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REGOLITH IN THE PIEDMONT UPLAND SECTION, PIEDMONT PROVINCE, YORK, LANCASTER, AND CHESTER COUNTIES, SOUTHEASTERN PENNSYLVANIA

W. D. SEVON

Pennsylvania Geological Survey
P. O. Box 8453
Harrisburg, PA 17105-8453

ABSTRACT

Regolith has been mapped in the Piedmont Upland Section of the Piedmont Province in York, Lancaster, and Chester Counties, southeastern Pennsylvania. The Piedmont Upland Section is an area of rounded hills and flat-floored valleys developed by weathering and erosion of schist, gneiss, metaquartzite, and other metamorphic rocks. In situ regolith includes weathered rock and saprolite. Transported regolith includes alluvium, colluvium, fluvial terrace deposits, and anthropogenic deposits. Weathered rock occurs almost everywhere except where erosion has exposed unweathered bedrock in valley bottoms. Thin colluvium occurs discontinuously on hill tops and side slopes while thicker colluvium occurs in heads of first-order drainage basins and in small valleys lacking perennial streams. Alluvium is present in all valleys with perennial streams. This regolith is the product of early to middle Cenozoic weathering, middle to late Cenozoic erosion, Pleistocene periglacial erosion and deposition, and recent anthropogenic activity.

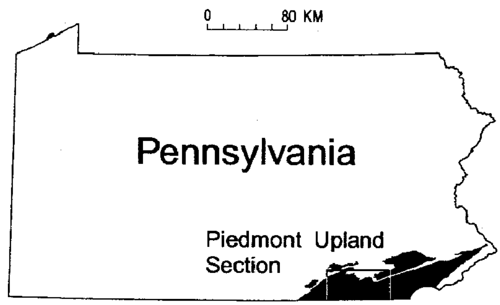


Figure 1. Map showing area of the Piedmont Upland Section, Piedmont Province (black area) in southeastern Pennsylvania. Small rectangle within the Piedmont Upland Section and adjacent area shows location of Figure 2.

INTRODUCTION

Regolith includes all the unconsolidated material at the surface of Earth's crust, regardless of its origin (Merrill, 1897). Regolith of diverse character and origin covers much of the Piedmont Upland Section of the Piedmont Province in southeastern Pennsylvania (Fig. 1). Until recently this regolith received little attention from the geological community. Various soils reports (e.g., Custer, 1985; Hersh, 1963; Kunkle, 1963) address the uppermost part of the regolith as a material, but do not touch on its origin or historical significance. This paper presents information obtained during recent mapping of regolith in southeastern Pennsylvania.

The Pennsylvania Geological Survey started to investigate the bedrock geology of the Piedmont Upland Section of Lancaster County in 1987. In 1989 this work was expanded in a cooperative project with the Maryland Geological Survey to map the surficial geology of the York 1:100,000-scale quadrangle (Fig. 2), an area of 32 1:24,000-scale quadrangles in York, Lancaster, and Chester Counties, Pennsylvania and Carroll, Baltimore, Harford, and Cecil Counties, Maryland. Twelve full and 6 partial 1:24,000-scale quadrangles (Fig. 2) were mapped in Pennsylvania and the project terminated upon completion of open-file reports (Sevon, 1996).

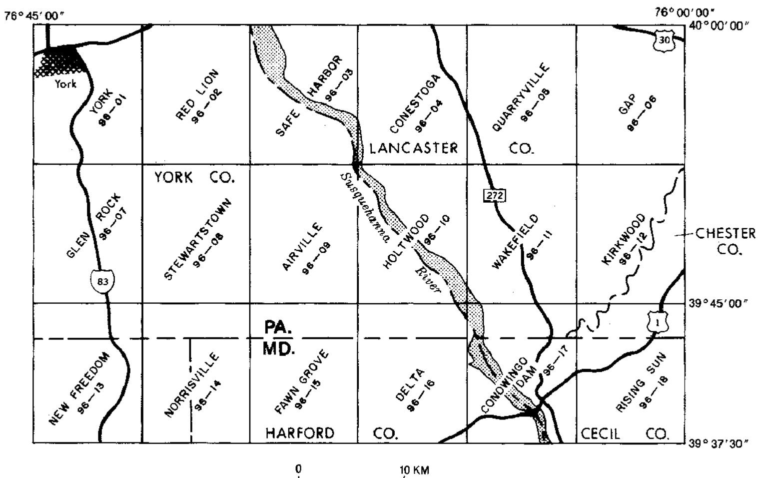


Figure 2. Index map showing that part of the York 1:100,000 quadrangle, Pennsylvania-Maryland, mapped and reported on herein. The York quadrangle is subdivided into 1:24,000-scale quadrangles whose names and open-file report numbers are in diagonal lettering.

BEDROCK GEOLOGY

Bedrock

Bedrock in the Piedmont Upland Section in York, Lancaster, and Chester Counties is mainly schist, but a variety of other metamorphic rocks occur. The Geologic Map of Pennsylvania (Berg and others, 1980) shows the schist as either Wissahickon Formation or Peters Creek Formation, both of presumed lower Paleozoic age. Valentino (1994) indicates that schist north of the Peters Creek Formation in the western Piedmont should be termed Octoraro Formation rather than Wissahickon Formation. That terminology is followed here (Fig. 3).

The Octoraro Formation consists of numerous lithologically distinct members including pelitic schist, plagioclase-bearing schist, units of interlayered schist and metasandstone, and phyllonite. All of these rocks contain moderate to large amounts of muscovite and small to moderate amounts of quartz.

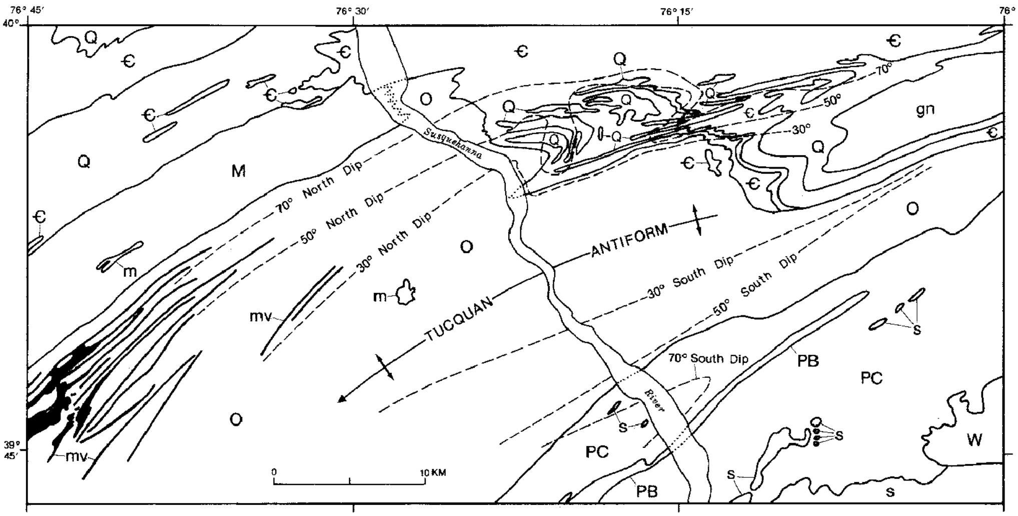
The Peters Creek Formation has three metasedimentary lithofacies: quartzose schist, graded metasandstone, and massive metasandstone (Valentino and Gates, 1995). The quartzose schist consists of about equal parts of quartz, chlorite, and muscovite. The other lithofacies are dominated by quartz with smaller but abundant quantities of feldspar.

Other rocks include metabasalt, mica-chlorite quartzite schist of the Marburg Schist, serpentinite, Peach Bottom Slate, Cardiff Conglomerate, metaquartzites of the Cambrian Chickies and Antietam Formations, phyllites and schists of the Cambrian Harpers Formation, and gneiss. The character of all of these rocks, except for gneiss, is discussed in Stose and Jonas (1939). These other rocks all have very small areal distribution except for the Marburg Schist and the gneiss (Fig. 3).

Structure

From a tectonic point of view, structure in the Piedmont Upland is complex and involves multiple episodes of metamorphism and deformation (Valentino, 1994). From a regolith point of view, structure is relatively simple. Most of the rocks are dominated by a well developed schistosity that generally trends $060^\circ \pm 10^\circ$ azimuth but locally may diverge considerably from that orientation (Wise, 1970). This schistosity is considered to be parallel or subparallel to the bedding of the pre-metamorphosed sedimentary rocks.

The schistosity dips south at angles generally



EXPLANATION

Є Cambrian and Ordovician carbonates	M Marburg Formation	W Wissahickon Formation	gn Gneiss	m Marble
Q Metaquartzites of the Chickies, Antietam, and Harpers Formations	O Octoraro Formation	PB Peach Bottom slate and Cardiff conglomerate	s Serpentinite	mv Metavolcanics
	PC Peters Creek Formation			

Figure 3. Bedrock geologic map of the mapped area (from Berg and others, 1980). Axis of Tucquan antiform and contours of dip of foliation (dashed lines) modified from Wise (1970).

greater than 30° in much of the area (Fig. 3). In the north-central part of the area (Safe Harbor, Conestoga, and Quarryville quadrangles in Fig. 2) the dip of schistosity flattens and reverses direction across the Tucquan antiform (Fig. 3). Two other well developed but less prominent schistosities occur. Fractures are abundant. Serpentinite and gneiss are massive rocks that lack the systematic planes described above.

GEOMORPHOLOGY

Terrain of the Piedmont Upland Section consists of rounded hills and narrow to broad, flat-floored valleys. Uplands are never absolutely flat, but some in Lancaster County have small areas that are nearly flat. More than two thirds of the landscape is gently sloping and undulating to moderately sloping and rolling (Custer, 1985; Hersh, 1963; Kunkle, 1963). Less than 15 percent of the landscape is steeply sloping (Custer, 1985; Hersh, 1963; Kunkle, 1963). Slopes are gentle in the headwaters of first-order drainage basins and increase in steepness gradually downstream as the valley becomes well defined and deepens relative to adjacent uplands. The steepest slopes occur in the lower reaches of tributaries to the Susquehanna River and along the Susquehanna River itself.

The Susquehanna River cuts through the upland in a gorge that is 120-150 m deep through most of its length, but lessens to only 60 m deep near the boundary between Pennsylvania and Maryland. All other drainage in the mapped area is to the Susquehanna River.

Drainage pattern inland from the Susquehanna River is mainly dendritic (e.g., Muddy Creek in the Airville and Stewartstown quadrangles [Fig. 4]). Trellis pattern occurs in the northern part of the Glen Rock quadrangle (Fig. 4) where alternations of rocks of different hardness parallel the dominant schistosity. Many short reaches of streams throughout the mapped area trend parallel to the plane of dominant schistosity (e.g., southwest quarter of the Gap quadrangle; western quarter of the Wakefield quadrangle [Fig. 4]).

Streams entering the Susquehanna River are entrenched in their valleys for a kilometer or more upstream from their mouths. These streams flow on bedrock in the entrenched reaches where there is generally no floodplain

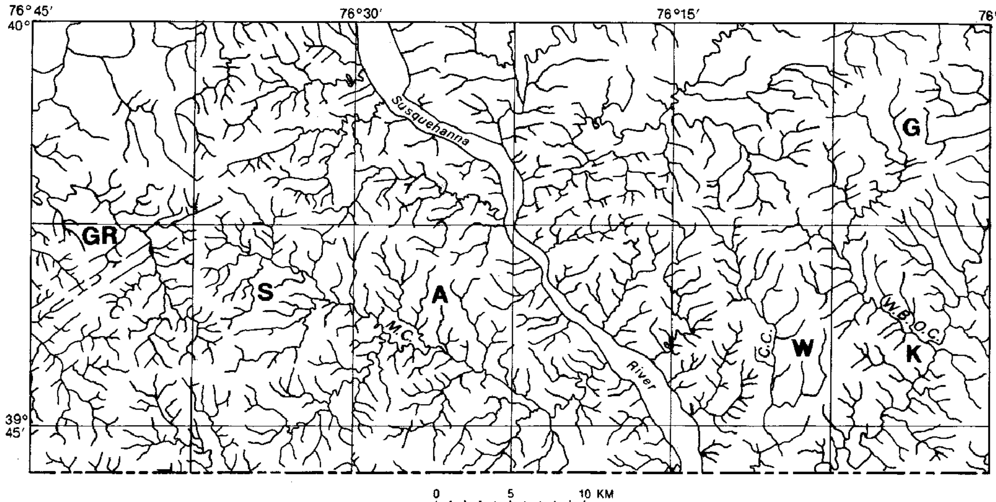


Figure 4. Map of drainage pattern in part of the York 1:100,000 quadrangle. Stream names are: C.C. - Conowingo Creek; M.C. - Muddy Creek; W.B.O.C. - West Branch Octoraro Creek. Quadrangles referred to in text are: A - Airville; G - Gap; GR - Glen Rock; K - Kirkwood; S - Stewartstown; W - Wakefield.

and some to abundant exposure of bedrock along the valley walls. The entrenched reach terminates upstream at a knickpoint. Upstream from the knickpoint there is a broad floodplain and little or no bedrock exposed within the valley. Larger streams such as West Branch Octoraro Creek in the Kirkwood quadrangle and Conowingo Creek in the Wakefield quadrangle (Fig. 4) have additional knickpoints upstream from the lowermost one. Lengthy and well developed floodplain reaches separate each one of these additional knickpoints.

Maximum elevation in the area is 318 m; minimum, 34 m. Elevation in about half the area is between 183 and 213 m. The highest area east of the Susqehanna River is on the crest of the Tucquan antiform (Fig. 3); west of the Susquehanna River, on the drainage divide between north and south flowing drainage (Fig. 4). Local relief in York County is generally 60-90 m; in Lancaster County, generally 30-60 m; in Chester County, generally 30-50 m. The Piedmont Upland is separated from the Piedmont Lowland to the north by an abrupt, well defined, steep slope that rises 50 m or more from the lowland to the upland.

Views from the tops of many uplands give a strong visual impression of elevation accordance with adjacent and distant uplands. In addition, there appears to be, in places, a downward stairstepping of accordant levels. These aspects of accordance, which are more visual than real, contributed to earlier interpretations of numerous peneplain levels (Knopf and Jonas, 1929).

REGOLITH

Introduction

Regolith in the Piedmont Upland Section of the mapped area comprises in situ and transported materials. In situ regolith consists of weathered bedrock (Graham and others, 1994) and saprolite (Stolt and Baker, 1994). Transported regolith consists of alluvium, colluvium, and anthropogenic deposits. Except for material present in fluvial terrace deposits along the Susquehanna River, all of the mapped regolith originated within the Upland Section. Occasional occurrences of high silt content in the uppermost part of soil profiles on uplands near the Susquehanna River probably indicate the presence of locally derived loess (Pollack, 1992),

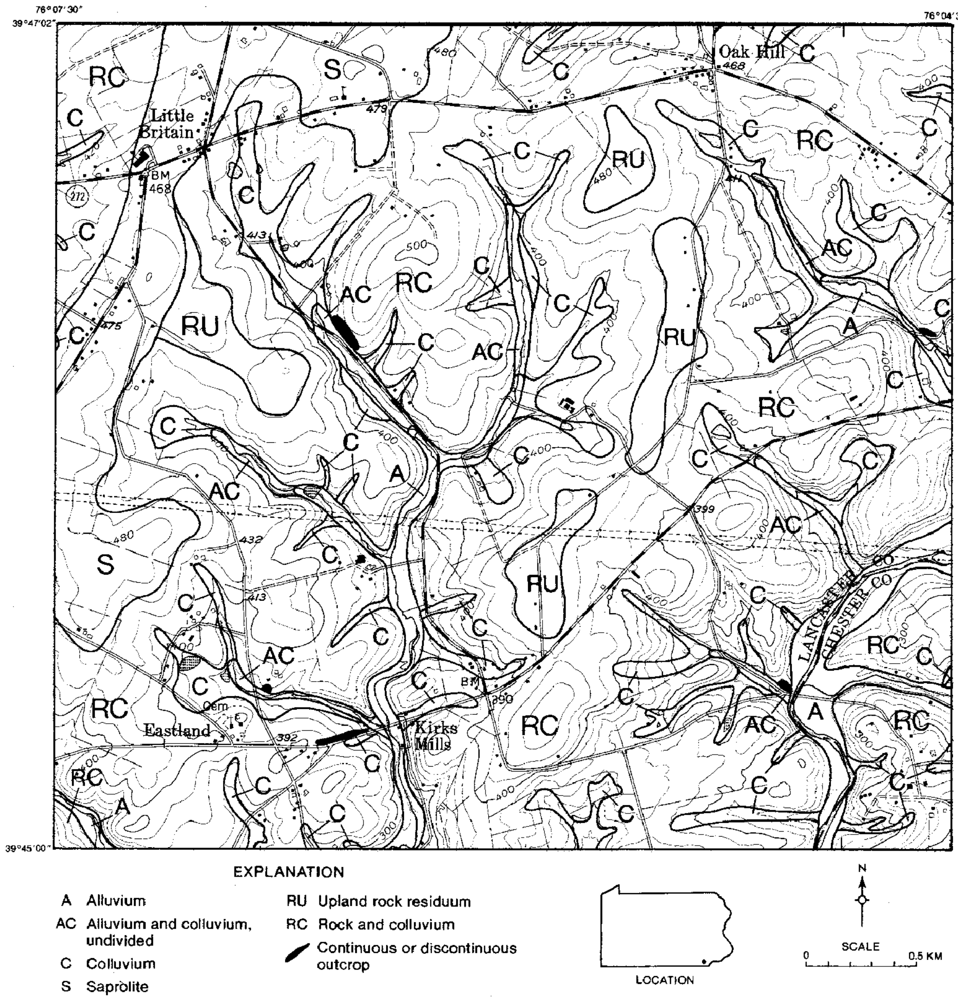


Figure 5. Geologic map of the regolith in part of the Kirkwood quadrangle, Lancaster and Chester Counties, Pennsylvania (See Fig. 2 for location.). Contour interval is 20 feet.

but the silt is a very minor component of the regolith. Soils occur on all of the nonanthropogenic regolith materials, but are not discussed here (see Custer [1985], Hersh [1963], and Kunkle, [1963] for soils information). Figure 5 is an example of a map of the regolith.

Saprolite and upland rock residuum are in situ regolith units on the map. The upland rock residuum is deeply weathered rock that is not weathered sufficiently to be classified as saprolite and that underlies a relatively flat upland. Rock of the rock and colluvium map unit underlies sloping uplands and side slopes and is generally less weathered than upland rock residuum. Alluvium and colluvium are transported regolith units. Alluvium and colluvium undivided is a map unit utilized wherever both alluvium and colluvium occur in the same valley bottom, but cannot be differentiated at the 1:24,000 map scale.

In Situ Regolith

Weathered Bedrock

Weathered bedrock comprises all in situ rock that occurs between the surface (or saprolite or an overlying transported regolith) and unweathered bedrock at depth. Not all weathered bedrock is regolith. Only weathered bedrock that is broken or breaks readily with application of minimal force is considered regolith. Chemically weathered bedrock that retains coherence and resistance to breakup is not considered regolith.

Table 1 indicates the depth to what water-well drillers consider unweathered bedrock in the map area. The records from which the data come are inadequate to indicate the nature of the weathered-bedrock zone. A few outcrops show that the upper part of this zone comprises either bedrock that is broken or bedrock that is easily broken. The lower part probably comprises bedrock that is chemically weathered to some extent, but not broken or easily broken.

Near-surface bedrock breaks along planes of foliation and fracture. This zone of broken bedrock may be several meters thick (Fig. 6). Foliation in the upper part of the broken-bedrock zone rotates to a downslope direction and a slope-parallel orientation. There may be a well-defined plane of detachment separating weathered-bedrock regolith from non-regolith weathered bedrock. The amount of separation between broken pieces is variable but is generally in the range of a few millimeters to a few centimeters. The size of the broken pieces is variable and is controlled by spacing of the planes of foliation and fracture. Bedrock breakup results from physical and chemical weathering and stress-release fracturing caused by erosion (Ferguson, 1967; Wyrick and Borchers, 1981).

Table 1. Thickness of regolith in the Piedmont Upland section of part of York, Lancaster, and Chester Counties.

Bedrock	Mean$_1$	Standard deviation	Range	Number of wells$_2$
Schist	11	7	0-69	2864
Metaquartzite	13	9	0-72	428
Gneiss	13	6	2-28	71

$_1$ - Depth to bedrock in meters.

$_2$ - Data from water well records on file at the Pennsylvania Geological Survey, Harrisburg, PA

Considerable variation occurs in bedrock-fragment quantity, size, and degree of weathering. This variation is best seen in plowed fields. The presence of large, unweathered, rock fragments indicates that unweathered bedrock is near the surface. The presence of only small, deeply weathered, rock fragments indicates that unweathered bedrock is not near the surface. This distinction is subjective and is best observed in fields that have been plowed but lack crops, have been rained upon one or more times since being plowed, and have continuous exposure from upland top to valley bottom.

Some plowed fields show considerable rock-fragment variation within very short distances, a few meters or less. Small areas with abundant, large, unweathered, rock fragments may occur adjacent to areas with much smaller, more weathered, rock fragments or adjacent to material interpreted as saprolite that has very few or no rock fragments. These rock-fragment variations usually occur in bands that parallel dominant foliation.

Mineral alteration of bedrock in the weathered-bedrock zone is variable, but has not been studied in the mapped area. Much of the bedrock is iron stained from weathering of iron-bearing minerals such as magnetite. The degree of chemical alteration is not enough to produce a saprolite but is enough to aid bedrock breakup.

Lithofacies and foliation control bedrock weathering and saprolite development. Lithofacies within the schists can vary almost meter by meter (Valentino, unpublished data on file at the Pennsylvania Geological Survey, Harrisburg). Consequently, it is common to have very weathering-susceptible lithofacies interspersed with weathering-resistant lithofacies and thin zones of weathered bedrock or saprolite adjacent to essentially unweathered bedrock (Fig. 7). In much of the mapped area, foliation dips south at greater than 30° (Fig. 3). In this area depth to unweathered rock is generally greater than 10 m (Table 1), but unweathered rock and saprolite distribution and depth to unweathered bedrock

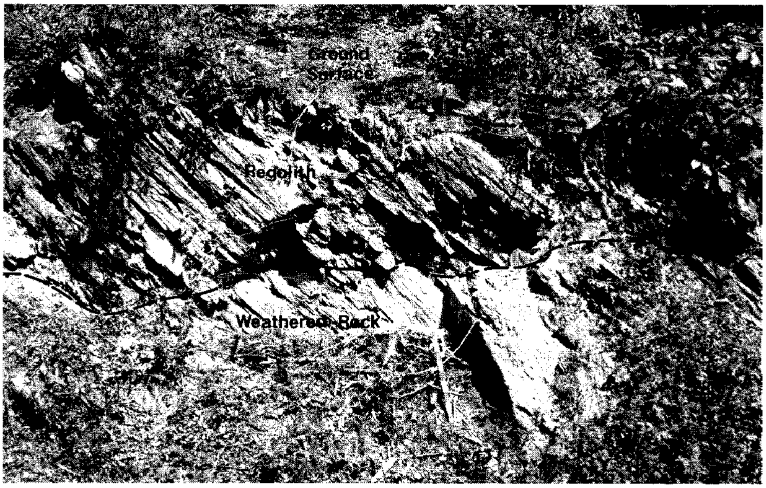


Figure 6. Photograph of an outcrop of regolith composed of broken and weathered rock in Lancaster County. Regolith has slight separation of weathered rock along foliation planes, some rotation near the surface, and a hint of detachment from less weathered and unbroken bedrock in the lower part of the outcrop (at dashed line). Bedrock is schist of the Peters Creek Formation. Scale is divided into 10-cm intervals.

Figure 7. Photograph of an outcrop of unweathered bedrock (on left) adjacent to saprolite (on right) in Lancaster County. Bedrock is schist of the Peters Creek Formation. Foliation is dipping to the right (south). Scale is divided into 10-cm intervals.

are variable because of variations in bedrock lithofacies (Fig. 8). The relationship between bedrock lithofacies and degree of saprolite development has not been studied in this area.

In the north-central part of the area where foliation flattens across the Tucquan antiform (Fig. 3), unweathered rock is almost at the surface. Where foliation is parallel to the surface, water infiltration and subsequent rock weathering is inhibited and depth of weathering is small.

Two weathered rock units were used in mapping to subdivide the large area of weathered rock that occurs in the Piedmont Upland. Up-

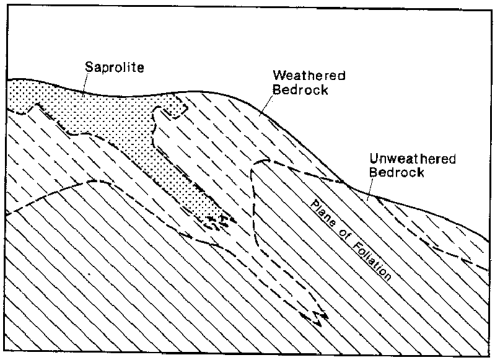


Figure 8. Cross section of landscape (no scale) showing hypothetical variability of thickness of weathered bedrock and saprolite as a function of foliation and lithofacies differences.

land rock residuum comprises weathered rock that underlies relatively flat uplands but is not weathered sufficiently to be called saprolite. Most of the Piedmont Upland slopes are underlain by rock that is variably weathered, but is not as weathered as upland rock residuum. It is possible that this widespread weathered rock unit could be subdivided into two units based partly on degree of weathering and partly on slope position. However, availability of outcrops and plowed fields were not sufficient to allow such subdivision during this mapping project.

Saprolite

Saprolite, as the term is used here, refers to material that "is isovolumetric with the underlying bedrock, as indicated by the retention of texture and fabric of the parent material, and it exhibits gradational chemical and mineralogical changes of composition going from the parent to the geomorphic surface" (Pavich, 1985, p. 308; see also Stolt and Baker, 1994). In addition, there has been little or no "movement of alteration products. Leaching has changed feldspars to clay minerals and oxidation of ferrous iron to ferric iron has given the saprolite a brownish color" (Carroll, 1970, p. 19-20). Saprolites are typically soft and are easily dug with a shovel or cut with a knife.

Mappable (1:24,000 scale) saprolite occurs in Lancaster and Chester Counties, but is generally absent in York County. Local, small occurrences of saprolite may occur anywhere, but are generally undetectable except by chance exposure. Mappable saprolite occurs only on the highest uplands and is probably not more than a few meters thick. Unfortunately, data from water-well drill holes (Table 1) is not adequate to permit discrimination of saprolite from weathered bedrock. Plowed fields on saprolite are almost totally devoid of rock fragments and those fragments that occur are small and deeply weathered. Surfaces generally devoid of rock fragments and interpreted to be underlain by saprolite may have abundant fragments of vein quartz. Vein quartz is common, but not ubiquitous in the Piedmont Upland area. Rock fragments typical of weathered rock are found only a few meters in elevation below the upper surface of those few uplands underlain by saprolite. As indicated previously, saprolite may occur adjacent to unweathered bedrock because of differences in weathering susceptibility of schist lithofacies (Fig. 7). Narrow, foliation-parallel bands of saprolite occurring between larger bands of weathered schist are sometimes recognizable in plowed fields because the band of saprolite is significantly redder in color than the adjacent weathered schist.

Saprolite formed from metaquartzite is very uniform and is composed entirely of gray, quartz sand. Saprolite formed from schist is variable in character depending on the parent schist. In the Octoraro Formation saprolite is mainly quartz and muscovite with occasional seams of vein quartz and is yellow brown to reddish in color. Rocks in the Peters Creek Formation are dominated by quartz; the associated saprolites are generally gray and contain lots of quartz and some muscovite. Exposures of saprolite in other rock types have not been observed.

Transported Regolith

Alluvium

Alluvium is material that has been transported and deposited by running water (Buol, 1994). Alluvium occurs throughout the mapped area in the bottoms of valleys possessing peren-

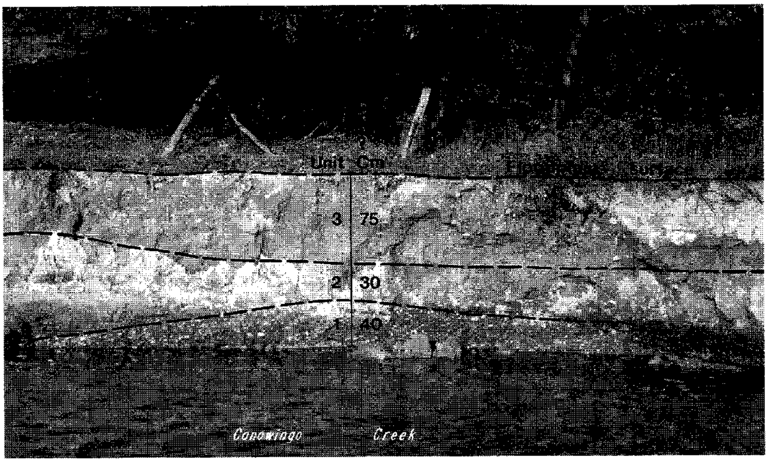


Figure 9. Photograph of alluvium exposed along Conowingo Creek, northern Wakefield quadrangle, Lancaster County (See Fig. 4 for location of quadrangle). Measurement and description at vertical bar. Unit 1 is a gravel bar composed of platy fragments of schist (90% ±) and vein quartz (10% ±). Pebbles are mostly in point contact and 0.5-4 cm in largest dimension. Platy fragments are imbricated. Interstices are filled with clay, silt, and 2-5 mm quartz granules. Matrix is light to medium gray because of organic content. An additional 40 cm of gravel bar occurs below water level. Unit 2 is medium to dark gray, organic-rich silt and clay with scattered 2 mm- to 1 cm-diameter quartz pebbles in the lower 10-15 cm. Unit thickens laterally away from crest of gravel bar and changes to light gray and reddish yellow mottled silt and clay with a basal organic-rich zone that is gradational into the underlying gravel and a thin (< 10 cm) organic zone at the top. Unit 3 is brown, uniform, vertically-burrowed silt and clay with almost no sand or pebbles. No soil development occurs at the floodplain surface.

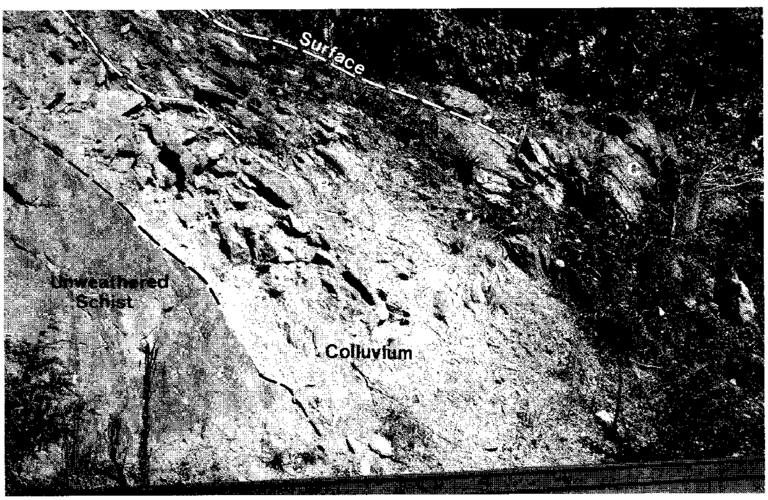


Figure 10. Photograph of a man-made outcrop of colluvium along the Conrail railroad line at Peters Creek in Lancaster County. Rock fragments are derived from schist of the Peters Creek Formation. Note irregular shape and random orientation of rock fragments in Unit A (lower) and slope-parallel orientation of platy rock fragments in Unit B (upper). C is one of several large blocks of schist that occur at the base of the deposit.

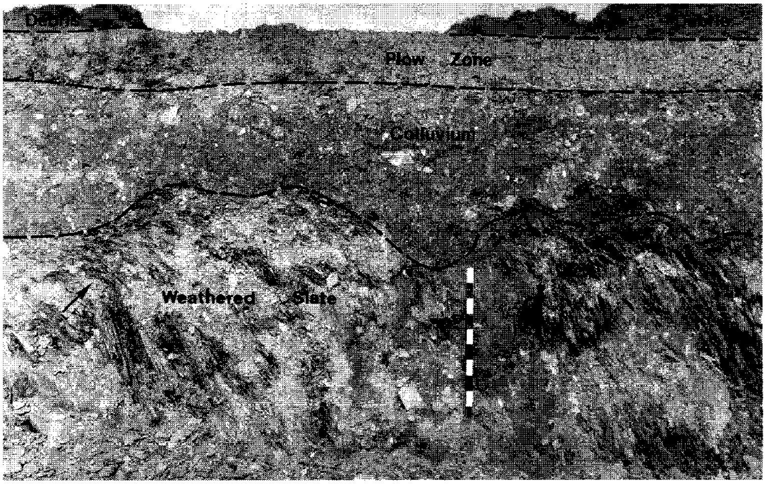


Figure 11. Photograph of fine-grained colluvium overlying weathered slate of the Cambrian-age Chickies Formation in a temporary excavation near York in York County. Arrow points to slate that is bent by down-slope creep. Colluvium is derived from deeply weathered slate or saprolite farther upslope. Most, if not all, of the exposed weathered slate is sufficiently broken and separated along planes of foliation to be called regolith. Slope is less than 5°. Scale is divided into 10-cm intervals.

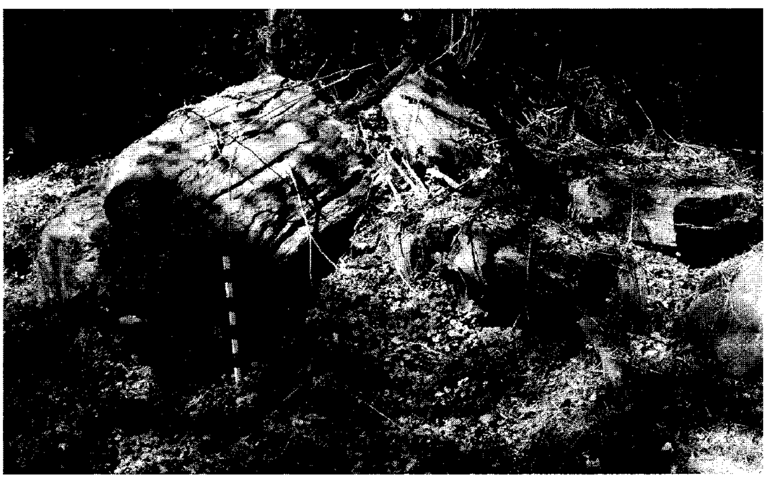


Figure 12. Photograph of blocks of schist that comprise part of colluvium at the base of a typical steep bedrock slope in Lancaster County. Blocks are derived from the Peters Creek Formation. Scale is divided into 10-cm intervals.

nial steams. The alluvium comprises deposits of the floodplains and stream channels. The floodplains are a few to many tens of meters in width, are quite flat, and have well defined changes in slope gradient at their margins. In almost every valley the stream has eroded into the floodplain sediments to a depth of a meter or more. Exposures in cutbanks along these streams provide the only available information about the alluvium.

Most exposures of alluvium show two contrasting components: lower coarse-grained material and upper fine-grained material (Fig. 9). The lower material is composed of schist fragments and/or pieces of vein quartz in a matrix of sand, silt, and clay. Stratification and sorting are present and platy fragments are imbricated. These coarse materials are generally capped by a few to many centimeters of fine-grained sediment that is either light to dark gray throughout because of high organic content or is capped by a dark organic zone, a presumed paleosol A-horizon. This organic zone has a sharp upper boundary. It is overlain by up to a meter of fine-grained sediment that is brown in color, has very few or no rock fragments, little or no stratification, and no soil development.

The data available indicate that the alluvium is seldom more than a few meters thick in most valleys and is often little more than a meter thick.

Colluvium

Colluvium is mass-transported, unconsolidated material (Buol, 1994) composed of a poorly sorted to unsorted mixture of clay, silt, sand, and rock fragments (Fig. 10). The rock fragments are derived from local bedrock, are surrounded by a fine-grained matrix, are generally in contact with each other, and often comprise the bulk of the colluvium. A vertical sequence of colluvium may have abrupt changes in matrix texture, rock-fragment content, and color (Pollack, 1992).

Rock fragments impart character to the colluvium. Derived mainly from either schist or quartzite in the mapped area, the fragments are usually platy when only a few centimeters long but are irregular in shape when larger. The fragments may have any orientation within the colluvium (Fig. 10), but the platy fragments tend to be aligned subparallel to the slope and often the alignment gives the appearance of crude bedding. The rock fragments are variably weathered depending upon the degree of weathering of the parent bedrock and the length of time in residence as colluvium. Rock fragments are generally sparse to absent in colluvium derived from saprolite or deeply weathered rock (Fig. 11). Colluvium at the base of steep slopes where unweathered bedrock is close to the surface is usually composed of blocks a meter or more in at least one dimension (Figs. 10 and 12). The character and relative abundance of clasts on the surface are invaluable aids to mapping.

The matrix material is variable, again dependent upon the nature of the parent material. Matrix derived from metaquartzite is mainly sand with some silt. Matrix derived from schist is composed of granules, a moderate amount of sand and silt and a little clay. Small to large variations in matrix texture and color are common.

Cb	Brown colluvium: high rock fragment content, low matrix Content, abrupt base, occasional basal stonelines.
Clr	Light red colluvium: 7.5YR5/6±, low rock fragment content, High matrix content, abrupt to transitional base, occasional basal stonelines.
Cdr	Dark red colluvium: 2.5YR4/8-5YR5/6, moderate to high rock fragment content, moderate matrix content, may have several discrete red layers, abrupt base.
Ps	Pseudo-saprolite: color and mineralogic banding, finely bedded, bedding parallels slope, abrupt base.
S	Saprolite
Rw	Weathered rock
R	Unweathered rock

Figure 13. Idealized stratigraphic sequence occurring in areas of colluvium.

The primary stratigraphic sequence within the colluvium in the mapped area is shown in Figure 13. Where observed in cross section (generally in back-hoe pits), the boundaries between units are sharp, the order of the sequence is invariable, and the various units sometimes have stonelines at their boundaries. The three-dimensional continuity of colluvial units is not known. However, observed cross-sections in backhoe pits as close together as 15 m have no correlation of specific colluvial units. Sequences examined in many backhoe pits and other exposures (Pollack, 1992) indicate that any number of the stratigraphic units may be absent at a particular site. The lower red colluvium is of particular interest because the parent material is not red. Pollack (1992) indicates that, except for its color, the red unit lacks indicators of deep soil development: i.e., clay films and well-developed structure. Therefore, the lower red unit may represent either material deeply weathered prior to downslope transport and deposition or material that was transported, deposited, deeply weathered, partly stripped, and then frost churned.

Not all sequences of colluvium fit the simple stratigraphy in Figure 13. Some sequences have more than four discrete colluvial units. These

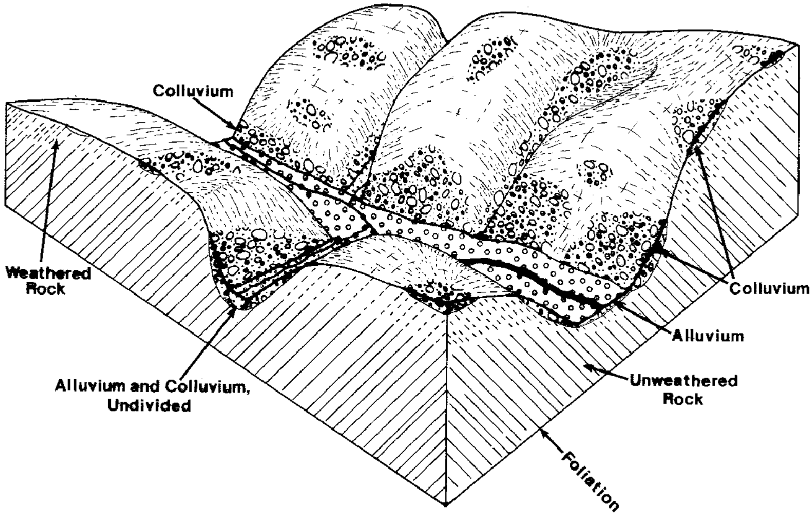


Figure 14. Block diagram showing variability in occurrence and thickness of colluvium in different landscape positions.

are distinguished by sharp to transitional boundaries, changes in matrix texture, rock-fragment content, and color. Within the numerous sequences containing many thin, discrete units, no consistent vertical stratigraphy exists beyond that shown in Figure 13.

Ice wedge casts and involutions, structures interpreted to be periglacial in origin (Pollack, 1992), occur in the colluvium but are not often seen because of lack of good exposures. Similar structures are known from many places elsewhere in Pennsylvania (Ciolkosz and others, 1986). These structures occur in interfluve areas and are formed mainly in the lower red colluvium (Fig. 13).

Colluvium is widespread within the mapped area. It may be found anywhere except on nearly vertical slopes and broad floodplains. Its thickness is variable and unpredictable within the same landscape element (interfluve, shoulder, backslope, and footslope), but predictably thinner in divergent (convex) slope positions and thicker in convergent (concave) slope positions (Pollack, 1992). Colluvium is absent at the slope shoulder where bedrock is near or at the surface. Colluvium generally thickens downslope from the shoulder and is typically thickest at the base of the footslope. Figure 14 is a hypothetical diagram showing colluvium variability. Colluvium is usually less than 2 m thick except in centers of small first-order drainage basins lacking perennial streams. However, thick colluvium may occur almost anywhere on the landscape.

Pseudo-saprolite

Included within the category of colluvium is a deposit different from the colluvium described above. This material is composed of quartz and muscovite grains, is very evenly bedded at the millimeter scale, has striking alternations of color, and has bedding that is similar in appearance to layering in saprolite. The deposit, where present, is always at the base of the colluvial sequence (Fig. 13) and rests on a surface that truncates either saprolite or bedrock. Bedding of the deposit is parallel to subparallel to slope. The material is very friable and well sorted within individual layers. The deposit is not known to be more than a few tens of centimeters thick. Because of its appearance, this material can be easily confused with saprolite in small isolated outcrops. However, observed saprolite in the area is not as finely layered and muscovite in the saprolite does not have the appearance of being discrete, detrital grains. Observation of limited exposures indicates that this is saprolite-derived material that has been transported from its original position by creep and has suffered minimal disturbance during the process, which is why it resembles saprolite so closely.

Alluvium and colluvium undivided

Alluvium and colluvium undivided is a unit of mapping convenience. It occurs in valleys that are too narrow to allow map separation (1:24,000 scale) of the two units. Limited exposures show that stratified alluvium is laterally interbedded with unstratified colluvium. In some of these valleys colluvial slopes from adjacent valley sides meet along limited stretches in the valley center and no floodplain exists even though a perennial stream is present. The general character of the materials appears to be the same as described above for alluvium and colluvium. Distinct stratigraphic units in the colluvium, such as those in Figure 13, were not observed.

Fluvial terrace deposits

Fluvial terrace deposits exist in the mapped area along the Susquehanna River, but have not been mapped because they are less than 2 m thick. These deposits have been studied in detail by Pazzaglia and Gardner (1993) and their interpretations are critical to the discussion of geologic history presented below.

Although mappable (1:24,000 scale) fluvial terrace deposits occur at several different levels outside the Piedmont Upland Section (Engel and others, 1996), deposits of each level are generally absent within the gorge cut through the upland by the Susquehanna River. The steepness of the gorge walls has prevented preservation of these deposits except in a few places where rock-cut straths occur. Thin fluvial terrace deposits are preserved on the uplands adjacent to and within a kilometer of the Susquehanna River. Materials in these upper terrace deposits are primarily resistant lithologies (quartz, quartzite, and sandstone) derived from outside the Piedmont upland. The lower terraces contain lithologies that can only have been derived from Grenville rocks in Canada and were brought into the upper Susquehanna River basin by glaciers during the Pleistocene Epoch within the last 1.8 Ma.

Several exposures in stream valleys tributary to the Susquehanna River show gravels composed of quartz and schist fragments. These gravels are a few centimeters thick and occur in positions on the landscape above the modern floodplain level. The gravels are presumably fluvial terrace deposits. However, they have not been mapped as such because there is no associated terrace morphology, the deposits are buried beneath colluvium, and they are less than 2 m thick.

Anthropogenic deposits

Most regolith materials of anthropogenic origin in the mapped area are the result of erosion of soil since settlement and land clearing (Trimble, 1974). Most of this material is included in mapped deposits of alluvium and colluvium. Small, unmapped deposits of this type include the following: (1) The upper reaches of first-order drainage basins often have fence rows normal to valley length. Accumulations of eroded sediment on the upslope side of the fence row are often a half meter or more thick. (2) Small, fan-shaped deposits of eroded material are often present at the base of slopes adjacent to floodplains. Here, soil eroded from upslope fields has been channeled by convergent slopes to the base of the sideslope. The bulk of this material lies on floodplain alluvium and is mapped as alluvium. (3) The fine-grained, brown alluvium that lies above the buried organic zone in floodplains of all sizes is sediment eroded from the landscape since land clearing and the start of cultivation. (4) Additional mappable (1:24,000 scale) anthropogenic materials include solid-waste landfills and artificial fill used extensively to elevate roadways.

In urban areas where a lot of development has occurred, much of the landscape can be termed ***disturbed land.*** Here the regolith materials have been removed, rearranged, and relocated in a variety of ways. However, a few years after disturbance, construction, and landscaping are completed, it is difficult to recognize the type and amount of disturbance unless reference is made to pre-disturbance aerial photographs. These areas of disturbed land have not been mapped.

GEOLOGIC HISTORY

Mesozoic

There is little real data about the history of the Piedmont Upland Section during the Mesozoic. Up to 12 km of material have been eroded from the Piedmont since the end of the Alleghanian orogeny about 260 Ma (Kohn and others, 1993). The Cenozoic history discussed below requires that most of the 12 km thickness be eroded during the Mesozoic. Drainage was to the northwest during at least the early part of the Mesozoic (Sevon, 1994).

The Piedmont uplands contributed sediment to the Mesozoic basin that lay to the northwest during the late Triassic and early Jurassic (Glaeser, 1966). There is no absolute evidence to indicate when northwest-flowing drainage reversed and the Susquehanna River began to flow from the interior of Pennsylvania to the Atlantic Ocean. However, isopach maps of allostratigraphic units in the Salisbury Embayment, Baltimore Trough (Poag and Sevon, 1989; Poag, 1992) show sediment accumulations probably attributable to the Susquehanna River as early as the start of the Cretaceous (144 Ma). These isopach maps indicate that all sediment sources between Cape Cod (Massachusetts) and the James River (Virginia) provided continuous but fluctuating quantities of sediment to the Baltimore Trough throughout the Cretaceous. Presumably the Piedmont Upland Section contributed sediment to the Susquehanna River once its present course was established.

Paleocene-early Miocene

Poag and Sevon (1989) and Poag (1992) indicate that from the end of the Cretaceous through the early Miocene, very little clastic sediment was deposited in the Baltimore Trough by any of the contributing drainage systems. Climate in eastern Pennsylvania during this time was at least as warm and wet as today. Part of the time the climate was probably warmer and wetter than today, particularly during the Eocene (Wing and Greenwood, 1994). Erosion of clastic material was at a minimum and chemical erosion was at a maximum throughout this period of time.

Geologists speculate about the appearance of the landscape in the Piedmont Upland Section of York, Lancaster, and Chester Counties during early and middle Cenozoic time. Pazzaglia and Gardner (1993) investigated the fluvial terraces of the Susquehanna River and proposed that the highest fluvial terrace, (unit Tg1) at 140 m above the present Susquehanna River channel in the upland area, was deposited during the late early to early middle Miocene (~20-15 Ma). Tributaries would have been graded to the Susquehanna River at that level. I hypothesize that local relief in these tributary drainage basins would have been no greater than today, and may have been less, perhaps 50 m or less. The landforms may have been similar to those of today, but the preceding extended period of uninterrupted erosion (>40 my) more likely produced a landscape of more subdued topography with broader valleys and gentler slopes (a peneplain?). The lower reaches of tributaries to the Susquehanna River would not have been incised as they are today. I assume that the extended period of chemical erosion produced a land surface underlain by thick saprolite and deeply weathered rock (Fig. 15:1).

Middle Miocene-present

The offshore record (Poag and Sevon, 1989; Poag, 1992) indicates that starting in the middle Miocene large quantities of clastic sediment were eroded from eastern North America. The Susquehanna River incised to within 40 m of the present river channel level in the Piedmont Upland (Pazzaglia and Gardner, 1993) by about the start of the Pleistocene (1.8 Ma). Tributaries were graded to this new level and headward erosion carved the basic form of today's landscape (Fig. 15:2, 3). Some of the saprolite and weathered rock formed during the preceding period of weathering was preserved on uplands, but much of that material was eroded. Valleys with broad floodplains developed when streams established equilibrium profiles.

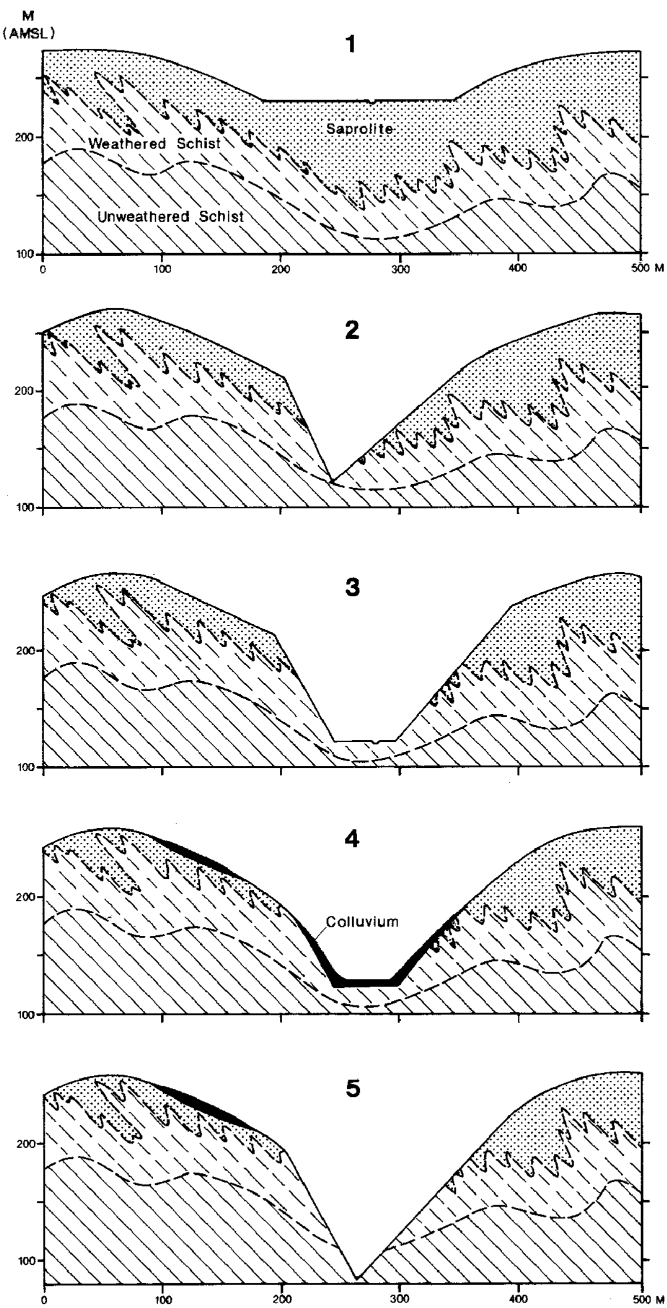


Figure 15. Cross sections illustrating a generalized model of landscape evolution and regolith development in the Piedmont Upland Section, York, Lancaster, and Chester Counties, Pennsylvania prior to settlement in the 18th century. 1. A low-relief, erosional surface was developed by physical erosion prior to the middle Miocene. Chemical weathering produced thick saprolite and weathered rock. 2. Erosion starting in the Middle Miocene caused entrenchment of the Susquehanna River that, in turn, rejuvenated erosion by streams tributary to the Susquehanna River. Headward erosion incised the tributaries and caused erosional lowering of the uplands. 3. By the start of the Pleistocene the tributary streams had attained equilibrium gradients, widened their valleys, and deposited alluvium on the floodplain. Slopes and uplands suffered minimal further erosion. 4. Pleistocene periglacial activity moved material downslope and deposited it as colluvium. Upland tops were lowered. Some sediment was transported out of the area via streams; some was stored on floodplains. 5. Pleistocene lowering of base level caused stream incision in the lower reaches of tributaries to the Susquehanna River, which in turn caused destruction of the floodplain, removal of some colluvium, and exposure of unweathered bedrock. AMSL = Above mean sea level.

Northeastern and northwestern Pennsylvania experienced four documented glaciations during the Pleistocene: late Wisconsinan (Crowl and Sevon, 1980); Late Illinoian (oxygen isotope stage 6) (Gardner and others, 1994); pre-Illinoian (pre-Illinoian F or G of Richmond and Fullerton, 1986) (Gardner and others, 1994); and an older glaciation of unknown age (White and others, 1969). Braun (1989) argues that four more glaciations, undocumented in Pennsylvania, would also have affected Pennsylvania during the past 850,000 years. During each of these glaciations the nonglaciated part of Pennsylvania was subject to a periglacial environment that profoundly affected the landscape.

Watts (1979) indicates that during these glacial intervals most of nonglaciated Pennsylvania was tundra and that continuous to discontinuous permafrost was present. Other climatic modeling (Kutzback, 1987; Woodcock and Wells, 1990) place the Piedmont uplands in a climate that was marginal for permafrost. Gardner and others (1991) suggest that permafrost existed in parts of Pennsylvania only during glacial maximums, but that a vigorous periglacial climate was present during both the waxing and waning phases of glaciation. Numerous observed periglacial features (Ciolkosz and others, 1986) support the former existence of periglaciation in Pennsylvania. Some of these features may be interpreted to indicate the presence of permafrost.

Intense freeze-thaw associated with periglaciation caused considerable breakup of both weathered and unweathered rock. In addition, solifluction moved unconsolidated material from higher to lower slope positions (Fig. 15:4). This material, the widespread colluvium, tells a story of multiple events through its stratigraphy. The four-part stratigraphy in the colluvium (Fig. 13) suggests deposition during four glacial intervals, but there is no age-dating evidence to support this interpretation. Those sequences that possess more than four stratigraphic units may reflect a better preservation of colluvial units formed during the eight probable periglacial episodes that affected Pennsylvania (Gardner and others, 1991).

I suggest that erosion and deposition was unequal across the landscape during each of the multiple intervals of colluviation, and that any or all (except the most recent) of the discrete colluviums could have been removed, disturbed, or left undisturbed during a subsequent periglacial episode. I suggest also that the red color of the oldest colluvium (Fig. 13) derives from interglacial weathering that followed a glacial interval that occurred more than 770,000 years ago (Gardner and others, 1994). Weathering of comparable degree and color occurs on old colluvium deposited elsewhere in Pennsylvania (Hoover and Ciolkosz, 1988; Ciolkosz and others, 1990; Waltman and others, 1990). Soil development on the uppermost brown colluvium (Fig. 13) is comparable to that on till and other materials that were deposited in Pennsylvania during the late Wisconsinan (Ciolkosz and others, 1979).

Base level dropped as the Susquehanna River eroded downward during the Pleistocene glacial epoch (Pazzaglia and Gardner, 1993) and knickpoints moved up Susquehanna River tributaries. This caused incision of the lower reaches of these tributaries, erosion of some of the colluvial deposits, and exposure of unweathered bedrock (Fig. 15:5). Coarse-grained alluvium was deposited upstream from the knickpoints while finer-grained materials were carried out of the drainage basins and deposited elsewhere.

Following the last glaciation, temperatures and precipitation fluctuated but gradually increased and Pennsylvania was revegetated (Webb and others, 1993). That vegetation inhibited erosion of clastic material and the landscape remained relatively undisturbed until about 300 years ago when European immigration commenced. Subsequent land clearing and cultivation created an erosion-susceptible landscape. Much of the soil eroded from this landscape is stored within the drainageways of the Piedmont Uplands, particularly on the floodplains (Trimble, 1983). The fine-grained alluvium above the buried organic zone is interpreted to be the result of post-settlement deposition (Trimble, 1974). Changes in land use during the latter half of this century have reduced the amount of erosion and resultant sediment load in streams. Consequently, streams are now eroding their channels. More recent anthropogenic activities have added artificial deposits of various kinds to the landscape.

SUMMARY

The Piedmont Upland Section in southeastern Pennsylvania has undergone weathering and erosion since the end of the Alleghanian orogeny about 260 Ma. A long period of minimal physical erosion accompanied by maximum chemical erosion extended from the late Mesozoic to the middle Miocene. Deep weathering during this interval produced two mappable in situ regolith units, weathered rock and the end product of rock weathering, saprolite. Physical erosion commencing in the middle Miocene produced the basic form of the landscape that exists today. This erosion left remnants of saprolite and weathered rock beneath uplands and exposed unweathered rock in valley bottoms. Weathered rock underlies side slopes everywhere and is the most areally extensive part of the in situ regolith. Weathered and unweathered rock materials were moved from higher to lower slope positions during Pleistocene periglacial episodes to produce colluvium, the most abundant form of transported regolith in the Piedmont Upland Section. The colluvium has variable texture and stratigraphy produced by multiple periglacially-driven movements of locally derived material. Alluvium composed of locally derived material was deposited during the Pleistocene and also after the land was cleared following settlement in the 18th and 19th centuries. Artificial fill associated with construction and solid waste add to the complement of regolith materials.

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