Landslides associated with the Kope Formation

Two different modes of failure occur in the colluvial materials overlying the Kope Formation. In the first mode large landslides involving areally several thousand square feet of failed materials, such as those that have occurred along the Ohio River in Bromley, Kentucky, and Hillside Avenue and East Miami River Road in Hamilton County, Ohio, have the morphology of a typical slump (fig. 4). The crown area is characterized by open, crescent-shaped cracks, and the foot area by a series of transverse ridges which are suggestive of earthflow. The principal failure surface appears to have a composite geometry that is nearly vertical in the crown area, parallel to the bedrock surface in the interior of the slide, and curved, concave-upward in the foot area. Much of the length of the failure is along the gradational contact between the colluvium and weathered bedrock. A slide of this type is first indicated by one or more crescent-shaped cracks that develop in the upper part of the slope. A slope can exist in this state for several years. A fully developed failure surface is indicated by downward slumping in the area of the cracks, accompanied by bulging in the lower part of the slope. Movement tends to be slow, usually only a few feet per year, and there appears to be scant change in the morphology of the slope failure after it has become fully developed. The characteristic transverse ridges and bulges in the foot area that are suggestive of earthflow do not typically mobilize into flows. Small slumps commonly form in the main scarp of the landslide after it has become fully developed.

Weathered bedrock is significantly more permeable than the underlying unweathered bedrock or the overlying colluvium. Water is commonly encountered in borings in this zone, and water levels after completion of drilling are, in many instances, higher than where first encountered. This suggests that excessive uplift pressures may exist under the colluvium, and failure may thus be enhanced. Excess water pressures seem to be a reasonable explanation for slope failures where strength of the material as measured by several types of tests in the laboratory appears sufficient to support the slope. The areal extent and magnitude of the excess water pressures have not been thoroughly studied, and their influence remains speculative.

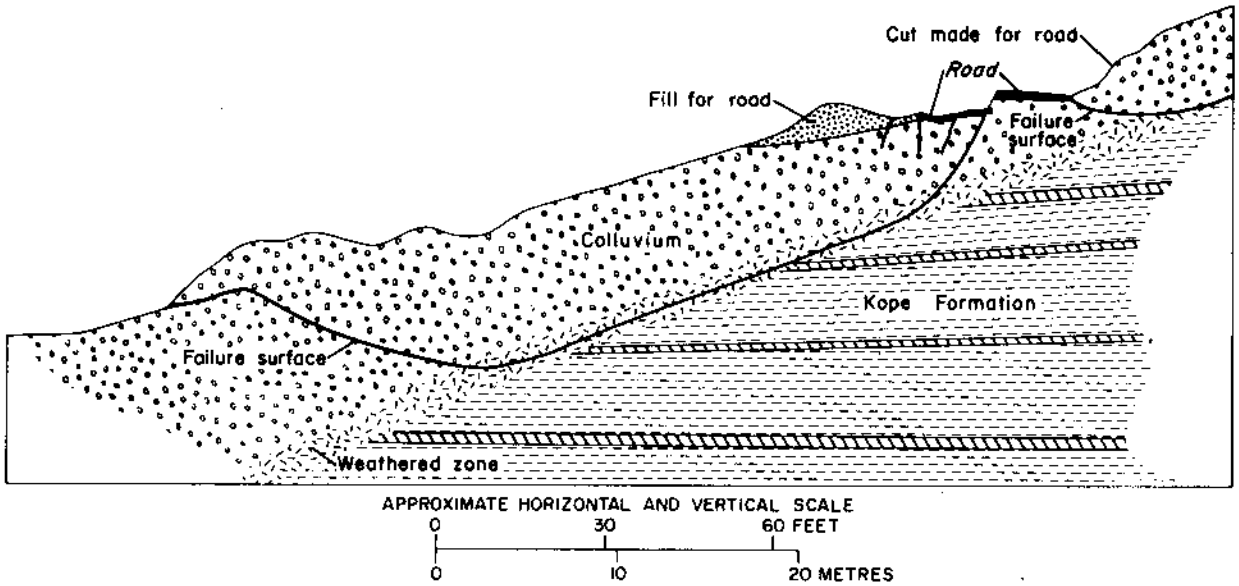

Figure 4.--Sketch of typical deep-seated landslide in colluvial material on the Kope Formation.

A second mode of slope movement associated with the colluvium overlying the Kope Formation is rapid earthflow. Failures of this type are common in steeper slopes of the Kope Formation in areas such as Columbia Parkway and Elberon Avenue (location 2 on fig. 1) in Cincinnati. Such failures most commonly occur in the early spring, after the soil has thawed but before vegetation has sprouted. These failures occur in areas where the entire colluvial cover, usually less than 6 feet (2 m) in total thickness, becomes mobilized and exposes the underlying weathered bedrock. Water apparently is a dominant agent in this process as well. A layer of weathered bedrock which extends under the shallow colluvial cover has similar potential for development of excess hydrostatic pressure to that of the larger, deeper seated landslides. After several cycles of freezing and thawing in the winter months, the density of the upper part of the soil is at a minimum. Heavy rains saturate the soil, increase its weight, and reduce its strength. These factors, perhaps combined with excess pressures in the water in the weathered bedrock, produce rapid failure.

Figure 5 illustrates a rapid earthflow that occurred in 1975 along Columbia Parkway. The earthflow moved over the retaining wall into the street, exposing layers of weathered bedrock below the surface of rupture.

Table 1 contains a compilation of some physical property data on slide materials in colluvium and on slightly weathered to unweathered shale of the Kope Formation. Data have been obtained from several geotechnical firms with experience in slope-movement problems in these materials. The large differences in clay fraction and Atterberg limits of the colluvial materials at the Hillside Avenue and Mt. Adams localities (fig. 1) appear to reflect contributions of materials other than the slaking of the Kope Formation.

Because the Kope is a persistent stratigraphic unit and because the overlying colluvium can be directly tied to the Kope Formation, areas of relative landslide susceptibility can be determined. Hough and Fleming (1974) prepared a landslide susceptibility map for the incorporated areas of Cincinnati by combining the location of outcrop of the Kope Formation with maps of 10-percent slope (5.7°) and 20-percent (11.3°) slope. On the basis of empirical observations, areas of 20-percent slope or steeper

Figure 5.--Earthflow on Columbia Parkway, spring 1975. The semicircular channel on the left is part of the exposed failure surface.

Table 1.--Summary of physical property data related to Kope Formation

[Sources of data are listed in "Acknowledgments"]

	Liquid limit (% H_2O)	Plastic limit (% H_2O)	Moisture content (percent)	Dry density (lb/ft^3)	Unconfined compressive strength (t/ft^2)	Clay (% <2μ)
			Colluvium on Kope Formation			
Hillside Ave------	27 (4)*	18 (4)	20 (3)	108.5 (4)	2.6 (9)	19 (3)
East Miami River Road------	-------	-------	22 (30)	104.2 (47)	3.2 (39)	-------
Mt. Adams---------	46 (26)	23 (26)	24 (5)	100.4 (4)	2.6 (5)	50 (44)
Clifton-McMicken--	36 (1)	19 (1)	18 (4)	----------	--------	-------
			Shale in Kope Formation			
Mt. Adams---------	43 (8)	19 (8)	5 (2)	----------	61.3 (2)	46 (7)
Clifton-McMicken--	-------	-------	5 (4)	142.0 (4)	20.8 (4)	-------

*Number in parentheses is number of determinations averaged to obtain indicated property.

appear to be in "critical natural stability" (Hough and Fleming, 1974), and areas of between 10- and 20-percent slope are susceptible to sliding if improperly graded.

Merritt (1975) has prepared a similar map for the Hamilton County Regional Planning Commission for the unincorporated areas of Hamilton County. In that study, he elected to consider slopes in the Kope Formation inclined at 15 percent (8.5°) or more to be in a potentially unstable state. His model for landslide susceptibility also considers presence or absence of vegetation and Fairmount soil as stability factors. The Fairmount soil as classified and mapped by the U.S. Department of Agriculture, Soil Conservation Service, appears to include the colluvial soils developed by weathering of the shales.

Generalized nature and distribution of glacial deposits

Landslides that occur in glacial deposits in the Greater Cincinnati area are not so readily predictable in terms of location and potential hazard as those associated with the Kope Formation because the distribution and nature of the glacial deposits are less predictable.

Southwestern Ohio was invaded by at least three continental glaciers that caused profound drainage changes and deposited a variety of materials in the valleys, along the hillsides, and on the upland surface. The distribution of the various materials is directly related to the sequence of glacial events and their effects. The following discussion, which is taken largely from Durrell (1961a, b) and Teller (1970, 1973), summarizes this history for the Cincinnati region.

Prior to the first ice advance in pre-Illinoian time, drainage was developed on a surface with 100 to 200 feet (30-60 m) of relief between upland divides at elevation 950 feet (290 m) MSL and drainageways. This drainage system, called the Teays system, flowed northward. The first ice advance into the Cincinnati area (called Kansan(?) or pre-Illinoian by different authors) caused ponding of the north-flowing streams, resulting in deposition of laminated clays in the lakes and initiation of major drainage changes. Erosional remnants of the clays are exposed near Claryville in Campbell County, Kentucky (fig. 1), and in some upland areas of Hamilton County, Ohio (Ettensohn, 1970; Teller, 1970). After retreat of the ice, the new river and many of its tributaries were cut several hundred