, in engineering terms, is all unconsolidated material above bedrock, essentially any material that doesn't require blasting to excavate.) Physically, these large differences mean that a molecule of water may take months or years to travel through a clay layer, but only hours or days to travel through a gravel layer of the same thickness. Therefore, high-conductivity layers are generally best for water wells, whereas low-conductivity layers are desirable for landfills. A term related to hydraulic conductivity is transmissivity, which is the hydraulic conductivity of a water-bearing deposit multiplied by the the thickness of the deposit.

If a body of soil or rock is conductive enough to yield significant amounts of water, it is termed an aquifer. Conversely, a deposit which has the ability to transmit only small amounts of water is known as an aquitard or an aquiclude. An aquifer that is bounded on both top and bottom by aquitards is said to be confined. In contrast, an aquifer that has a free upper surface is said to be an unconfined or water-table aquifer. Most shallow domestic and commercial wells in the Tri-State area produce water from unconfined aquifers.

The material above the water table, which contains some water, but not enough to flow freely, forms the unsaturated, or vadose, zone. The material below the water table, in which all pores are saturated with water, forms the saturated zone. Ground water flows in response to changes in both elevation and pressure; for example, from hills to valleys. Humans can also perturb natural flow systems by pumping ground water from wells, as illustrated in figure 6. (We will not discuss in any detail the drilling or construction of water wells; however, the manual by Driscoll, 1986, provides an excellent summary of ground-water production.) Although the regional component of flow is from left to right, following changes in elevation of the water table, flow is re-directed from right to left near a pumping well. If the long-term rate of pumping exceeds the rate at which an aquifer is replenished, for example by percolation of rainwater or snowmelt, then the water table will fall. If the rate of replenishment is decreased, for example due to long-term climatic changes or extensive urbanization (and attendant paving), the water table will fall as well.

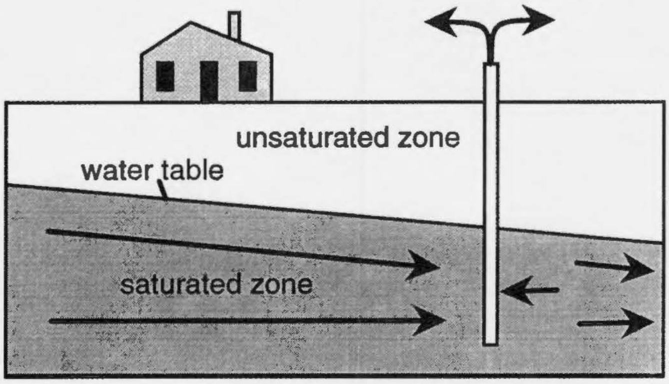

FIGURE 6.—Schematic diagram illustrating regional and local flow. Regional flow component is from left to right, but pumping from a well causes localized perturbations.

The effect of excessive pumping is illustrated in figure 7, which shows the results of a computer simulation of ground-water flow to three wells in a hypothetical 20- by 20-km (12- by 12-mile) aquifer. Water is pumped from one of the wells at a rate 0.001 cubic meter per second (16 gallons per minute), which is about the rate that one might expect for a good domestic well. The pumping rate for the other two wells is 10 times as great. The value of aquifer transmissivity, which is the product of hydraulic conductivity and aquifer thickness, used in the model is 0.1 square meter per second (645 square feet per minute). The water table drops about 0.3 meter (1 foot) in the vicinity of the two larger wells, forming a cone of depression several kilometers in diameter, but changes very little near the domestic well.

In humid regions such as the Midwest, the effects of drawdown go unnoticed by most people, because shallow aquifers are replenished on a fairly steady basis. In parts of the American Southwest, however, water tables have fallen tens to hundreds of feet in some locations, due largely to heavy pumping for irrigation. As a result, the land surface has subsided measurably and large open cracks known as earth fissures have appeared in many places (*e.g.*, Holzer, 1984; Poland, 1984). In addition to the potential for damage to roads, buildings, aqueducts, and pipelines posed by land subsidence, the cost of irrigation increases when water must be pumped from greater depths.

Although a shallow source of pure water may be a great advantage, especially for homeowners who cannot afford to drill deep wells, it can easily become a great liability.

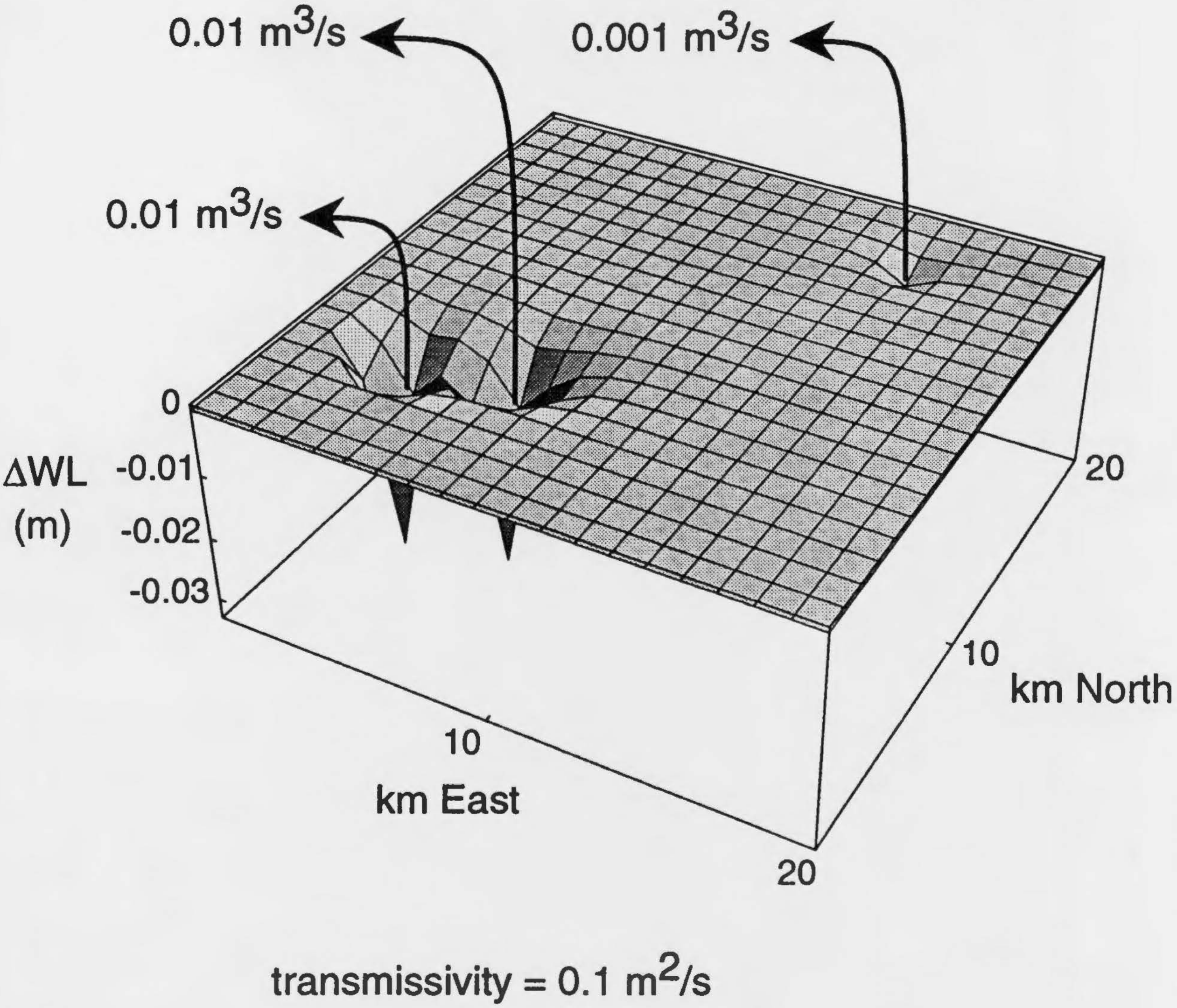

FIGURE 7.—Results of a finite-difference computer simulation of ground-water flow to three wells in a hypothetical 20-kilometer by 20-kilometer (12-mile by 12-mile) aquifer. Water is pumped from two of the wells at a rate of about 0.01 cubic meter per second (160 gallons per minute), and from the third well at a rate of 0.001 cubic meter per second (16 gallons per minute). The vertical axis (Δ WL) indicates the change in the elevation of the water table around the wells that occurs due to pumping.

Shallow ground water is easily polluted by septic-tank discharge, urban storm runoff, agricultural chemicals, and commercial sources. Among the factors that affect the susceptibility of an aquifer to pollution are depth to water, rate of replenishment, type of aquifer material, type of soil at the ground surface, topography, type of unsaturated-zone material, land use, and hydraulic conductivity of the aquifer (see Aller and others, 1987). Although many people believe that large factories are major polluters, it turns out that farms, feedlots, and residential septic tanks can be culprits as well. Country water can be just as polluted, if not more so, than city water! During recent years, a great deal of time and money has been expended in attempts to clean up polluted aquifers. This is a difficult, if not impossible, task that should emphasize the fact that it is much easier and less expensive to avoid ground-water pollution than it is to clean up afterward.

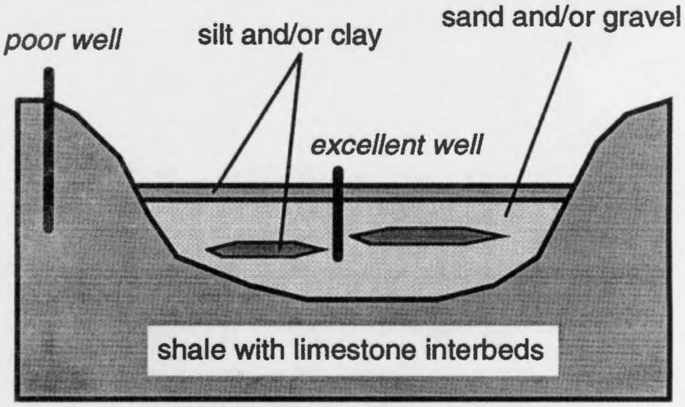

FIGURE 8.—Schematic diagram illustrating a valley-fill aquifer system, similar to that in the Little Miami River valley. Wells drilled into the shale and limestone bedrock, which has very low hydraulic conductivity, will have poor yields. Wells drilled into the high-conductivity valley fill, however, will be prolific.

GROUND WATER IN THE LITTLE MIAMI RIVER VALLEY

The Little Miami River valley is an excellent example of a valley-fill aquifer system (fig. 8), in which a bedrock valley has been filled by layers of sand, gravel, silt, and clay. In the Midwest, most valley-fill material is glacial outwash carried downstream from Pleistocene ice sheets. Water resources in this area are described on the map by Walker (1986). The hillsides on either side of the valley are underlain by low-conductivity Ordovician shales and limestones similar to those we examined earlier. If water is found at all in the bedrock, it is generally in fractures near the surface, and wells seldom yield more than about 3 gallons per minute. This rate of flow is generally not even enough to supply a small household. Wells developed in the Quaternary gravels and sands that fill most of the Little Miami valley (as well as the Great Miami and Mill Creek valleys on the west side of Cincinnati) are much more prolific, typically yielding from 100 to 500 gallons per minute, which is enough for municipal, agricultural, or industrial water supplies.

Much of the information used to find and evaluate ground-water resources is in the form of borehole logs, which are based upon descriptions of material brought to the surface during drilling operations. In Ohio, the Ohio Department of Natural Resources in Columbus maintains files of logs from wells drilled throughout the state. Figure 9 is a schematic cross section of the Little Miami valley, constructed using logs from three water wells drilled near the Beechmont Levee. All three logs show a 20-foot-thick silt and clay layer near the surface; this layer reduces the potential of ground-water contamination from the surface. The water table is 30 to 35 feet deep in all three wells, but occurs within a silty to clayey layer in the middle well. The depth of the water table is important, because wells should be designed and constructed so that water is pumped from high-conductivity layers (in this case sands and gravels). Also notice that the lower silt and clay layers in two of the wells are discontinuous. It is difficult, if not impossible, to correlate these layers between wells. Silt and clay layers within an aquifer reduce transmissivity and can also cause problems during well construction.

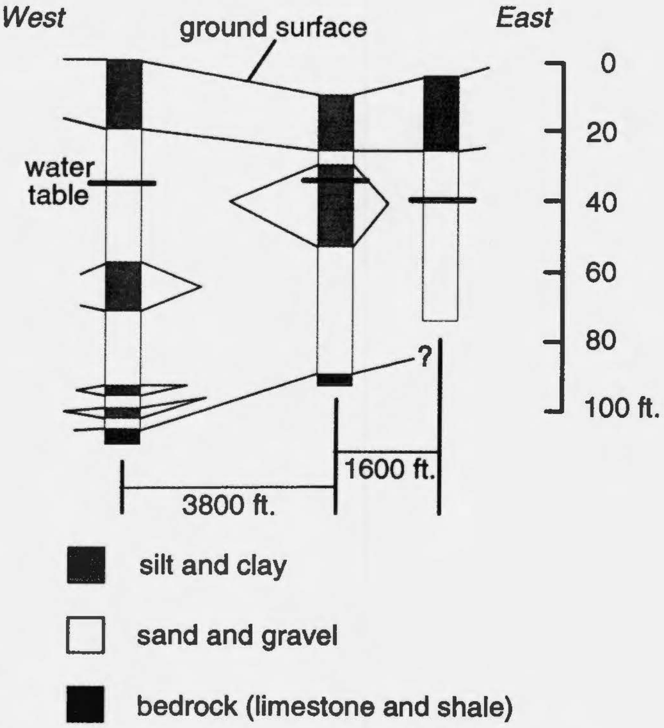

FIGURE 9.—Cross section constructed using drillers' logs from three wells drilled along the Beechmont Levee (U.S. Rte. 50). Vertical exaggeration is approximately 110 times.

PLEISTOCENE HISTORY OF THE OHIO RIVER VALLEY (STOPS #2, 5, 6)

by Richard E. Pohana

The Pleistocene Epoch, popularly known as the Ice Age, lasted from about 2 million to 10,000 years ago. Southwestern Ohio and southeastern Indiana lie along the southern boundary of glacial advances, which produced a complicated succession of deposits as ice sheets advanced and retreated. Classical glacial chronology consists of four major glacial advances and retreats, named the Nebraskan, Kansan, Illinoian, and Wisconsinan. We will look at deposits from the latter two.

Pleistocene geology is an important part of engineering and environmental geology, because the topography and surficial deposits that have the greatest effect on humans are commonly the youngest. In the Cincinnati area, the Pleistocene Epoch was a time of valley cutting and filling, so virtually every engineering project must contend with the legacy of glaciation.

The following is a summary of the Pleistocene history of southwestern Ohio, which was marked by the advance and retreat of at least two continental glaciers. It is based on work by Durrell (1961) and Teller (1970, 1973). The summary is followed by a description of an Illinoian depositional terrace. Stop #2 will be at the Alms Park overlook, where we can observe and retrace the course of the pre-Illinoian Deep Stage Ohio River. Stop #5 will be at the California Golf Course, where we will be on the surface of a depositional terrace. At Stop #6, across from River Downs, we will inspect the composition of the depositional terrace.

PRE-ILLINOIAN DRAINAGE

The upland surfaces in the Cincinnati area are remnants of a gently rolling, widespread surface known as the Lexington Peneplain. Reconstruction of this surface in southwestern Ohio and northern Kentucky by Desjardins (1934) revealed large, northward-trending river valleys at altitudes of about 800 feet above sea level; divides were at elevations of 900 to 960 feet. Either the surface was uplifted or the base level was lowered during late Tertiary time, causing streams to incise themselves to elevations of 600 to 800 feet and establishing the Teays River system. The main trunk of this system, the Teays River, headed in the Appalachians and flowed northwestward across central Ohio, Indiana, and Illinois to the Mississippi Embayment (fig. 10). Durrell (1961) suggests that the preglacial drainage was across northern Ohio and Indiana into the Great Lakes, and the the west-flowing Teays system was not established until after the invasion of Nebraskan glaciers into Ohio; however, other authors (for example, Teller, 1973) doubt this story.

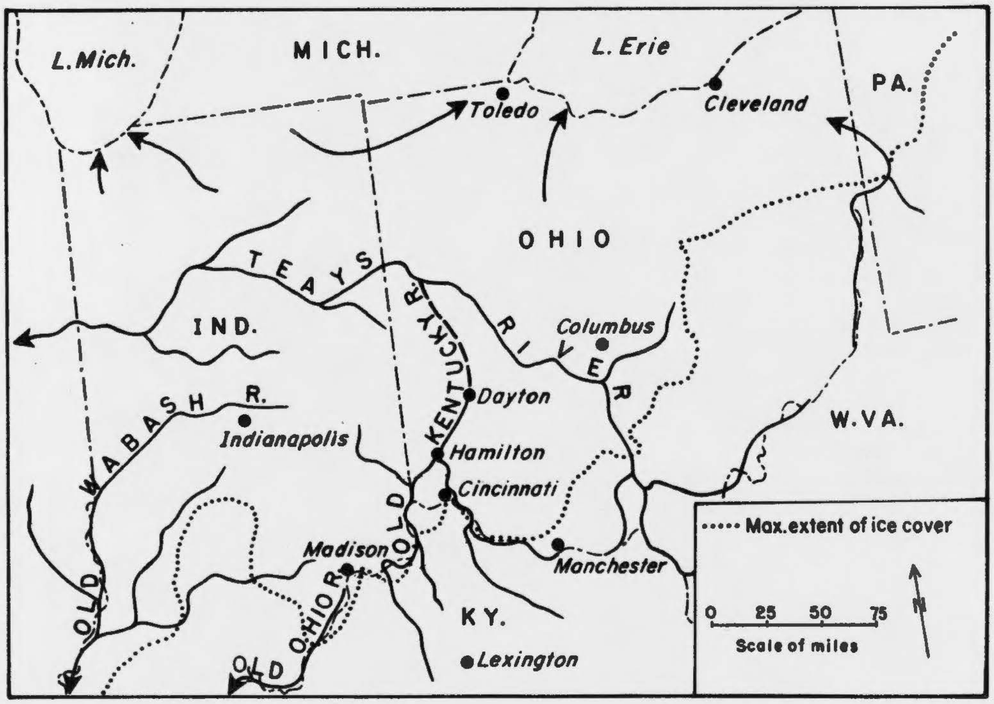

FIGURE 10.—Preglacial (Teays-age) drainage in Ohio, Indiana, and northern Kentucky (from Teller, 1973).

Desjardins (1934) and Durrell (1961) have traced the course of the Teays drainage in southwestern Ohio and northern Kentucky. The main Teays drainages in the Cincinnati area were the Licking River and the Kentucky River, which flowed northward and joined the Teays River in west-central Ohio. The ancient valley system was about 200 feet above the present drainage and was 100 to 200 feet below the uplands.

A pre-Illinoian glacial advance from the north dammed the Teays drainage system and caused the deposition of lacustrine silts and clays in the Teays-age Kentucky and Licking River basins. Topographic divides were breached as the ponded waters sought new outlets around the ice. A new drainage system, the Deep Stage, was established before the ice sheet retreated. The new drainage routes flowed in many of the Teays-age valleys, but commonly in the reverse direction (Durrell, 1961). The valley bottoms were very wide and entrenched 200 feet or more below the floors of the older Teays valleys. The Deep Stage Ohio River followed the present alignment of the Ohio River to California, Ohio. There, it turned north through the valley now traversed by the Little Miami River. The Deep Stage Ohio was joined by the Deep Stage Licking River at Norwood.

ILLINOIAN AND WISCONSINAN GLACIATIONS

The advance of the Illinoian ice sheet into southwestern Ohio created, except for minor details, the present drainage lines. Illinoian ice extended into Hamilton County as two great lobes. The Harrison Lobe invaded the area from the north and affected western Hamilton County; the Clermont Lobe advanced from the northeast and affected northern and eastern Hamilton County. A large lake formed when the ice crossed and dammed the northern loop of the Deep Stage drainage near Hamilton, Ohio, and the impounded water rose until it breached the divide between Anderson Ferry, Ohio, and Bellevue, Kentucky. The course of the Deep Stage from California, Ohio, up the present-day Little Miami valley to Lawrenceburg via Hamilton was abandoned in favor of the more direct route, which coincides with the present Ohio River valley.

As Illinoian ice advanced southward, till was deposited on top of recently deposited lakebed sediments and on the uplands. The southernmost limit of the Clermont Lobe of the Illinoian ice sheet is marked by Fourmile and Twelvemile Creeks in Kentucky, which acted as marginal channels for the Ohio River drainage during the southernmost Illinoian glacial advance (Durrell, 1961). In a similar fashion, the present course of the Great Miami River marks the terminal boundary of the Harrison Lobe in western Hamilton County (Teller, 1970).

The Wisconsinan glacier extended only to northern Hamilton County and did not disrupt the drainage system in southwestern Ohio. As the ice melted, large amounts of sand and gravel outwash were deposited. Near Cincinnati, the Wisconsinan terrace of the Ohio River occurs at an elevation of 540 feet, or approximately 90 feet above the present river level. We will not have the opportunity to examine in detail any Wisconsinan deposits on this trip.

ILLINOIAN TERRACE AT RIVER DOWNS

A well-defined depositional stream terrace of the Deep Stage Ohio River extends westward from Five Mile Road to California, Ohio, and then northward up the Little Miami River valley. The extent of the terrace was mapped by examining landforms and sedimentary deposits. Figure 11 shows the boundaries of the terrace as a physiographic unit and the locations of outcrops of terrace deposits. The top of the terrace is approximately 600 feet above sea level and 130 feet above the Ohio River. The maximum width of the terrace—near the reservoirs of the Cincinnati Water

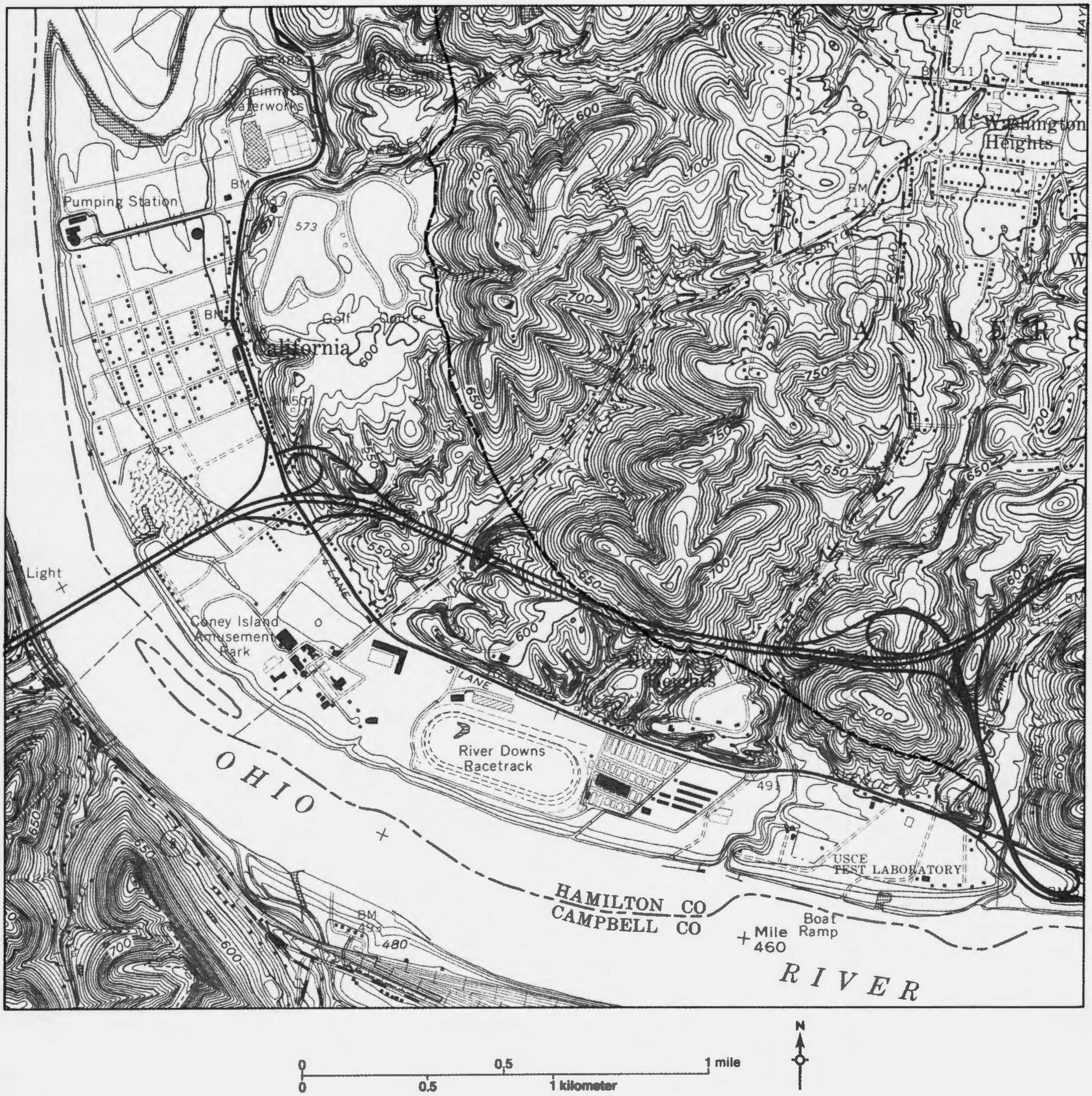

FIGURE 11.—Portion of the Newport 7.5-minute U.S. Geological Survey topographic map illustrating the Illinoian terrace near River Downs. Contour interval 10 feet.

Works—is about one-half mile. The flat surface is generally well-preserved, although it has been slightly dissected by some small stream valleys.

A stratigraphic section of the exposure at River Downs (fig. 12) graphically describes the upper part of the terrace deposit. The terrace consists of sand and gravel partly overlain by Illinoian till and, in some places, loess (wind-blown silt). In 1983, the basal deposits of the terrace were exposed at the intersection of Three Mile Road and Kellogg Road. This outcrop has been covered and is no longer exposed. These lowermost deposits consist of approximately 20 feet of well-sorted, medium-grained, cross-bedded sand believed to have been deposited along a river bottom. The change from deposition of sand to deposition of gravel suggests two periods of river aggradation. The large amount of gravel was presumably eroded from unprotected valley
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walls far upstream and was transported by seasonal meltwater from the advancing Illinoian glacier. The gravel was deposited in longitudinal bars, point bars, and channel fills along a braided stream valley. Bed contacts are gradational, suggesting fluctuating and pulsating deposition (Collinson and Thompson, 1982). Indistinct cross-bedding and imbricated clasts indicate paleocurrent flow to the west in the area between Five Mile Road and California.

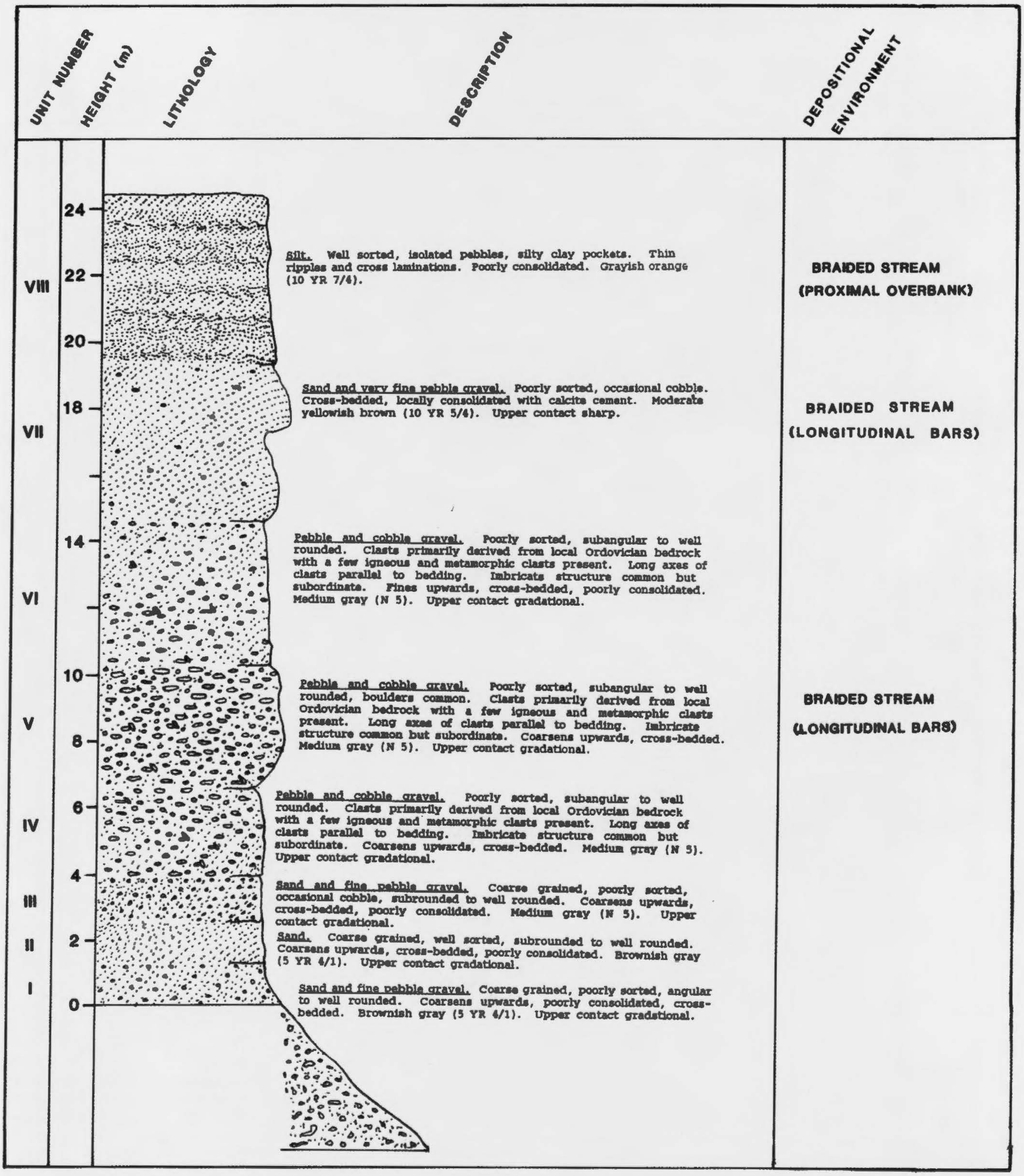


FIGURE 12.—Stratigraphic section of the River Downs terrace exposure (from Pohana, 1983).

Interbedded silt and fine sand with current ripple marks reflects periods of lower flow. A decrease in flow velocity also caused the deposition of the fine-grained sediments in the upper 33 feet of the River Downs section. Percolating lime-rich water cemented some of the gravelly layers, forming localized lenses of conglomerate. The retreat of the ice lobe caused a change in the discharge and the sediment load of the Ohio River. This change in turn caused the river to cut down into the glacial and periglacial deposits lining the river valley, at which time this terrace was formed.

BEDROCK GEOLOGY AND PALEONTOLOGY (STOP #7)

by Sharon C. Diekmeyer

Cincinnati is a classic area for the study of Upper Ordovician sedimentary rocks and fossils. During this stop, we will have the opportunity to study in some detail the stratigraphy and paleontology of shales and limestones exposed in a northern Kentucky road cut. In addition to its purely scientific attraction, bedrock geology also has an influence on modern-day geologic processes such as landsliding and the flow of ground water, as discussed at other stops on this trip.

The Riedlin Road/Mason Road site (fig. 13) is a well-known exposure of three Cincinnatian formations, the upper part of the Kope Formation, the Fairview Formation, and the Bellevue Formation. It also contains at least two tongues of the Miamitown Shale facies. Safe access to all the formations is provided by the road that winds up along the outcrop. This site is at the intersection of Kentucky Route 16 and Riedlin Road/Mason Road, 0.4 mile north of Interstate 275 (Exit 79), and is on the Covington (Kentucky-Ohio) quadrangle, Kenton County, Kentucky. The best overview of the exposed rocks is provided by starting at the bottom of the road at the stop sign, where the lowest exposure of the Kope Formation occurs. Walking up the road to the outcrops at the top of the hill (Bellevue Formation) allows the observer to note changes in rock type/arrangement and fossil content.

STRATIGRAPHY

Rocks exposed in the Cincinnati area consist of a series of alternating shales and limestones of the Cincinnatian Series that span the entire Upper Ordovician section. Figure 14 shows the position of the Cincinnatian Series within the geologic time scale. There is considerable debate about the absolute dates bracketing the Cincinnatian. This paper will use 458 to 438 million years before present. The succession of formations in the Cincinnatian is shown in figure 15. The Kope Formation is part of the Edenian Stage; the Fairview and Bellevue Formations and the Miamitown Shale are part of the Maysvillian Stage. Formation boundaries were originally based on both faunal zones and changes in the rock characteristics. Most recently, the unit boundaries have been redefined on the basis of the original unit descriptions and the sequences of related facies (rock types with similar characteristics thought to have formed under similar conditions) within each unit (Tobin, 1982). Boundaries established by Tobin (1982) have been used (with some modifications) in this paper. Figure 16 is a stratigraphic column of the Riedlin Road/Mason Road section. It shows rock type/thickness and unit boundaries.

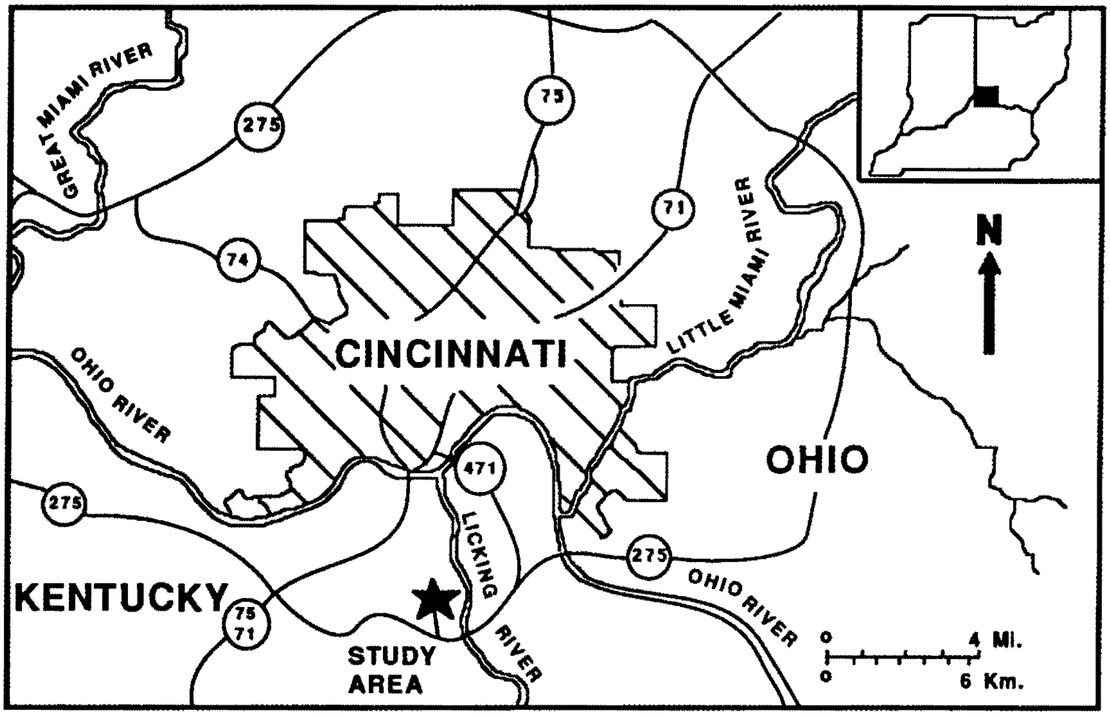
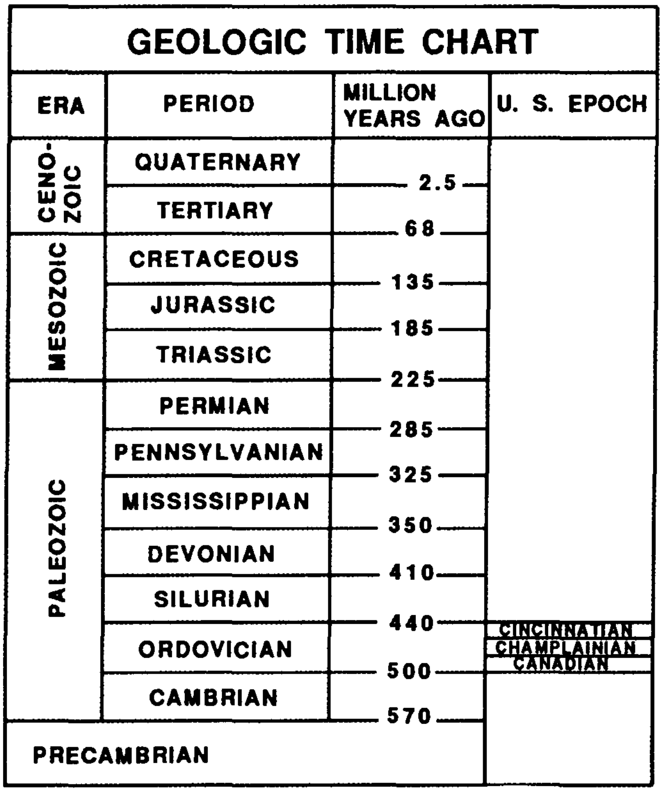


FIGURE 13.—Map of the Cincinnati, Ohio, area showing the location of the Riedlin Road/Mason Road site (modified from Jennette, 1986).



GEOLOGIC TIME CHART			
ERA	PERIOD	MILLION YEARS AGO	U. S. EPOCH
CENO-ZOIC	QUATERNARY	2.5	
	TERTIARY	68	
MESOZOIC	CRETACEOUS	135	
	JURASSIC	185	
	TRIASSIC	225	
PALEOZOIC	PERMIAN	285	
	PENNSYLVANIAN	325	
	MISSISSIPPIAN	350	
	DEVONIAN	410	
	SILURIAN	440	
	ORDOVICIAN	500	CINCINNATIAN CHAMPLAINIAN CANADIAN
	CAMBRIAN	570	
PRECAMBRIAN			

FIGURE 14.—Geologic time chart showing the position of the Cincinnatian Series and approximate ages of rocks located at the boundaries between periods.

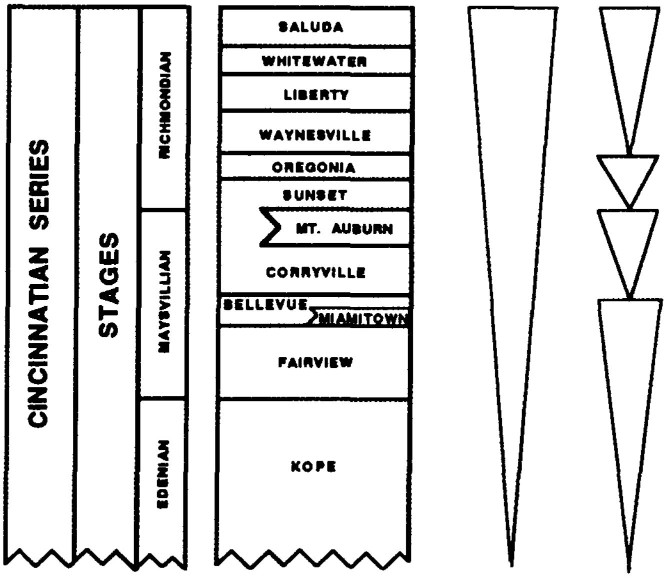


FIGURE 15.—Stratigraphy of the Cincinnatian Series. The inverted triangles represent four shallowing sequences within the larger scale shallowing sequence spanning the entire Cincinnatian Series (modified from Tobin, 1982; Jennette, 1986; Holland, 1990).

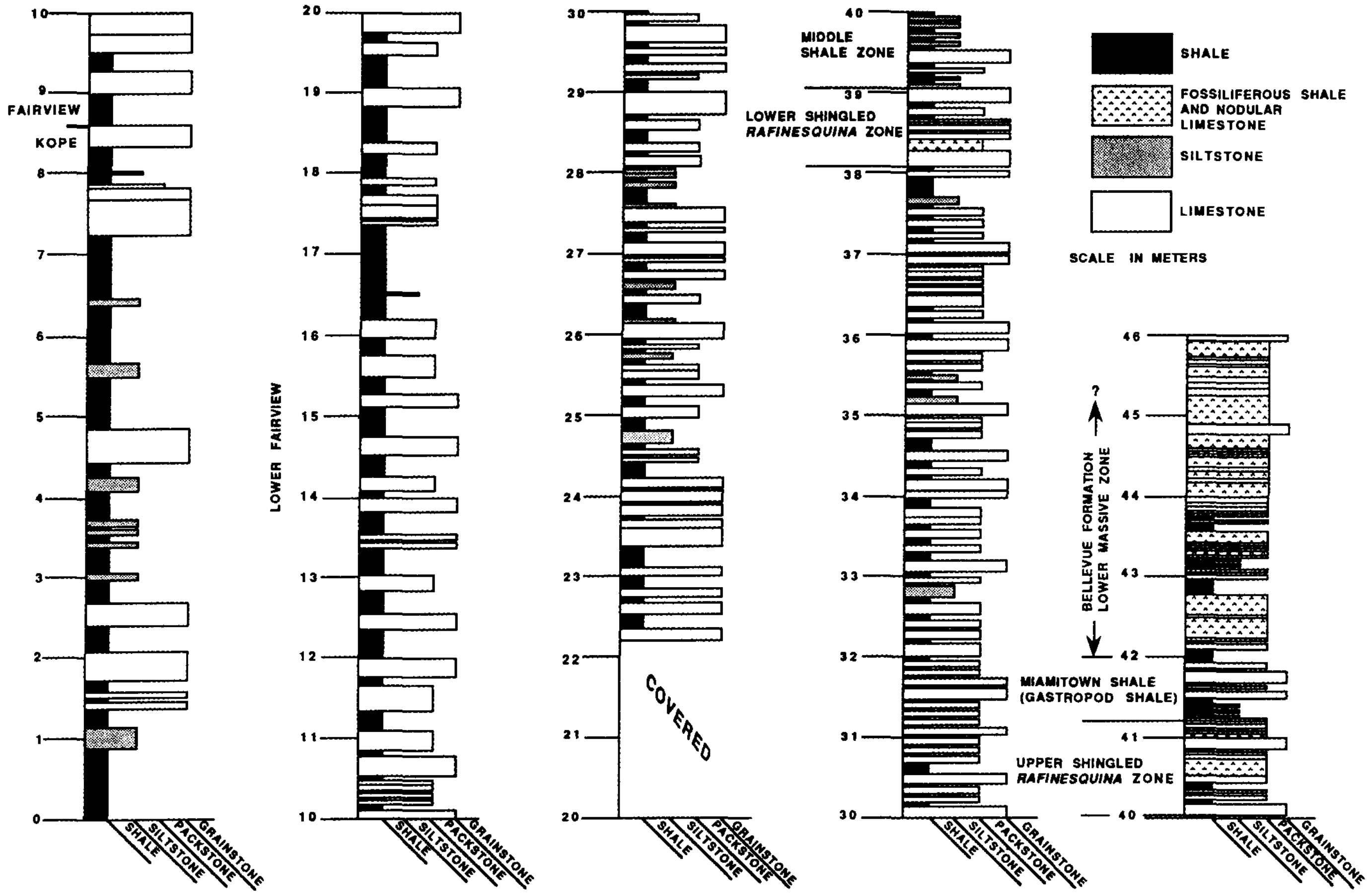


FIGURE 16.—Stratigraphic sections at the Riedlin Road/Mason Road site. A, Upper Kope and lower Fairview; B, Upper Fairview through Bellevue. Numbers on the left are in meters (from Diekmeyer, 1990).

LITHOLOGY, SEDIMENTOLOGY, AND PALEONTOLOGY

Kope Formation

The upper 28 feet (8.5 meters) of the Kope Formation is exposed at Riedlin Road/Mason Road. The Kope consists of generally unfossiliferous blue-gray calcareous shales (beds dominated by clay-sized particles) interbedded with calcisiltites (beds dominated by calcareous silt-sized particles), thin, fossil-rich packstones (grain-supported calcareous beds with some mud matrix) and wackestones (mud-dominated calcareous beds with less than 10 percent grains), and thick, continuous packstones and grainstones (grain-supported calcareous beds with less than 1 percent mud matrix) containing abundant whole and broken fossils. The shale makes up about 75-80 percent of the exposed rocks. Thickness of the shale intervals averages about 3 feet (1 meter). Fossils in the upper Kope are dominated by small twiglike bryozoans and small brachiopods. Other abundant fossils are trilobite fragments, crinoid fragments, graptolites, and trace fossils. One very prominent calcisiltite bed contains numerous specimens of the trace fossil *Diplocraterion* (a U-shaped burrow). The top of the formation is presently placed at the top of the uppermost thick packstone/grainstone bed overlying a 2-foot (0.66-meter) shale interval. Above this bed are the thinner shale beds and more abundant limestone beds of the Fairview Formation.

Fairview Formation

The Fairview Formation is characterized by more abundant and more closely spaced limestone beds. Shales in this formation are thinner and contain more fossils than those in the underlying Kope Formation. The entire thickness of the Fairview Formation is exposed at the Riedlin Road/Mason Road site (105.6 feet or 32.2 meters). About 50 percent of the total thickness is gray to blue-gray planar and lens-shaped fossiliferous limestone beds. The percentage increases from 45 percent in the lower part to about 55 percent in the upper part the section. Limestones are generally packstones and grainstones. Shales are less silty than in the Kope Formation. Siltstones are more common as discrete beds and capping thick grainstone/packstone beds. Fossils are predominantly large-valved brachiopods and small to large twiglike bryozoans. Large, anastomosing colonies of twiglike bryozoans are more common and appear to be toppled in place. Pelecypods (mostly internal molds) begin to appear toward the top of the Fairview Formation. Larger trilobite fragments are relatively more abundant than in the Kope Formation. Crinoid fragments are common and approach their greatest abundance in the upper Fairview. Abundant articulated stem fragments and, more rarely, whole calyces (cups) are present. Trace fossils are abundant and diverse. They are commonly the only fossils found in the siltstone beds. There is some disagreement about the upper contact of the Fairview Formation. There appears to be an intertonguing nature between the Fairview, the Miamitown Shale, and the Bellevue Formation at the Riedlin Road/Mason Road site. At the top of the Fairview Formation are two "shingled" brachiopod (*Rafinesquina*) zones separated by a shaly interval. Above these zones is the Miamitown Shale, followed by the Bellevue Formation.

Miamitown Shale

The Miamitown Shale has been interpreted to be a facies rather than a formation because the unit is difficult to map. The Miamitown Shale thickens significantly from northern Kentucky to the type section at Miamitown, Ohio. At the Riedlin Road/Mason Road outcrop there appear to be two intervals of the Miamitown Shale facies. The first interval is a 2.4-foot (0.75-meter) thick unit above the upper shingled *Rafinesquina* zone at the top of the Fairview Formation. This unit consists of 60 percent shale and is time equivalent to the Miamitown Shale (gastropod shale) at the type section. The second interval is a 1.3-foot (0.4-meter) thick unit; it lies just below the 43-meter mark on figure 16, although it is not labelled as Miamitown Shale. This Miamitown unit was identified by Tobin (1982) and represents a similar facies but is not time equivalent to the Miamitown Shale (gastropod shale) at the type section (Benjamin Dattilo, oral communication, 1992). This unit consists of 76 percent shale and contains limestone and siltstone stringers and nodules. Fossils are commonly gastropods and pelecypods; some graptolite fragments are present.

Bellevue Formation

The Bellevue Formation at Riedlin Road/Mason Road and other locations is characterized by wavy-bedded limestones composing 70 to 90 percent of the total unit thickness (Tobin, 1982). Most limestone beds are fossiliferous packstones and grainstones that are laterally discontinuous, although some beds may be traced along the length of the outcrop. The bases of the limestone beds commonly are composed of large, concave-down brachiopod valves. Mud and spar filling of brachiopod valves and bryozoans is common. (Spar, in this sense, refers to a form of translucent, coarsely crystalline calcite.) Thin, calcareous shale beds between the limestones and as partings within limestone beds are more fossiliferous than underlying shales. The Bellevue Formation is distinguished by an association of large, robust brachiopod valves, pelecypod internal molds and body fossils, and abundant ramose (branching), frondose (leaflike), and encrusting bryozoans. Orthoconic nautiloids are less common faunal elements that also commonly contain spar filling. Crinoid and trilobite fragments are restricted to only a few limestone and shale beds in the Bellevue intervals. They are predominantly fragmental and less common than in the underlying Fairview Formation. The upper contact of the Bellevue Formation is not present at the Riedlin Road/Mason Road site. However, the contact at other locations appears to be a sharp termination of the wavy-bedded limestones and the beginning of the thicker, planar-bedded limestones and shales of the Corryville Formation (Tobin, 1982).

PALEOECOLOGIC INTERPRETATION

Ordovician paleogeography

Several recent studies indicate that during late Ordovician time the Cincinnati region lay between 15 and 25 degrees south latitude, rotated about 45 degrees north from present-day orientation (Kreisa, 1981; Tobin, 1982; Weir and others, 1984; Jennette, 1986; Jennette and Pryor, in press). Several paleoslope indicators (longitudinal fossil orientation, ripple-crest orientation, migration of facies, and faunal associations) have been used to infer a northward-dipping ramp during late Ordovician deposition. Researchers, using knowledge of modern storm characteristics (hurricanes and severe winter storms) and reconstructing ancient oceanic and wind circulation patterns, have inferred a south-southwest storm track impinging on the

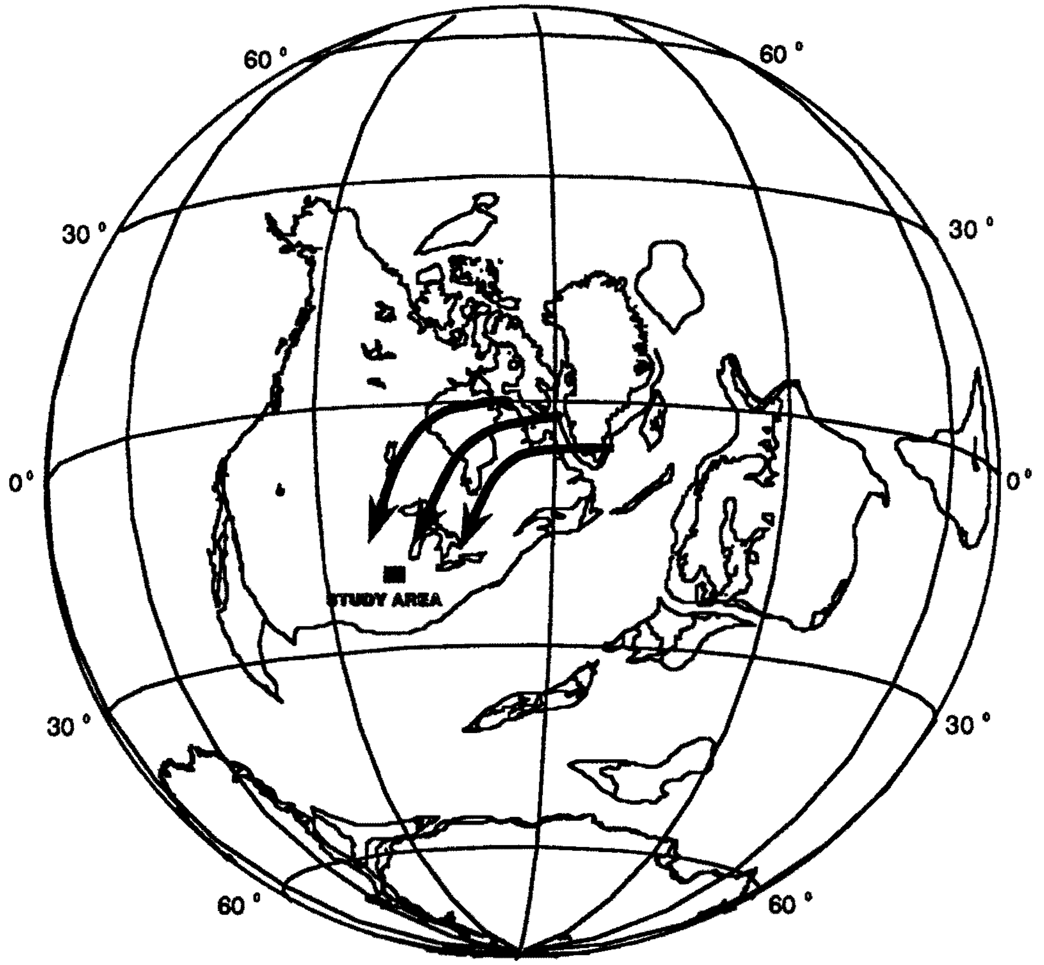


FIGURE 17.—Paleogeographic reconstruction showing the location of the study area during Late Ordovician time, about 438 million years ago (modified from Scotese and Denham, 1988). Arrows indicate the inferred paths of hurricanes and severe storms as they approached the Cincinnatian ramp.

Ordovician ramp (Ziegler, 1981; Tobin, 1982). Figure 17 shows the paleogeographic location of the Cincinnatian ramp and the reconstructed storm tracks.

Storm-dominated sedimentation

Cincinnatian deposits, consisting of alternating shales and limestones, show considerable evidence of storm sedimentation. Figure 18 shows the distribution of sediments thought to result from storms. Storms sweeping southward from the equator create a pressure gradient offshore, causing a movement of water toward shore. A corresponding current is thought to flow offshore beneath the incoming flow. This offshore flow is responsible for winnowing the fine material from the nearshore fossil accumulations (limestones). This fine material, consisting of silts and clays (siltstones and shales), is then deposited offshore during waning storm conditions. The offshore flow also erodes channels (gutters) on the sea floor that fill in with finer debris (gutter casts) as the storm wanes. Other evidence of strong current flow include tool marks, flute casts, and cross-lamination. Tool marks result when solid objects, swept along by currents, impact on the sea floor. Flute casts develop from scouring current action, producing a spoon-shaped depression that is later filled with sediment and appears as a bulge on the bottom of siltstone or sandstone beds. Cross-lamination is generally produced by migration of small ripples that form laminations less than 0.5 inch (1 centimeter) thick and inclined to normal bedding. The storm-winnowing process is thought to be responsible for the alternating limestones and shales noted in the Cincinnatian. Consolidation of shell material resulting from the winnowing process of successive storm events may be responsible for providing a firmer substrate. Many organisms (brachiopods, bryozoans, crinoids) need a firm bottom for attachment. Upon death, the skeletons of these organisms add to the shell debris on the bottom, making the sea floor firmer and shallower. When subsequent storms occur, the winnowing process will leave behind a consolidated (amalgamated) shell layer. A subsequent transgression (rise in seal level relative to the land surface) will deposit mud on the consolidated shell layer. This process produces the characteristic alternating limestone and shale layers of the Cincinnatian.

Superimposed on this process are at least three scales of regressions (decreases in sea level relative to the land surface). The smallest of these are meter-scale cycles found in the upper Kope and lower Fairview Formations (fig. 19). These cycles consist of a shale-rich component and a limestone-rich component (Tobin, 1982). Some of these cycles can be traced across the Cincinnati area, indicating a widespread response to regressive-transgressive (shallowing-deepening) events (Jennette, 1986). Faunal content also appears to respond to

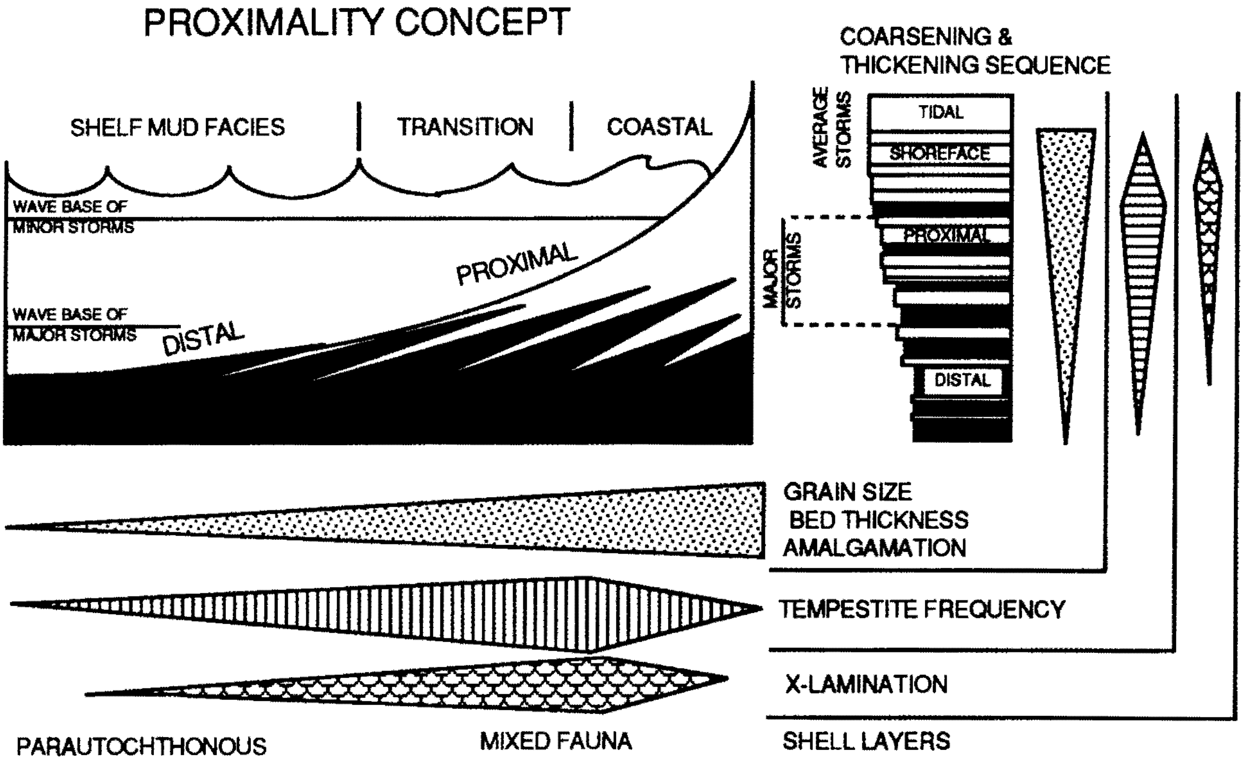


FIGURE 18.—Proximal-distal storm model showing the distribution of facies along the sea floor. The column on the right shows the vertical stacking that results from buildup of sediments through time. The shapes indicate where the storm beds (tempestites) are most common and the resulting increased size of grains and bed thicknesses. Abundant cross-lamination in this zone of most common tempestites indicates storm deposition. Parautochthonous deposits contain shell material brought downslope by waning storm events. Mixed fauna indicates fauna that died where they lived and shells brought in by storms. Shell layers represent amalgamated shell beds from which much of the fine-grained muds and silts have been winnowed and carried downslope (from Jennette, 1986).

these regressive-transgressive processes (Diekmeyer, 1990) The loss of ability to discern these meter-scale cycles above the lower Fairview may be a direct response to the overprinting of these cycles by overall shallowing conditions that occurred from deposition of the middle Kope to deposition of the top of the Bellevue.

Sedimentologic, stratigraphic, and fossil evidence points to the existence of a large-scale regression spanning the interval represented at Riedlin Road/Mason Road (fig. 15) (Tobin, 1982). There are other regressions of this magnitude in the later Cincinnatian (Tobin, 1982; Holland, 1990). Shallowing conditions are inferred from the decrease in shale and corresponding increase in limestone content up section. Further, the wavy-bedded character of the Bellevue is thought to represent deposition at or near fair-weather wave base (fairly shallow). Increased size and shell strength of fossils have been inferred to be a response to more energetic conditions in shallowing environments. A general pattern of increasing size and thickness of brachiopod valves and bryozoan colonies can be observed when walking up through the section at Riedlin Road/Mason Road. Additionally, an increase in encrusting organisms most likely results from the increased abundance of shelly substrate available for encrusting.

The fossil content also varies through the regressive interval. The Kope Formation is characterized by the small brachiopods *Onniella* and *Zygospira* and the thin-valved *Rafinesquina*. Bryozoans generally consist of small and medium branching forms of *Parvohallopora, Dekayia,* and *Batostoma*. Fragments of the trilobites *Isotelus* and *Flexicalymene* are fairly common. Crinoid fragments are predominantly small, slender species of *Iocrinus* and *Ectenocrinus*. Fairview Formation fauna consists of alternating beds rich in the brachiopods *Rafinesquina, Plectorthis, Platystrophia,* and *Zygospira*. These brachiopods (except *Zygospira*) are larger than the Kope brachiopods. Bryozoans consist of large, thick colonies of *Constellaria, Heterotrypa,* and *Dekayia*. *Parvohallopora, Homotrypa,* and *Escharopora* are also common bryozoan elements. Large fragments of the trilobite *Isotelus* are more common than in the underlying Kope Formation. Crinoid fragments and stem sections increase in abundance up through the Fairview Formation and represent *Glyptocrinus* and *Iocrinus* species. Finally, the Bellevue Formation contains abundant large, robust brachiopods: *Platystrophia, Rafinesquina,* and *Hebertella*. The small-valved brachiopod *Zygospira* becomes abundant again in both Miamitown Shale intervals and in the lower Bellevue. Large ramose and frondose colonies of *Dekayia, Batostomella, Parvohallopora,* and *Monticulipora* abound. The pelecypods *Ambonychia* and *Caritodens* are common as molds and body fossils. *Cyclonema* (gastropod) and nautiloids are notable in the Bellevue and the Miamitown. Abundant fragments (arm and stem fragments and holdfasts) of the crinoid *Anomalocrinus* are found in the upper Bellevue interval (Meyer and others, 1990).

The largest scale regression occurs over the entire Cincinnatian (fig. 15) (Tobin, 1982). Evidence for this regression has been gathered from the sedimentology, fossil data, and stratigraphic signals observed within this interval.

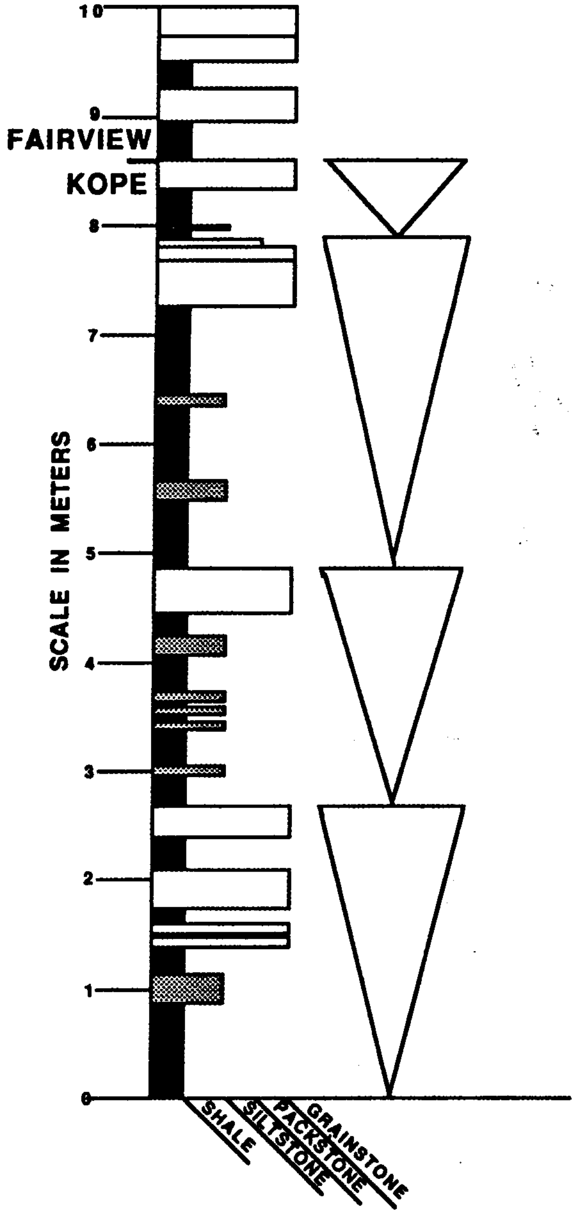


FIGURE 19.—Stratigraphic interval representing four meter-scale shallowing-upward sequences in the Kope Formation (from Jennette, 1986).

There still remains considerable study in order to determine how the interaction of these different scales of regression affected the depositional and faunal patterns that are evident within the Cincinnatian interval.

HILLSIDE EVOLUTION AND LANDSLIDES AT DELHI PIKE (STOP #8)

by Mary M. Riestenberg and William C. Haneberg

Landslides along Delhi Pike are excellent examples of geologic processes at work in a relatively undeveloped setting. Here we will have the chance to examine the mass wasting and gradual retreat of slopes along the Ohio River valley, including the effects of vegetation, rainfall, and erosion on the geologic evolution of a young landscape.

The Delhi Pike landslide complex is on the south-facing slope of a steep ridge overlooking the Ohio River in southwestern Cincinnati (fig. 20). This ridge and its neighboring valley walls border a part of the Ohio River which was rerouted during the Illinoian glaciation (Durrell, 1961). The re-routing resulted in the development of a stretch of the Ohio River that is actively incising into its uplands and which has developed no floodplain. The part of the ridge associated with the Delhi Pike landslide has a break in slope, or bench, which was utilized by early inhabitants of the area as a pad for a road connecting the lowlands by the Ohio River with the uplands of Delhi Township in Greater Cincinnati. County records show that the road was petitioned for on November 7, 1886, completed in 1911, and paved more than 70 years ago (Edward Riley, Delhi Township Trustee, oral communication, 1991).

The road and all homes bordering Delhi Pike were damaged by landsliding in the spring of 1973. The road was soon closed, and the homes demolished. The magnitude of the damage prompted studies of the slope failure by scientists of the Department of Geology at the University of Cincinnati and the U.S. Geological Survey. Most of the following description of the landslide is condensed from their combined studies (Fleming and others, 1981; Baum, in press).

In the area of landsliding, Delhi Pike lies about 100 feet topographically below the contact between the Kope Formation and the overlying Fairview Formation, which is marked by a subtle change in slope at about 700 feet above sea level. Both the Kope and the Fairview Formations are composed of nearly flat-lying, interbedded layers of fossiliferous limestone and calcareous shale. The relative thickness of the layers and relative abundance of shale with respect to limestone differs between the formations. The Kope Formation contains more shale than the Fairview, about 70 percent shale near its base and about 80 percent in the upper 40 feet; the Fairview is approximately 50 percent shale (Fleming and Johnson, in press). The difference in shale content gives the formations different resistance to weathering. The Kope Formation tends to deteriorate faster than the Fairview, so sites underlain by the Kope Formation generally have a more gentle slope and thicker soil than areas underlain by the Fairview Formation. In the study area the land downslope from the road (underlain by the Kope Formation) has an average slope of 10 to 12 degrees (horizontal:vertical ratios of 5.6:1 to 4.7:1) and a residual, silty-clay soil (colluvium) as thick as 50 feet; the study area upslope from the road is underlain by colluvium, which may be only 3 feet or so thick, and has a slope ranging from 18 to 25 degrees (3.1:1 to 2.1:1) (Fleming and Johnson, in press). The landslides associated with the site are of two types: a thick slump between Delhi Pike and Hillside Avenue and a thin, planar landslide above Delhi Pike (fig. 21).

THE THICK LANDSLIDE

A set of limestone steps leads downhill through a tangle of shrubs to a grassy, flat bench between Delhi Pike and Hillside Avenue that was once occupied by a 100-year-old house, garage, shed, and barn. In the spring of 1973, a year of unusually heavy rainfall, a 400-year-old tree fell on the house. Within a few days, landslide movement destroyed the rest of the house and other buildings. These buildings, like others along Delhi Pike, were subsequently removed. Studies of the curvature of trunks, abrupt bends in stems, reaction wood, and tree rings of two pine trees growing west of the limestone steps showed that the hillslope had undergone slow movement since the mid-1940's, and that one other major landslide had occurred in 1958 (Fleming and Johnson, in press).

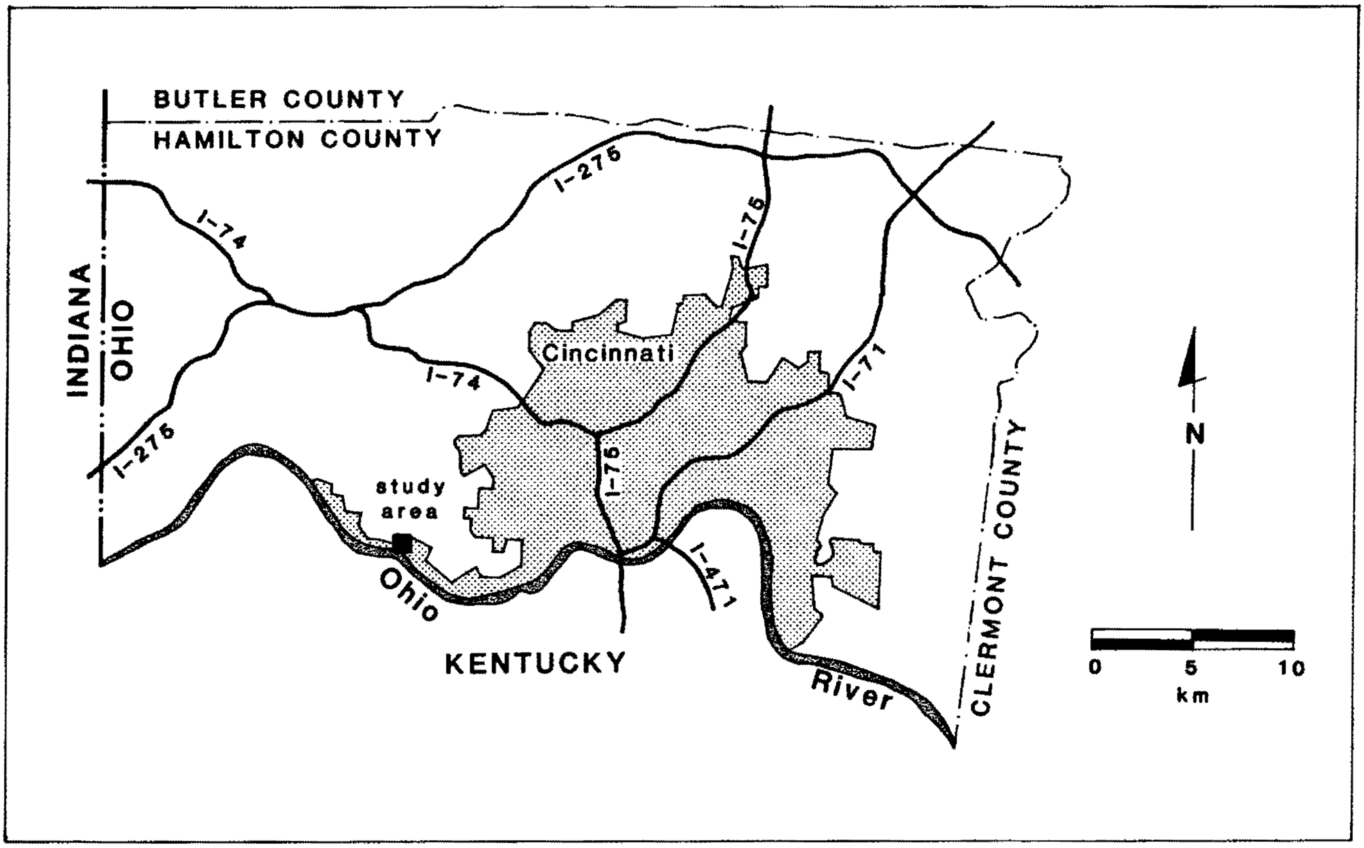


FIGURE 20.—Map showing the location of the Delhi Pike landslide complex along the Ohio River valley west of downtown Cincinnati.

Landslide features can be difficult to see here because of thick vegetation, but some features are preserved in the remaining steps and in the road itself. The road is broken by a series of long cracks or head scarps which are oriented parallel to the topographic contours. These scarps show more vertical offset than horizontal offset and mark the head or top of the thick landslide. The steps leading to Hillside Avenue mark the toe of the landslide and show more horizontal than vertical offset. Irregular bulges in the pavement along Hillside Avenue serve as additional signs of downslope mass movement. Studies of the borings and of landslide features exposed in a trench showed that sliding occurred along several failure surfaces. The failure surfaces apparently were produced sequentially over the years within the colluvium, resulting in a complex of buried lobes within the soil. This type of sequential failure drastically deformed the soil internally, commonly with little evidence of deformation at the ground surface (Fleming and Johnson, in press).

THE THIN LANDSLIDE

The land upslope from the road is covered with native vegetation and bears few remnants of human development. The slope, ranging from 18 to 35 degrees (3.1:1 to 1.4:1), supports a shrubby, disturbed plant assemblage on the more gently sloping surface near the road and a mature mixed-mesophytic forest with a well-developed canopy and little understory on the upper, steep segment of the hillslope. The soil upslope from the road is thin, rocky, and uneven with numerous swells, swales, benches, and fissures.

The landslide directly across the road from the limestone steps has scooped out an elongated section of the hillside measuring about 215 feet long and 100 feet wide. The thin landslide is bounded by several scarps, which are most apparent at the head of the failure and by a single toe that has overridden Delhi Pike. The landslide mass has an uneven surface. Sets of benches suggest that the colluvium has been rotated and stretched by arching of the thin colluvium over the limestone benches in the bedrock. These irregularities are illustrated in a slope profile along the line of a trench excavated by R. W. Fleming of the U.S. Geological Survey (fig. 22). A walk halfway up the landslide reveals a surprisingly intact head scarp. The scarp, developed in colluvium nearly 20 years ago, is U-shaped and concave-upward on its exposed face. Vertical and horizontal offsets are more than 3 feet each. Farther uphill are older scarps, worn and smoothed by weathering, which give the hillslope a stepped appearance.

Vegetation on Cincinnati's hillsides ranges from xerophytic (low water requirements) along hilltops to mesophytic (higher water requirements) along the middle and lower portions of hillsides. Recent studies (Riestenberg and Sovonik-Dunford, 1983; Riestenberg, in press) along Delhi Pike and adjacent Rapid Run, which is just over the ridge from Delhi Pike, also suggest a strong relationship between vegetation type, vegetation density, and landslides in thin colluvium. Stable zones are dominated by dense, older stands of white oak, chinquapin oak, white ash, sugar maple, buckeye, and hickory. Unstable zones are dominated by a canopy of less dense, younger stands of sugar maple and buckeye and an understory of sugar maple, ash, elm, black cherry, and buckeye. These differences are most likely due to some combination of the facts that (1) sugar maple rapidly colonizes newly disrupted landslide masses, and (2) white

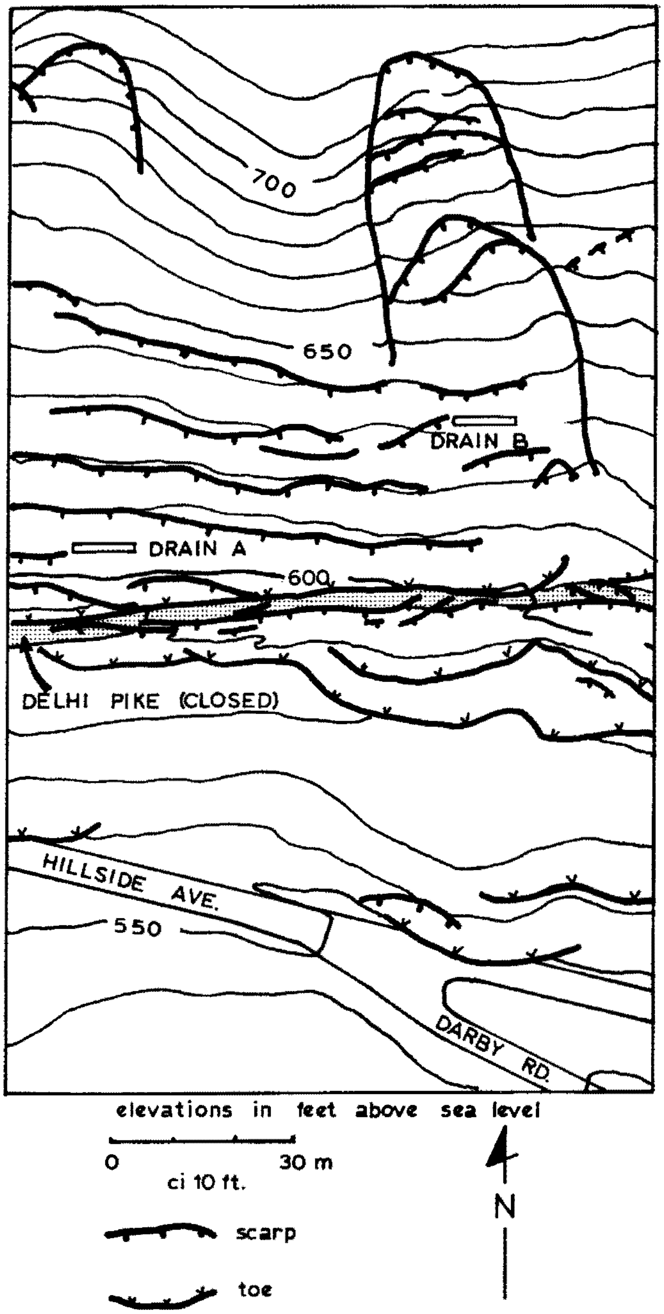


FIGURE 21.—Map illustrating landslide features in the vicinity of Delhi Pike, Hillside Avenue, and Darby Road (modified from Fleming and others, 1981). Drains A and B were installed as part of an experiment (Haneberg, 1989) to evaluate the possible stabilizing effects of drains in the thin landslide.

ash roots penetrate much deeper than do sugar maple roots, helping to strengthen and stabilize soils as deep as 3 feet.

MECHANISMS OF SLOPE INSTABILITY

The conditions necessary for landsliding to occur can be estimated by calculating a factor of safety against sliding, which is the ratio of the forces that resist failure to the forces that promote failure. The factor of safety is a concept that is used to analyze the design of slopes, dams, bridges, and nearly any other engineering work. If the factor of safety is equal to 1, the slope is on the verge of failure. If the factor of safety is greater 1, then the slope is stable. If the factor of safety is less than 1, the slope should have already failed. The U.S. Geological Survey has determined residual-strength parameters for colluvium for use in stability analyses (Fleming and Johnson, in press). Stability analyses of the thick landslide using these parameters and the water table between 3 and 6 feet above the shear surface show that the thick landslide failed as a series of rotational slumps, probably moving a few inches to several feet at a time.

In both the thick and the thin landslides the displacement is strongly correlated with seasonal rainfall. Rapid movements occur in late winter and early spring, but during some years the displacement may be virtually indetectable. Geologists and geotechnical engineers have known for many years that water within the soil exerts a buoyant effect, lifting and destabilizing the soil. Mechanically, this is much different than lubrication, so the two must not be confused.

Water levels in the thin landslide, as measured in observation wells, can in some cases rise within a few minutes of rainfall (Fleming and others, 1981). Research has shown that rapid water-level increases occur only if the colluvium is already moist from previous storms (Murdoch, 1987; Haneberg and Gökce, in press), as illustrated in figure 23. The frequency, intensity, and duration of rainstorms also control the impact of a given storm (Haneberg, 1991a, 1991b). Mathematical models, based upon the differential equations describing ground-water flow, have been used to analyze the relationship between rainfall and water pressure within the thin landslide during past storms (fig. 24). Accurate prediction of failure or stability during future storms, however, is not yet practical.

The thin landslide at Delhi Pike has moved only a few inches in the past 15 years, and its stability poses some unanswered questions. One likely explanation—based upon the field work and measurements of Murdoch (1987), Haneberg (1991a), and Haneberg and Gökce (in press)—is that the hillside soil only rarely contains enough water to slide. Other geologists have assumed that the thin colluvium is completely saturated on a regular basis and have proposed that soil strength must have been greater than that measured in the laboratory in order to explain the lack of movement. This strength gain may be due to roughness of the shear surface, shape of the shear surface, or variations in the stickiness of the shear surface (Fleming and Johnson, in press). Exposures of roots that penetrate the shear surfaces in a trench at Delhi Pike reveal that the roots are deformed by the soil at the shear surface and are realigned in the direction of soil displacement. This realignment suggests that roots may also contribute strength to the soil (or roughness to the soil shear surfaces) at shallow depths (Riestenberg, in press).

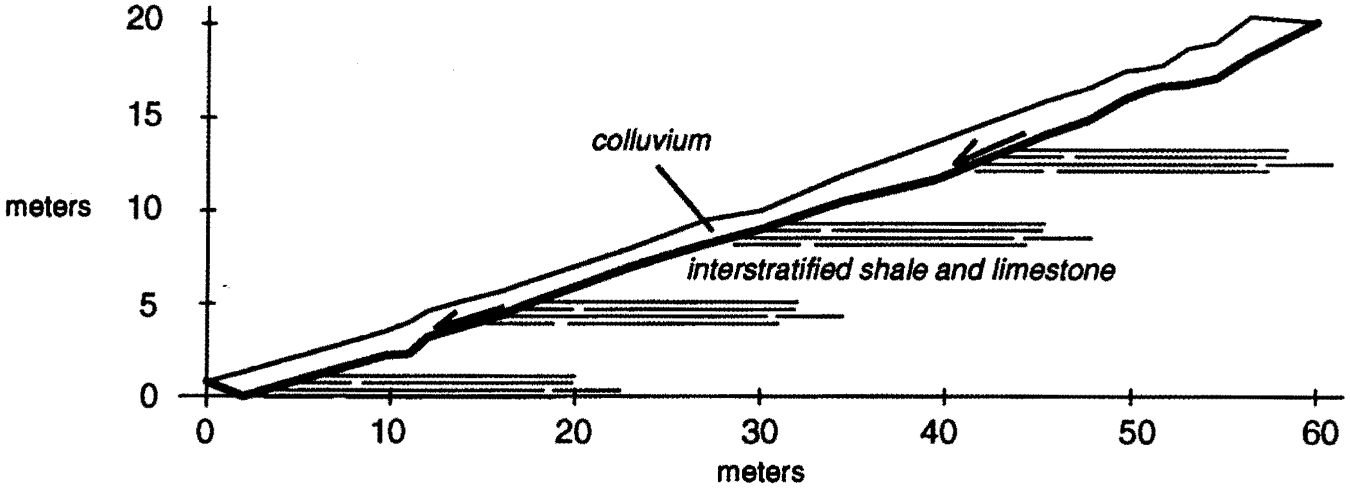


FIGURE 22.—Slope profile along a trench excavated through the thin landslide at Delhi Pike by R. W. Fleming (U.S. Geological Survey) (modified from Haneberg, 1991a).

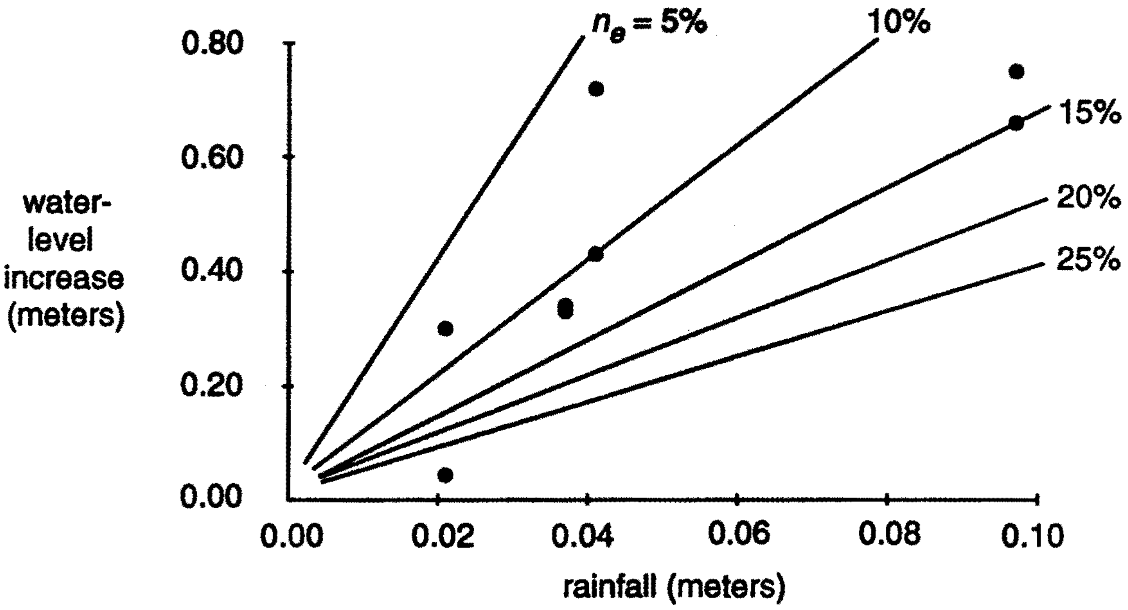


FIGURE 23.—Relationship between rainfall measured at Greater Cincinnati International Airport and water-level increase measured in observation wells in the thin landslide at Delhi Pike (modified from Haneberg, 1991a). Both rainfall and water-level increase are given in meters (1 meter = 39.37 inches). The lines labelled n_e represent calculated values of effective porosity before each storm. Total porosity of the colluvium is between 30 and 50 percent, meaning that most of the pore space in the colluvium was filled with water before the storms.

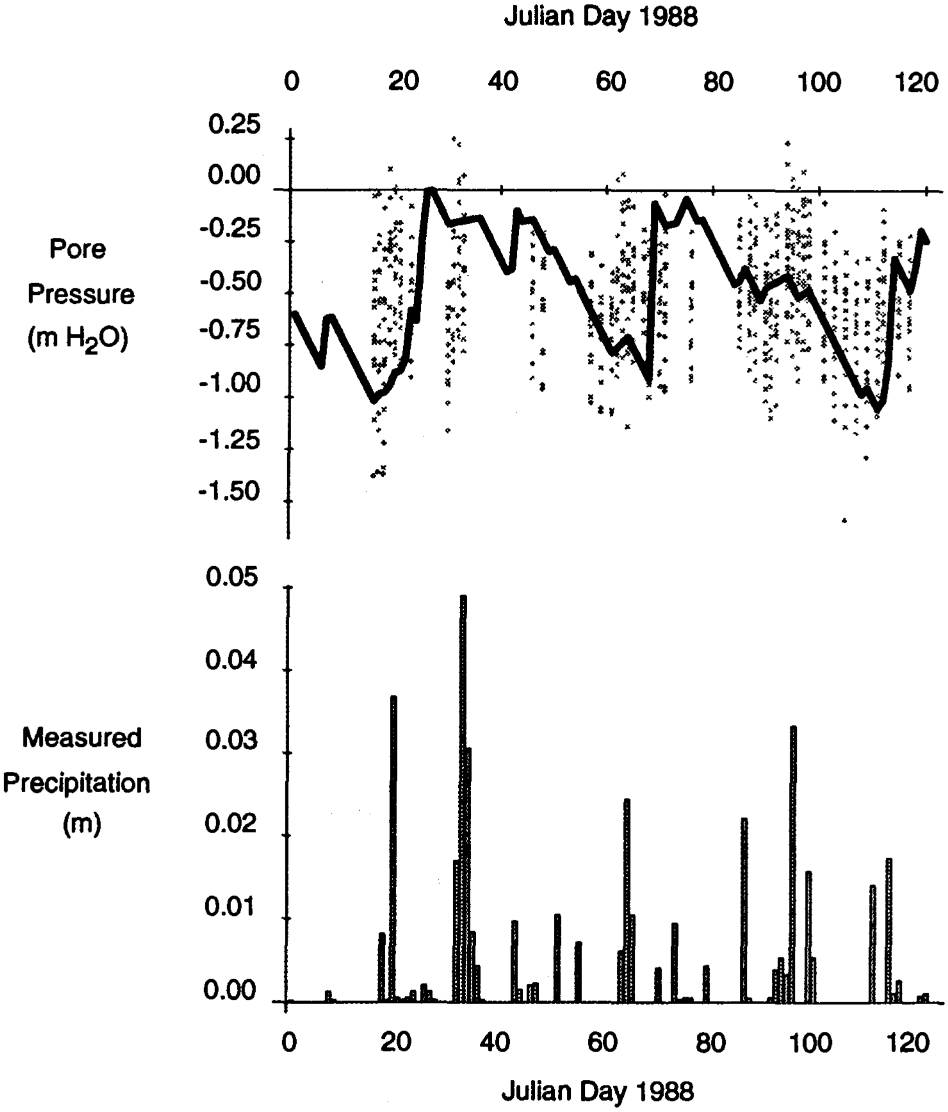


FIGURE 24.—Results of a computer simulation of the effects of rainfall on water pressure within the thin landslide at Delhi Pike (from Haneberg, 1991a). Measured rainfall values are from the spring of 1988. Gray dots in the upper part of the graph are measured values of pressure head (given in meters of water); the heavy black line in the upper part of the graph is the result calculated using an average annual effective porosity of 9 percent and a constant evapotranspiration rate of about 0.00026 m/day (0.01 inch/day). Although the model can be used to simulate the effects of past storms, changes in effective porosity through time limit the effectiveness of the computer model as a predictive tool.

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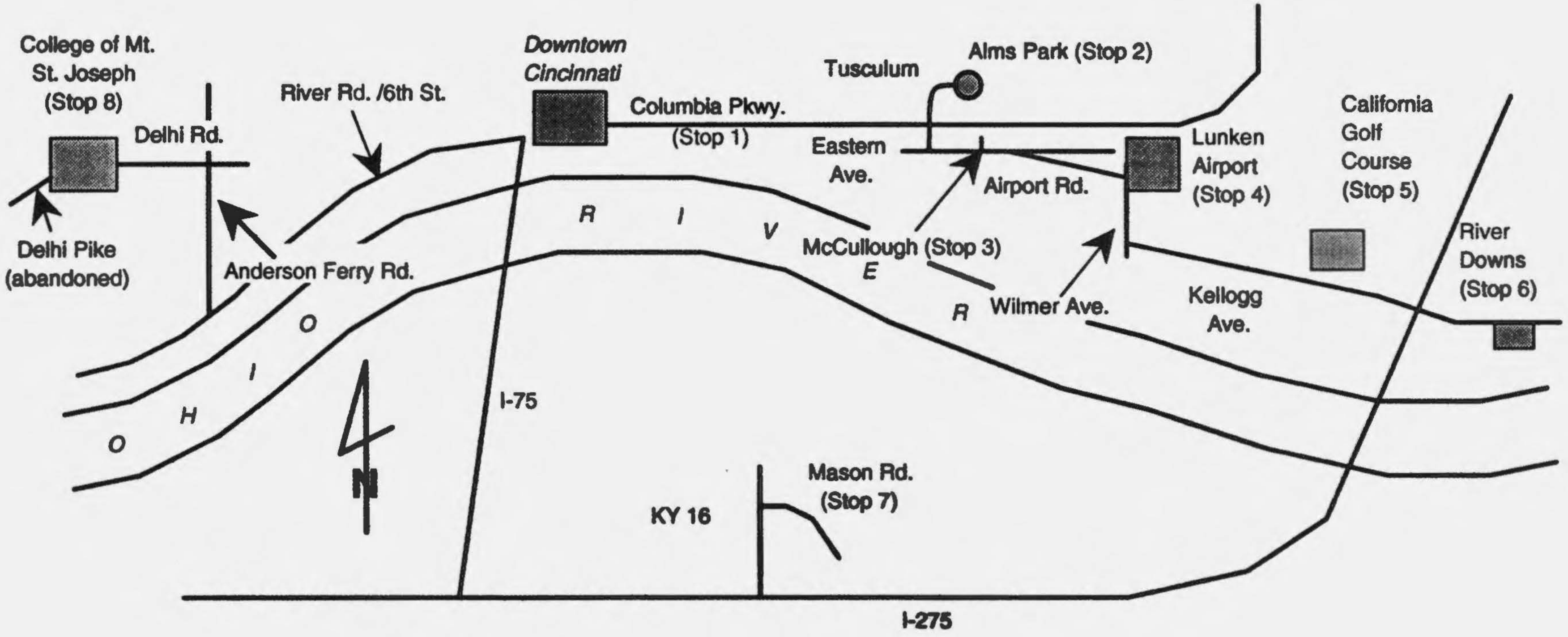

MAP OF FIELD-TRIP ROUTE, SHOWING SCHEDULED STOPS (NOT TO SCALE)