Interpretation of Cumberland Escarpment and Highland Rim, South-Central Tennessee and Northeast Alabama

GEOLOGICAL SURVEY PROFESSIONAL PAPER 524-C

Interpretation of Cumberland Escarpment and Highland Rim, South-Central Tennessee and Northeast Alabama

By JOHN T. HACK

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 524-C

Theories of landscape origin are compared using as an example an area of gently dipping rocks that differ in their resistance to erosion

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1966

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

TABLES

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

INTERPRETATION OF CUMBERLAND ESCARPMENT AND HIGHLAND RIM SOUTH-CENTRAL TENNESSEE AND NORTHEAST ALABAMA

By John T. Hack

ABSTRACT

South-central Tennessee and northeast Alabama are underlain by gently dipping rocks of Ordovician to Pennsylvanian age. Rock types and topographic forms are closely related. Resistant sandstones, interbedded with some shale and coal, underlie the Cumberland Plateau and form the caprock of the Cumberland Escarpment. The lower slopes are underlain by limestone, and the escarpment retreats as a result of sapping by solution. Sandstone blocks and colluvium collect on the slopes and are washed down to form extensive alluvial deposits in the coves that indent the escarpment. The stream channels in the coves are well graded in accordance with the coarseness of the alluvial material of the bed and banks. Size of this material decreases downstream as a result of selective transportation.

The Highland Rim is a low plateau formed in cherty limestone of Mississippian age. Its outer margin is a dissected hilly area capped by the Fort Payne Chert. The form of the stream channels depends on the materials which the streams cross. Stream profiles for a given discharge are gentlest at the inner margin of the Highland Rim where the rocks are less cherty than those nearer the Nashville Basin.

According to one interpretation, the topography formed in three cycles of base leveling, each of which were followed by periods of uplift, when the peneplains were warped and then partially dissected. According to this idea the Cumberland Plateau, Highland Rim, and Nashville Basin still contain areas in which the old peneplains are preserved in areas of resistant rocks. This interpretation is difficult to criticize without attacking the basic assumptions through an analysis of the processes involved in downwasting. The multiple cycles, however, cannot be proved by geologic evidence. The alternative interpretation is that the forms of the present landscape are adjusted to processes now acting on them or that acted on them in the recent geologic past. The landscape could have formed by continuous lowering of the surface, a process that involves slope retreat on beds of different resistance. This interpretation is the simpler of the two and is in accord with present conditions. It is supported by the distribution and character of the surficial deposits, which are adjusted to the outcrop pattern of the rocks now exposed.

INTRODUCTION

Northeast Alabama and adjacent Tennessee are underlain by a succession of gently dipping sedimentary rocks which form imposing escarpments because of pronounced contrasts in resistance to erosion. Most striking is the contrast between sandstones that cap the Cumberland Escarpment and the relatively pure oolitic limestones of Mississippian age that underlie its lower slopes. The Fort Payne Chert, at the base of the Mississippian sequence, is another resistant layer that outlines a lower upland, known as the Highland Rim. Throughout the region the topographic forms have a close and obvious relation to the characteristics of the bedrock.

In this paper the rather simple and striking relations between the bedrock and topography that are characteristic of the region are used as a means of comparing alternative interpretations of the geomorphology of the Appalachian Highlands. One interpretation, based on Davis' theory of the geographic cycle, holds that downwasting of the area proceeded in stages or cycles that were initiated by separate periods of vertical uplift in which broad areas were reduced to plains of low relief, still partly preserved. The other interpretation, previously discussed in general terms by the writer (Hack, 1960), is based on the concept of dynamic equilibrium and the idea that all elements of the landscape are mutually adjusted and are eroded at nearly the same rate. This idea holds that the present topography could have formed by continuous downwasting of a thick sequence of rocks and that, whatever the erosional history, the topography is now in almost complete adjustment; both highland and lowland areas, then, owe their relief and form to the resistance of the rocks in which they are eroded. This interpretation denies that any appreciable part of the present landscape has inherited its form from a previous cycle of erosion. Variations of both ideas have been presented in the past, but discussion of the problem is complicated by semantic difficulties. This paper is an attempt to clarify some of the problems by a discussion of an area in which the main geomorphic features are relatively simple and where there should be little disagreement as to how the two theories are applied.

GENERAL DESCRIPTION OF AREA

The area studied can be divided into physiographic units, shown in figure 1, which are closely related to the bedrock geology. The bedrock formations may be grouped into five units, each of which has a characteristic lithology that is related to a particular kind of landform (table 1). Figure 2 is a geologic section through the area and shows the relation of the chief rock types to the principal escarpments.

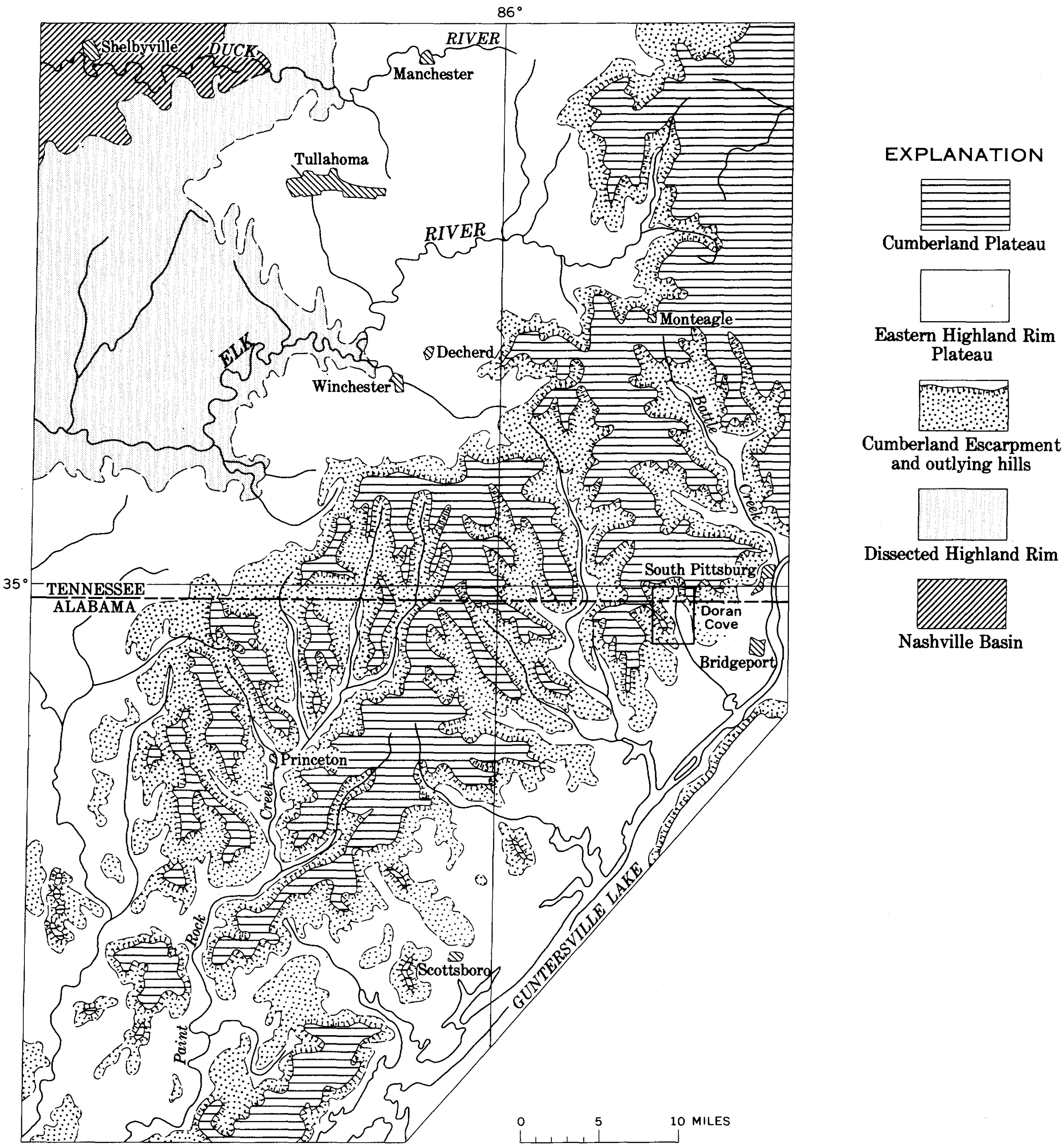


FIGURE 1.—Physiographic diagram of parts of south-central Tennessee and northeast Alabama showing the Cumberland Plateau and Highland Rim. Base from U.S. Geological Survey 250,000 series Gadsden quadrangle, Alabama, Tennessee, 1960; Columbia quadrangle, Tennessee, Alabama, 1960; Chattanooga quadrangle, United States, 1960; and Army Map Service 250,000 series Rome quadrangle, Georgia, Alabama, North Carolina, Tennessee, compiled in 1956.

TABLE 1.—*Principal rock units in area, based on similar lithology*

Chief rock formations included by other authors: Sources are Malmberg and Downing (1957), Peterson (1962), Stearns (1963), Theis (1936), Wilson (1949), and Wilson, Jewell, and Luther (1956).

Designation in this paper	Age	General description and area of outcrop	Chief rock formations included by other authors	Approximate thickness (ft)
Pottsville Formation	Pennsylvanian	Shale, coal, sandstone and conglomerate forming top of Cumberland Plateau. Lower part, only, is preserved.	Pottsville of Alabama; Gizzard Group and Crab Orchard Mountain Group of Tennessee.	0–350
Oolitic limestones	Mississippian	Thick sequence of coarse oolitic bioclastic crystalline limestone. Very cavernous. Some thin calcareous shale beds. Pennington Formation at top is interbedded shale, limestone, and dolomite. Underlies slope of Cumberland Escarpment. Generally mantled by colluvium from Pottsville Formation, but many areas are bare limestone.	Ste. Genevieve, Gasper, and Hartselle of Alabama; Monteagle, Cypress, Golconda, and Hardinsburg of Tennessee; Bangor and Pennington of Alabama and Tennessee.	800
Cherty limestones	Mississippian	Cherty limestones, mostly coarse grained and crystalline, but dense and platy in top part. Chert abundant, especially near base. Generally mantled by cherty soils in places to form rocky barrens. Underlies most of Highland Rim surface.	Fort Payne Chert; Tuscumbia of Alabama; Warsaw and St. Louis of Tennessee.	200–300
Chattanooga Shale	Devonian	Fissile black bituminous shale. Crops out just below edge of Highland Rim Escarpment.	Chattanooga Shale	0–35
Argillaceous limestones	Ordovician and Silurian	Mostly weakly resistant limestone and shale. Generally thin soil cover. Crops out in Nashville Basin and in dissected Highland Rim.	Chickamauga and Red Mountain of Alabama; Bigby, Cannon, Catheys, Leipers, and Fernvale of Tennessee.	0–300

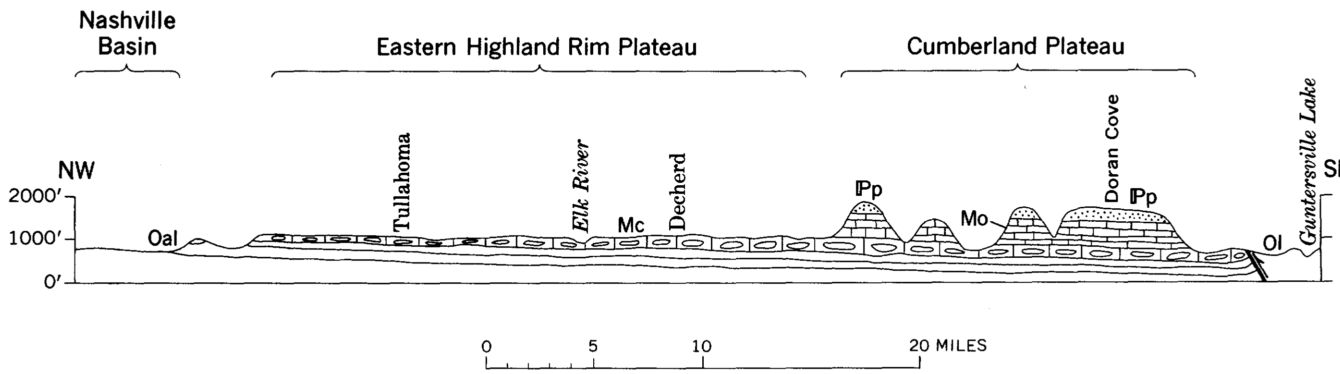


FIGURE 2.—Geologic section across Highland Rim and Cumberland Plateau from the vicinity of Shelbyville, Tenn., to Bridgeport, Ala. Oal, argillaceous limestones of Ordovician age, Chattanooga Shale of Devonian age at top; Mc, cherty limestones of Mississippian age; Mo, oolitic limestones of Late Mississippian age; Pp, Pottsville Formation; and Ol, limestones of Ordovician age in Sequatchie anticline.

The Cumberland Plateau, which forms the highest part of the area, is capped by sandstones and shales of the Pottsville Formation. The rim, known as the Cumberland Escarpment, is supported by the basal sandstones and conglomerates of this formation, and in most places it is marked by cliffs 20–50 feet high. The Plateau surface is not flat but consists of a hilly area of gentle relief underlain by shale, thin sandstone beds, and coal. Only about 20 feet of the Pottsville Formation is preserved in the southwestern part of the area, but more than 350 feet of it is preserved in the northeastern part, and the plateau surface rises in that direction. In this area the base of the formation is nearly horizontal or dips gently to the southeast. The increase in altitude of the plateau to the northeast along the strike roughly conforms to the increased thickness of the Pottsville in that direction.

The Cumberland Escarpment, in places more than 1,000 feet high, is capped by the Pottsville Formation and underlain by oolitic limestones, which are much less resistant and, being permeable and cavernous, retreat by sapping, as noted by Hayes (1899, p. 57) and Fenneman (1938, p. 336). Immediately below the sandstone caprock is a conspicuous zone of landslide blocks and hummocky topography. The lower slopes are mantled in many places by colluvium derived from the shale and sandstone above. The escarpment is deeply indented by valleys, know locally as coves. They are broad and flatfloored and are mantled by cobbly and gravelly alluvium washed downstream from the sandstone plateau. Limestone sinks are common at the margin and on the floors of many coves, where surface drainage may emerge from the limestones of the escarpment or disappear into them along tubular systems of caverns.

Along the outer margin of the Cumberland Escarpment is a narrow belt of outlying hills lower than the escarpment itself. The sandstone capping has been stripped from these hills, and only bare limestone remains. The colluvial mantle of sandstone blocks is also absent here. The scarcity of these hills and the fact that they are confined to a narrow belt marginal to the escarpment suggest that when a spur of the escarpment narrows so completely that the protective sandstone cap disappears, the remaining limestone is rapidly eroded down to the level of the lowland.

The Cumberland Escarpment and outlying hills are bordered on the west by a rolling plain of low relief known as the Eastern Highland Rim (Straw, 1940). This plain is a sort of low plateau, broken by the narrow valleys of the Elk and Duck Rivers. The underlying limestones are cherty. In most places the soil mantle is stony; in some places it forms rocky barrens (fig. 6*A*). In the southern part of the area, where the Cumberland Plateau is broken into isolated mesas, the cherty limestones do not crop out, and the underlying rocks are the oolitic limestones. These rocks contain little insoluble residue; as a result, the intermontane plains are extraordinarily flat and contain many swampy alluvial areas that are mantled by sand, which was transported there by the main streams.

West of Winchester and Tullahoma is a hilly area in which the relief is 250–300 feet; it is referred to in this report as the dissected Highland Rim. This area would be described in classic geomorphic terms as maturely dissected. Virtually all the land is in slope except the bottom lands of large streams. This land forms a transitional area between the Highland Rim Plateau and the Nashville Basin, and many of the hilltops are capped by remnants of Fort Payne Chert, the lowest formation in the cherty limestone unit.

The floor of the Nashville Basin occupies only the northwest corner of the area studied. Relief there is very low. Flaggy limestone and calcareous shale are the dominant rock types. The soil cover is generally thin, and there are large flat areas of bare limestone, known as glades (Galloway, 1919, p. 13).

CUMBERLAND PLATEAU AND HIGHLAND RIM AS DISSECTED AND DEFORMED PENEPLAINS

The classical exposition of the origin of the topography in this area is based on the theory of the geographic cycle and was first made by Hayes and Campbell (1894). Many refinements of their exposition have been proposed and were succinctly summarized by Theis (1936, p. 8–26). It is not necessary to repeat here the details of the theory as applied to the area, but the essential elements should be emphasized. According to the peneplain concept the area has undergone three periods of base leveling, during which three peneplains or partial peneplains were formed. The highest of them, first called the Cretaceous peneplain but later renamed the Cumberland peneplain (Hayes and Campbell, 1894, p. 71; Hayes, 1899, p. 23), is roughly equivalent to the surface of the Cumberland Plateau and is preserved on the hard sandstone and conglomerate beds. This surface is regarded as a peneplain because the general summit level cuts across a sequence of beds of different ages, although locally it is related to rock resistance. Hayes (1899, p. 23) argued as follows:

> To the casual observer the level surface of the Cumberland and adjoining plateaus appears to be due wholly to the presence of horizontal beds of resistant sandstone. A more careful examination, however, discloses the fact that the plateau surface does not always, or even generally, coincide with a particularly resistant bed. It is true that the small isolated mesas are usually capped by a hard stratum but, when the broader plateau areas are considered, the surface is found to be composed of soft shale as well as harder sandstone. Again, the strata are not so nearly horizontal as the general plateau surface, which to a considerable extent truncates hard and soft beds alike. Hence it is evident that this surface is the result of degradation—that it is an imperfectly preserved base-level plain.

The Cumberland peneplain is considered to be deformed and highly dissected. Its remnants supposedly rise to the north and descend south of the Tennessee River to a level less than 1,000 feet above sea level. To the west the peneplain is completely eroded but presumably reappears as the surface beneath the Cretaceous sediments of the Mississippi embayment.

The second peneplain was called the Tertiary or Highland Rim peneplain in reports by Hayes and Campbell (1894, p. 83) and Hayes (1899, p. 29). This surface was believed to be fairly well preserved over large areas in the Eastern Highland Rim Plateau and to cut across limestone beds of Mississippian age at an altitude of about 1,000 feet. The Highland Rim peneplain is maturely dissected in the area south and east of the Nashville Basin, where the maximum relief is about 300 feet.

A third peneplain was believed to be preserved in the hills of the Nashville Basin, where the average relief is about 200 feet. Hayes (1899) correlated this surface with the Coosa peneplain.

Hayes (1899, p. 18) and other geologists who accepted his interpretation realized that there was a major difference in the resistance of the rocks that underlie these erosion surfaces. The highest and oldest surface, the Cumberland peneplain, is underlain by the most resistant rocks, whereas the youngest and lowest is underlain by the least resistant rocks. Hayes clearly stated that the Cumberland peneplain is preserved in places because it is underlain by resistant rocks. He held that it was once far more extensive than it is now and has been preserved only in areas of especially thick and resistant sequences of strata. Hayes and Campbell (1894, p. 70) discussed the "Cretaceous peneplain" throughout the southern Appalachians as follows:

> Although the whole province, as stated above, had been reduced to an almost featureless plain, the character of the underlying rock modified to a very slight extent the character of that plain. The soft rocks were somewhat more perfectly reduced than the hard rocks. Still the differences were not strongly marked. When, however, the nearly perfect plain was elevated and the activity of the streams was revived, differences in the underlying rocks became all important in determining the degree to which the plain would be preserved. Where the rocks were soft it was rapidly destroyed, and where they were hard it has retained in large measure its original form. Hence, the peneplain, although originally quite uniform, now shows great diversity and presents several distinct types, depending jointly on the amount of elevation and the character of the underlying rocks.

OBJECTIONS TO THE PENEPLAIN THEORY

The geology of the Highland Rim and Cumberland Plateau offers little to support the theory of ancient peneplains. The argument for the peneplains depends primarily on the claim that the present erosion surface is discordant with the structure and cuts across hard and soft strata alike. However, this discordant relationship is valid only if a very large area is considered and if local features are ignored. The accordance of topographic forms with the underlying rock strata seems to be a far more striking relationship.

The most obviously accordant relations are found where the erosional resistance of the rocks changes abruptly. Such changes are invariably marked by escarpments. The Highland Rim Escarpment is formed wherever the topographic surface intersects the contact of the Fort Payne Chert and the Chattanooga Shale. Similarly, the Cumberland Escarpment is formed where the sandstone and conglomerates of the Pottsville Formation are in contact with the shales and cavernous limestones of Mississippian age. These escarpments are accounted for in the peneplain theory by the argument that they separate remnants of ancient dissected peneplains that are still partly preserved because the resistant rocks have prevented their complete destruction.

On the present surface of the Cumberland Plateau, however, the topographic irregularities are less spectacular, and the present plateau surface was interpreted as an imperfect remnant of only one peneplain. Along the axis of the Cumberland Plateau, which trends northeast, the topographic surface on the rocks of Pennsylvanian age rises from about 1,500 feet near Huntsville, Ala., to more than 3,500 feet above sea level in Anderson County, Tenn., northeast of the area shown in figure 1. The rocks along this axis are gently folded and are broken by low-angle overthrust faults whose traces also trend northeast. The axis itself, however, is roughly horizontal, and the rise of the topographic surface to the northeast is accompanied by an increase in thickness of the rocks of Pennsylvanian age. In Anderson County, according to Keith (1896), considerably more than 3,500 feet of Pennsylvanian rock is present, and the base is below sea level; in the Huntsville area only about 50 feet is present. It is not known, of course, whether the increase in thickness is related to an increase in the depth of the original depositional basin or to the erosion of thousands of feet of rock at the southwest end of the Plateau. If it is assumed that the thinning is the result of erosion, then it is true, as Hayes thought (1899, p. 23), that the present erosion surface cuts across the resistant and nonresistant strata.

In detail, however, the topographic forms of the Cumberland Plateau do not crosscut the structure, and the rise is not gradual but is broken by a series of escarpments that mark the outcrops of resistant beds. The conformity of topography and rock structure is particularly evident in an area in north-central Tennessee, northeast of the area shown in figure 1, where differences in altitude of about 1,000 feet correspond closely to changes in altitude of resistant sandstone beds within the Pottsville Formation (Stearns, 1954, pl. I, fig. V). The Sequatchie Valley heads in this area. The valley is eroded in a breached anticline that trends southwest. At the northeast end the anticline is unbreached, and the uparched resistant sandstones form a high ridge (Conant and Swanson, 1961, p. 8). This evidence suggests that, though the entire surface of the Cumberland Plateau does not conform to a single stratum of rock, locally it does closely conform to structure; if it is regarded as the remnant of an ancient erosion surface, it must have been one having relief that almost matches that of the present Cumberland Escarpment.

Another objection to the peneplain theory is that when the surfaces of the ancient peneplains are restored on the basis of the present remnants, their gradients are in places too steep to have been formed by a drainage system that crosscut the structure so as to reduce it almost to base level. This difficulty in the theory was early noted and explained away by the introduction of the concept of warping. The argument for the peneplains seems to involve circular reasoning and is valid only if the existence of former peneplains is accepted as reasonable fact. If an area of nonresistant rock is at or close to the altitude of an area of resistant rock, both areas are presumed to have been parts of the same peneplain. If, however, the two rock types underlie surfaces of vastly different altitudes, it is argued that there must have been two peneplains. If the supposedly ancient surfaces are not level enough to be the remnants of base-leveled surfaces, it is argued that they have been warped. Given enough episodes of base leveling followed by episodes of uplift and warping, virtually any topography—no matter how complex or irregular—can be explained by the theory. Nevertheless the explanation is not a unique one, nor is it the simplest possible. Certain features of the landscape, such as the distribution of surficial deposits, are not predictable through its use.

EASTERN HIGHLAND RIM PLATEAU AS A MODERN PENEPLAIN

The writer has many times heard the suggestion that objections to the peneplain theory are based on semantic difficulties and that, in reality, when a surface is described as a peneplain it is only in approximation of an ideal. According to this idea many areas of the earth's surface are low enough or flat enough at the present time to be called peneplains. The Eastern Highland Rim Plateau is an example of a low-relief surface, and it seems appropriate to consider whether it might be called a modern peneplain, help up by the Fort Payne Chert, which might be supposed to act as a sort of local base level. The streams of the limestone region, according to this idea, are graded to the surface of the Fort Payne. We can agree that the relief is low. If relative relief is defined as the difference in altitude between the highest and lowest points within a 27 square mile area, then the relative relief of about half the Eastern Highland Rim Plateau is less than 200 feet (Straw, 1940, fig. 2). The relief of the remainder ranges mostly from 200 to 400 feet. Can this region be called a peneplain because it is "almost a plain"?

The term "peneplain" has traditionally been used by geomorphologists to describe low plains formed by processes of subaerial erosion near the close of a geomorphic cycle. Thornbury (1954, p. 187) stated:

> The term peneplain should be restricted to those gently undulating landscapes which develop under a base level control toward the end of a humid fluvial cycle in part through lateral planation by streams but more through mass-wasting and sheet wash on interstream areas than by stream erosion. Used in this sense, it has a definite meaning and implication in regard to the geomorphic history of the region that retains such a condition.

The term has always had a genetic significance, and if this is to be retained it is essential that it pertain only to plains produced at (or near) the close of a geomorphic cycle. If the term were used for any low plain or subaerial erosion surface of low relief, it could easily be confused with surfaces of different origin, such as pediments and stripped surfaces.

If the term "peneplain" is defined according to the traditional usage of geomorphologists, the Eastern Highland Rim Plateau cannot be referred to as a modern-day peneplain. This plateau is cut by the Elk and Duck Rivers and by other large streams that flow in valleys 50–100 feet below the general level of the hills on either side. Furthermore the plain surface slopes to the south, roughly parallel to the base of the Fort Payne Chert. Thus if the Eastern Highland Rim ever were a peneplain, it would have to be interpreted as by Hayes and Campbell, who believed that it is a dissected and deformed peneplain. In the traditional terminology of geomorphology, the present-day Eastern Highland Rim Plateau is much closer to being a stripped surface than a peneplain. It is formed over a very large area on a single sequence of cherty beds, the total thickness of which is only a few hundred feet.

EQUILIBRIUM CONCEPT AND THE PROCESS OF DOWNWASTING

The alternative to the peneplain theory is based on G. K. Gilbert's (1877) concept of interdependence of all parts of the landscape. This theory has been called the "equilibrium concept of landscape" (Hack, 1960). According to this theory the present topography formed during nearly continuous downwasting of the region. It is now in a state of adjustment; therefore, most (or all) traces of past changes that might have been expressed in the topography have been destroyed. Previous discussions of the theory (Hack, 1960; 1965) have dealt either with areas of homogeneous rocks or with areas of complexly folded rocks in which the same forms or very similar ones persist as downwasting proceeds. In areas of homogeneous rock, in particular, the landscape can be considered as being in a steady state. Downwasting in an area of nearly horizontal strata of varying resistance, such as south-central Tennessee and northeast Alabama, is somewhat different and must be accompanied by changes in the forms, because new rocks are exposed as the surface of erosion is lowered.

The basic geometry of the landscape depends on the fact that the form produced by a given process acting on any given rock is maintained as erosion proceeds. The drainage network forms the skeletal framework of the landscape, and longitudinal valley slopes are steep at the headwaters and gentle downstream, where the discharge is greater. Each kind of rock crossed by a given-size stream has its characteristic gradient. Channel gradients for a given-size stream are steeper on hard rocks than on less resistant ones. Because of the difference in discharge, there is always a great contrast in longitudinal slope between the short first-order streams, which are the most numerous, and the main trunk streams. Therefore, the main valleys are generally intrenched below the general level of the areas drained by smaller streams.

The slopes of interstream areas are, for the most part, convex upward or straight. The interfluves are curved ridges that bifurcate as do streams but in the opposite direction. Stream-channel slopes and interstream areas vary in form according to the kind of rock involved and the way it is affected by weathering and erosion. Slopes may be rugged and cliffy or gentle and rounded. Where hard beds overlie particularly soft ones, sapping generally occurs, and cliffs are maintained.

In an area of gently dipping sedimentary rocks, the slopes waste both horizontally and vertically; hence, they maintain the same overall gradient and form in each rock unit, both along streams and in interstream areas. For short periods of time certain components of the landscape, such as the outlying hills of the Cumberland Escarpment, may become out of balance. Thus, when the caprock is removed from an area of soft rock, the soft rock is rapidly eroded and returns to a form in equilibrium. In terms of the landscape as a whole and considering it as a single system, this is part of the general process, and the evolution of the landscape is a continuously changing pattern of similar forms. The escarpments and slopes adjust themselves as the outcrop patterns, which provide the geologic framework, change.

The process of change is exemplified by the hypothetical area shown in figure 3. The same area is shown in four sequential diagrams, each of which is a geologic map and section. Beds 2, 4, 6, and 8 are resistant rocks in which stream-channel slopes tend to be steep. Beds 1, 3, 5, 7, and 9 are nonresistant, and slopes tend to be gentle. In stage *A*, only beds 6–9 are exposed. Bed 8 has a very narrow outcrop area, both because it is thin and because its slopes are steep, and it forms a low escarpment. As outlined in other papers (Hack, 1960, 1965), alluvial aprons may form below the resistant bed along the largest streams. The channel slopes on bed 7 are too gentle for the coarsest debris shed by bed 8 to be carried off. It is therefore stored in a flood plain or in terraces downstream, where it is spread out and subject to weathering. Such alluvial aprons are part of the system in equilibrium.

At stage *B* (fig. 3), erosion has proceeded farther. The outcrop of bed 6 has now retreated upstream, occupies a large part of the area, and forms a high escarpment. At this stage the alluvial apron is much larger because the source of the resistant debris is so much larger.

At stage *C*, the outcrop of bed 6 has retreated farther, the erosion surface has exposed bed 4, and another escarpment has formed in the lower part of the area.

At stage *D*, the escarpment on bed 6 has retreated upstream beyond the area, and there are only low escarpments on beds 2 and 4. The large alluvial aprons have also disappeared because the large source of resistant gravel has been removed. Smaller aprons are associated with beds 2 and 4.

As indicated by the geometry of these diagrams the major direction of slope retreat on a retreating escarpment is related to the attitudes or dips of the erosion surface and the bedding. If the beds dipped downstream more steeply than the surface of erosion, the escarpments would retreat downstream.

CUMBERLAND PLATEAU AND HIGHLAND RIM AS A SYSTEM IN EQUILIBRIUM

The area studied by the writer appears to be an excellent example of the hypothetical landscape just described in which the slope forms and surficial deposits are in adjustment and in which features inherited from the past are not in evidence. Imposing escarpments occur on the resistant beds, such as the basal sandstones and conglomerates of the Pottsville Formation and the basal cherts of the Fort Payne Chert. Each of these is underlain by a sequence of especially nonresistant strata.

The surficial deposits, including both soils and alluvium, have a major bearing on the interpretation of the landscape. According to the peneplain concept the Cumberland Escarpment is (and has been for a long time) in retreat. The Highland Rim area below the escarpment on the west is presumably not downwasting vertically; it is at the same level now in relation to the escarpment as it was during the formation of the Highland Rim peneplain, and it was gradually uncovered as the escarpment retreated eastward. During the formation of the Highland Rim peneplain, the principal erosional energy was expended along the margin of the Cumberland Escarpment, and the rate of energy expenditure was comparatively low to the west. We should expect, then, that the gravelly residues derived from erosion of the escarpment would have been dumped at its foot as the escarpment retreated. The residues should have remained on the Highland Rim peneplain to form a thin mantle on its surface. This mantle could have been removed only after renewed uplift and during the subsequent dissection of the Highland Rim peneplain—a process that is presumably going on now. If this had been the evolution of the area, we might expect patches of the gravelly residues to be preserved on the surface of the Highland Rim, and expect small streams draining the Highland Rim to contain sandstone gravels in their beds.

Instead, the alluvial deposits are graded as though in adjustment with the rocks now present and the processes that are now acting on them. The surficial deposits both along the Cumberland Escarpment and along several streams that drain the Highland Rim were studied in order to describe this adjustment.

VALLEYS AND COVES OF THE CUMBERLAND ESCARPMENT

The Cumberland Escarpment (within the area of fig. 1) is generally about 1,000 feet high. It is capped by 50–350 feet of Pottsville Formation. Except for some shale and dolomite immediately below the Pottsville, the remainder of the slope is underlain by almost pure limestone. The limestone is porous and cavernous, as shown by many examples of cavernous weathering

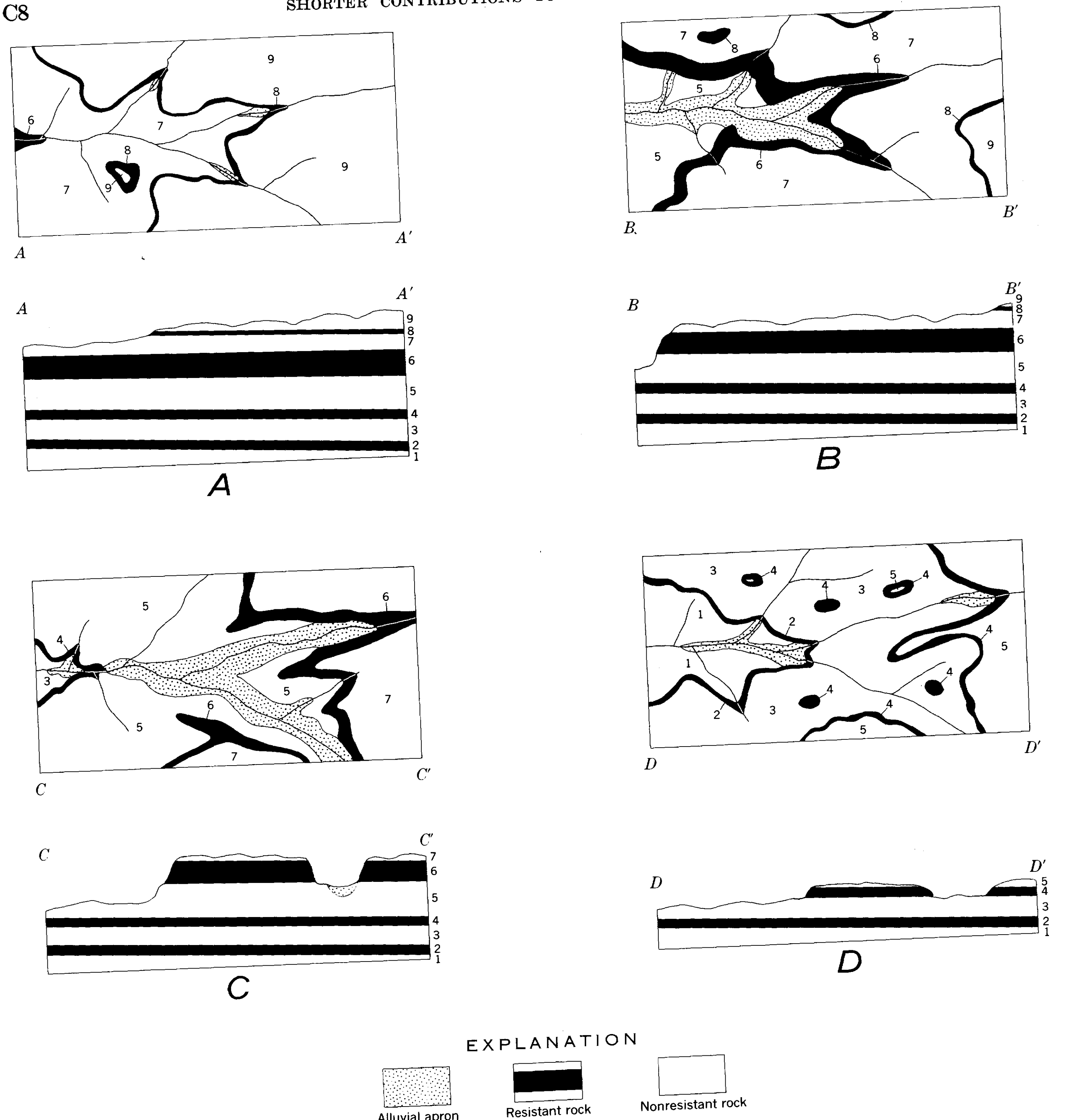


Figure 3.—Four sequential stages (*A*, *B*, *C*, *D*) in the evolution of a downwasting area of gently dipping rocks. Even-numbered beds are resistant to erosion; odd-numbered beds are nonresistant.

on the outcrops (fig. 4*A*) as well as by many sinks. This characteristic helps to maintain the steep lower slopes of the escarpment and the sandstone cliffs that mark the plateau rim. Most of the lower slope ends abruptly at the comparatively flat floor of one of the deep coves that indent the plateau margin. Many coves are mantled by cobbly and gravelly alluvium, which forms crudely terraced alluvial aprons whose extent generally depends on the thickness of the Pottsville Formation of the upper slopes.

Doran Cove is typical of many of the coves, and the material on its slopes as well as on its floor is part of a graded system (pl. 1). The massive sandstone at the base of the Pottsville is underlain by shale of Mississippian age, and a zone of springs and seeps occurs at this horizon about 200 feet below the crest of the plateau. The wet surface of the shale beds favors sliding, and the slope below is littered with landslide blocks. Topography below the landslides is hummocky for several hundred feet downslope, and outcrops of the underlying shale or carbonate rock are virtually nonexistent, except where there are deep roadcuts. Several hundred feet farther downslope the hummocky mantle thins, and many exposures of the underlying oolitic limestone are present. Yet in many places a thin mantle of bouldery colluvium extends all the way to the base of the slope. The colluvium is a markedly bimodal deposit consisting of weathered pebbles, blocks, and boulders of sandstone in a light-brown (5*YR* 6/4) clay matrix. It is probably a mixture derived from the sandstone and shale beds of the upper slopes. Clay has been washed from some ravines and has left a residue of large boulders (fig. 4*B*).

The floor of Doran Cove consists almost entirely of alluvium, which forms indistinct terraces. Except for small areas of red cherty clay derived by slope wash from the limestone, the alluvium is sand, gravel, and cobbles whose source is the sandstone of the Pottsville Formation. It is evidently an alluvial concentrate of the more resistant materials eroded from the colluvium on the slopes. The deposits are exposed in many deep intermittent stream channels. Like many other stream deposits, these grade upward from gravel at the base to sand and silt at the surface. The alluvium is also graded in a downstream direction. The upstream valley floors are cobbly, and downstream the material becomes progressively finer. The change in character of the channels is illustrated in figure 4, which shows stream channels at successively greater distances from their sources.

The downstream gradation of the bed material of the streams in Doran Cove is notably regular. This gradation is closely related to the size of the watershed that supplies the debris and to interrelated factors, such as discharge, stream length, and rate of decrease in slope. Measurements were made at various places in stream channels of the cove (table 2; pl. 1); at each place an estimate was made of the mean size of the bed material (by use of the Wolman (1954) method), and channel slope, width, and depth were measured. Generally both width and depth increase downstream, and width increases at a greater rate than depth. Stream length (measured downstream from the source), and watershed area are interrelated, as is also usual. The gradation of the bed material downstream is shown by a graph (fig. 5) that relates stream length to mean size of bed material. Rate of decrease is high, and within only 6 miles from the source of a stream on the plateau top, the average size of cobbles on the bed decreases by a factor of 10. Size affects the roughness factor; therefore channel slope is also affected and decreases downstream at an uncommonly high rate. Thus, the stream profiles are much more concave than usual—a circumstance that accentuates the abruptness of the escarpment and the flatness of the valley bottom. The cove floor appears to be an alluvial fan in which the slope is adjusted to carry finer and finer material, the farther it is from head of the cove. The alluvial fan does not extend indefinitely beyond the escarpment, but downstream below Montague the valley floor is mostly residual cherty clay, derived from the underlying limestone, and the sandy flood plain constitutes a smaller part of the valley.

The colluvium on the cove walls contains coarse materials throughout; the sources of the alluvial material on the cove floor include the side slopes as well as the plateau top and the head of the cove. Most material, of course, is transported by the main stream of the cove and has traveled some distance. Small contributions by side tributaries consist of coarser materials and are deposited in low tributary fans. The whole drainage network and the deposits carried by it form a graded system. The decrease in the size of materials is caused by selective transportation rather than simply by wear during transportation. The alluvial bottom lands are a complex of terraces and bodies of alluvium of different ages in which the sandstone fragments are stored during the wasting and retreat of the escarpment. Transportation of the coarser materials, at least, proceeds in steps from place to place during floods. The channel is laterally displaced across the alluvial valley over long periods of time, and fresh coarse materials are replaced by more weathered materials that have previously been brought down from upstream. Most of the coarser fractions of alluvium at the lower end of the cove are not derived from the head of the cove but from some temporary storage place upstream. Such material has probably survived a long history of reworking on the valley floor.

Along some other parts of the Cumberland Escarpment, especially on the west, the gravelly bottom lands are less extensive than in Doran Cove. Their extent is apparently related to the thickness of the sandstone beds in the Pottsville Formation, and they do not extend beyond the prongs of the escarpment. Some very large valleys like those of Paint Rock and Crow Creeks are more deeply eroded and pass through the plateau on fairly steep longitudinal gradients. The bedload of the stream in these valleys is primarily coarse cherty material derived from the extensive limestone outcrops.

TABLE 2.—*Measurements of stream channels at reaches in Doran Cove, Ala., and eastern Highland Rim, Tenn.*

Locality	Area (sq mi)	Length (miles)	Slope [1] (ft per mile)	Width (ft)	Depth (ft)	Bed material: Number of fragments in sample	Bed material: Mean size, in mm: Geometric	Bed material: Mean size, in mm: Phi	Bed material: Phi std deviation
AR71	4.1	3.6	84	16	3.0	99	64	−6.0	1.3
AR72	4.0	3.3	75	26	3.6	100	52	−5.7	1.5
AR73	12.0	5.4	35	52	----------	102	26	−4.7	1.5
AR74	11.9	5.3	28	34	5.0	110	45	−5.5	1.2
AR81	2.5	2.7	120	14.5	4.3	97	85	−6.4	1.2
AR82	2.1	2.0	170	12.8	2.4	98	90	−6.5	1.1
AR83	1.8	1.7	170	15.8	1.7	96	136	−7.1	1.4
AR84	6.6	3.9	68	25.4	3.9	99	79	−6.3	1.4
AR85	.1	.6	1,400	16.0	1.5	66	450	−8.9	1.3
6364	22.8	6.8	32	28	3.5	59	64	−6.0	1.4
6365	32.6	7.35	11.5	24	4.5	51	8.5	−3.1	1.3
6369	135	20.7	2.8	65	6	71	32	−5.0	1.4
6370	40.5	13.2	2.9	25	3	50	20	−4.3	1.0
6374	568	77.4	2.6	150	8	104	31	−4.9	1.2
6375	83.5	18	8.5	50	6	57	40	−5.3	.8
6376	26.0	9.7	19	32	2.6	31	52	−5.7	1.3
6377	18.8	8.3	12	40	5.0	50	26	−4.7	1.3
6378	8.3	5.9	36	34	4.0	51	30	−4.9	1.2
6379	1.9	2.8	48	24	3.2	51	56	−5.7	1.2
6389	17	7.6	15.5	50	4.0	52	5.0	−2.4	1.4

[1] At localities 6364–6389 channel slopes were not measured in the field. The value sat these localities were obtained from measurements on the 1:24,000-scale topographic maps.

LOCATION OF THE STREAM REACHES

[Quadrangles referred to are TVA series, 1:24,000 scale, U.S. Geol. Survey. Coordinate distances are given in feet, measured north from the bottom and east from left margin of the map]

AR71. Doran Cove quad., Alabama; Cluck Cove Creek 300 ft upstream from Dry Creek; 39,250 ft N., 18,700 ft E.
AR72. Doran Cove quad., Alabama; Cluck Cove Creek upstream from AR71. 39,250 ft N., 17,500 ft E.
AR73. Doran Cove quad., Alabama; Dry Creek at entrance to Russell Cave; 37,000 ft N., 19,500 ft, E.
AR74. Doran Cove quad., Alabama; Dry Creek 700 ft upstream from Russell Cave; 37,300 ft N., 19,950 ft E.
AR81. Doran Cove quad., Alabama; Cluck Cove Creek; 40,500 ft N., 15,450 ft E.
AR82. Doran Cove quad., Tennessee; Cluck Cove Creek; 43,450 ft N., 13,200 ft E.
AR83. Doran Cove quad., Tennessee; Cluck Cove Creek; 44,600 ft N., 11,900 ft E.
AR84. Doran Cove quad., Tennessee; Dry Creek 800 ft south of north edge of quadrangle; 44,400 ft N., 20,150 ft E.
AR85. Doran Cove quad., Alabama; Ravine on Montague Mountain, south of Russell Cave; 34,600 ft N., 19,380 ft E.
6364. Burrow Cove quad., Tennessee; Dry Creek south of Payne Ridge; 25,900 ft N., 14,700 ft E.
6365. Burrow Cove quad., Tennessee; Elk River 200 ft above junction of Dry Creek; 23,000 ft N., 6,850 ft E.
6369. Alto quad., Tennessee; Elk River above Rutledge Ford; 20,250 ft N., 17,000 ft E.
6370. Alto quad., Tennessee; Bradley Creek at road crossing west of Thacker Pond; 38,500 ft N., 6,300 ft E.
6374. Lois quad., Tennessee; Elk River below Farris Creek Bridge; 13,800 ft N., 16,700 ft E.
6375. Huntland quad., Tennessee; Beans Creek below road crossing east of Skeet Ridge; 44,300 ft N., 20,600 ft E.
6376. Huntland quad., Tennessee; Beans Creek below bridge on U.S. Route 64; 28,800 ft N., 34,400 ft E.
6377. Beans Creek quad., Tennessee; Beans Creek 1,000 ft downstream from railroad bridge at town of Beans Creek; 23,500 ft N., 600 ft E.
6378. Beans Creek quad., Tennessee; Beans Creek at road crossing south of Hatchett School; 21,300 ft N., 12,400 ft E.
6379. Beans Creek quad., Tennessee; Beans Creek in Buncombe Cove; 33,100 ft N., 22,000 ft E.
6389. Wartrace quad., Tennessee (northeast, of Shelbyville); Wartrace Creek, a tributrary of Duck River, at bridge on Route 82 east of Bell Buckle; 32,000 ft N., 10,600 ft E.

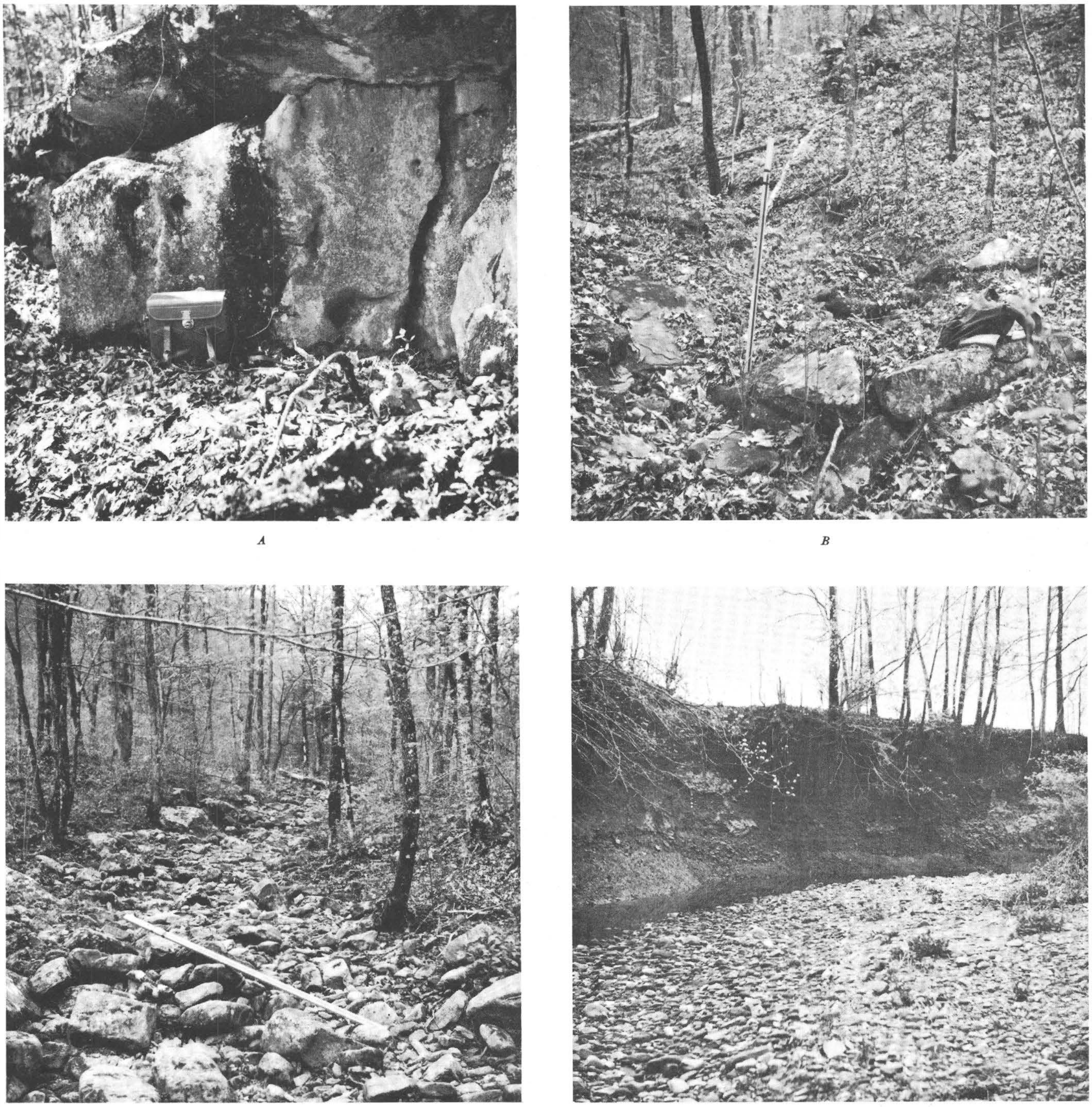
Sandstone cobbles are abundant only in the headwater areas. In the extreme south where, because of the structure, the noncherty oolitic limestones are brought down to the valley bottom, the gradients are very gentle; and the channels have sand bottoms composed of material transported from upstream.

SURFICIAL DEPOSITS OF THE HIGHLAND RIM

The Highland Rim is a low hilly area mantled mostly by cherty residual soils. The flat alluvium-covered areas in the coves of the Cumberland Escarpment end only a short distance from the escarpment edge, where they narrow and merge with the flood plains of the streams of the Highland Rim. These narrow alluvial bottom lands are floored by a gravel consisting predominantly of chert, but the floors of the larger valleys whose sources are in the Cumberland Plateau also contain sandstone pebbles. The size and relative abundance of these pebbles decrease downstream.

The interstream areas contain no alluvial deposits but are characteristically covered by a stony soil composed predominantly of chert (fig. 6*A*). In the outer parts of the Highland Rim where the rocks are more cherty, the chert is more abundant, and large tracts of barren land have chert cobbles exposed on the surface.

A small number of stream reaches on the Highland Rim within the Elk River basin were examined, and measurements were made, as in Doran Cove (table 2). In the Highland Rim area the streams do not flow across broad alluvial bottom lands as they do in the coves of the Cumberland Escarpment. These streams flow on narrow flood plains and are bordered by low rolling country in which the rocks are mantled by cherty residuum. The transition from the gravelly valley floors of the escarpment to the more rolling Highland Rim is fairly abrupt and occurs close to the foot of the escarpment. The character of the bed material changes also—from predominantly sandstone to predominantly chert.



A B C D

FIGURE 4.—Features of the Cumberland Escarpment in Doran Cove. *A*, Outcrop of porous oolitic limestone on slope above Russell Cave. Note characteristic solution holes and smooth rounded surfaces. *B*, Small ravine on lower part of limestone slope near Russell Cave showing large sandstone boulders concentrated there by wash from colluvial mantle. Rod with dark stripe is 6 feet long. *C*, Channel of small stream in Cluck Cove; locality AR83. Rod is 6 feet long. *D*, Channel of larger stream—Dry Creek—upstream from Russell Cave; locality AR74.

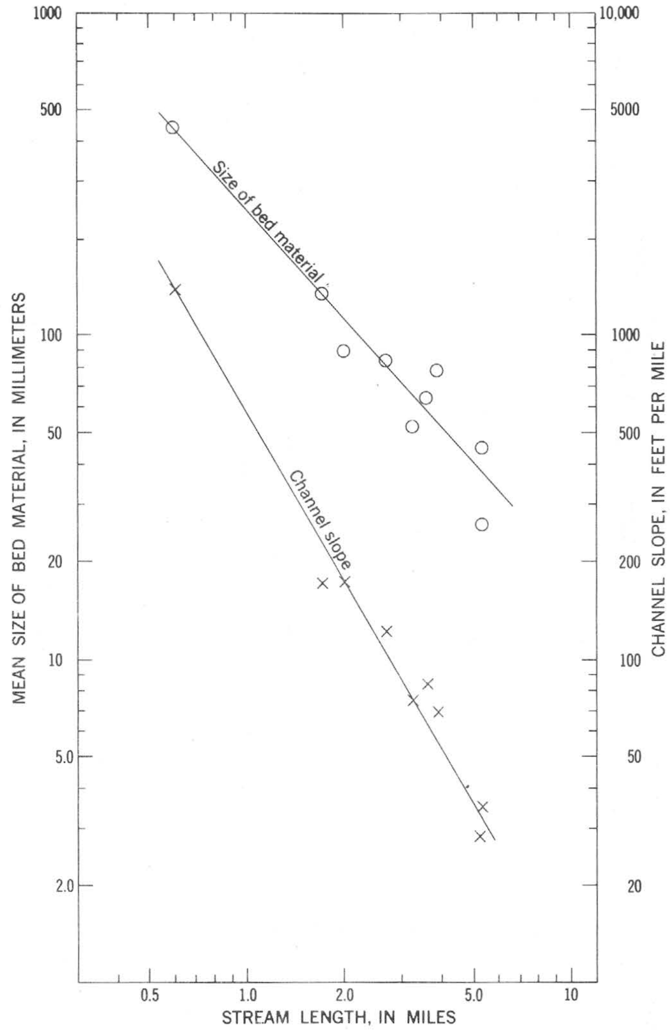


FIGURE 5.—Channel equilibrium conditions in Doran Cove, Tenn. and Ala.

The mean size of the bed material in relation to stream length is shown in figure 7. The range in size is large, but there is no systematic decrease downstream. The mean size of the bed material in the Elk River channel, 77 miles from where it heads, is about as large as that in the upstream reaches of smaller streams. The average size of bed material at all the localities is 33 mm. The absence of a systematic change in size is related to the fact that the rocks of the Highland Rim yield a similar chert, and at the erosion rates that prevail in the area, the chert weathers and breaks up to approximately the same sizes. This chert is available to the stream channels throughout the area because it is a residue in the soil and is a resistant component of the bedrock at many outcrops in the channels. The variations in size of bed material are probably related to local differences in the amount of chert available as well as to differences in its properties.

Channel slope, also, is shown in relation to stream length in figure 7. Slope decreases downstream as discharge increases, but, because there is no systematic decrease in size of bed material, the flattening of the slope is not as abrupt as that in the coves of the Cumberland Escarpment. A line of best fit, drawn by the multivariate method (Snyder, 1962), has the equation

$$S=140L^{-1.06},$$

in which S is channel slope and L is stream length measured from the head of the stream. The exponent in the preceding equation is virtually unity; therefore, the channel slope in these streams is inversely proportional to length. In the Shenandoah Valley of Virginia, streams that have no systematic change in size of bed material along their courses (Hack, 1957) exhibit slope-length relations of this kind. In such streams the profile is logarithmic in form, and the decline in altitude of the channel is proportional to the logarithm of the distance from the head of the stream. This applies to the streams of the Highland Rim. Even though these streams are actually eroding—as indicated by many bedrock outcrops in the channels—the slope of their channels is adjusted or graded so that material of about the same size is transported. Presumably, therefore, the rate of downcutting is approximately the same throughout the stream system.

ELK RIVER PROFILE

The longitudinal profiles of the major streams in the area reflect the close relation of topographic forms and stream deposits to the underlying bedrock. The Elk River heads on the Cumberland Plateau, north of Monteagle, Tenn., and leaves the Cumberland Escarpment only 6 miles downstream, after passing through a typical cove. It crosses the Fort Payne Chert 30 miles downstream, and from a river length of 45–105 miles, near Fayetteville, Tenn., it flows in the hilly country marginal to the Nashville basin. The profile of the river and the values of channel slope are shown graphically in figure 8. The slope values range from 2 to 1,000 feet per mile; hence, they are plotted on a logarithmic scale to make the graph less awkward in appearance and to emphasize the lower range of downslope values.

The slope steepens abruptly on the Cumberland Escarpment and is very steep where the stream is eroding the oolitic noncherty limestones of Late Mississippian age. This is in a cove where sapping is the dominant process of erosion. The bed material in the cove is sandstone gravel, and the size decreases downstream. At a stream length of only 7.4 miles, the mean size decreases to only 8 mm, and the slope declines to 11 feet per mile (fig. 6*C*). A short distance downstream the slope becomes even gentler until at about 10 miles, the value is at a minimum of 2.8 feet per mile. This low value is despite the small discharge. In this reach the channel is relatively deep, and at the time of the writer's visit, the bottom was so muddy that it was not possible

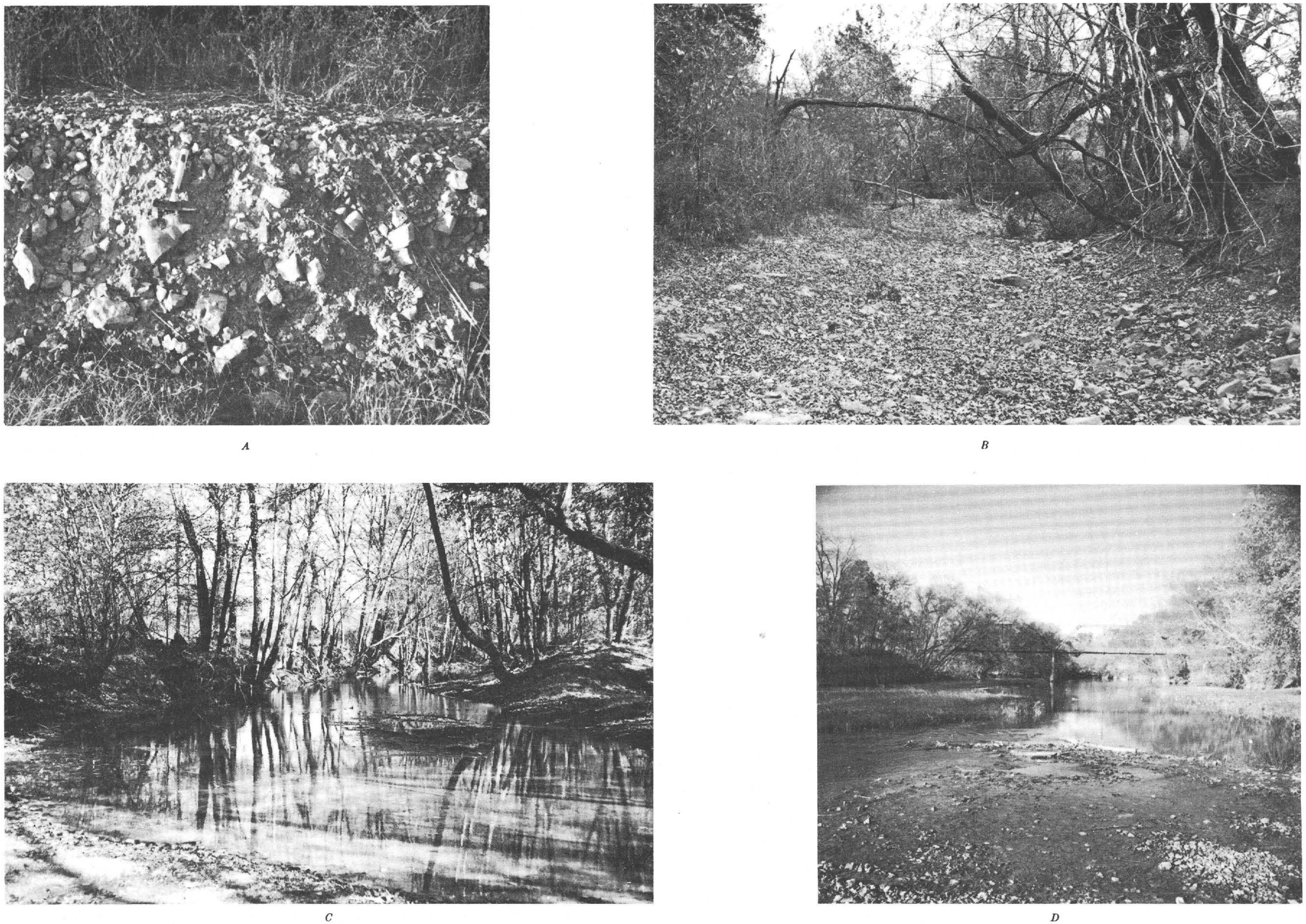


FIGURE 6.—Features of Highland Rim in Elk River basin. *A*, Roadcut showing cherty soil on Fort Payne Chert southwest of Winchester, Tenn. *B*, Channel of Beans Creek southwest of Winchester and cherty bed material at locality 6378. *C*, Channel of Elk River north of Monteagle at reach that has low gradients; locality 6365. *D*, Channel of lower Elk River and, in foreground, bar of chert gravel; locality 6374.

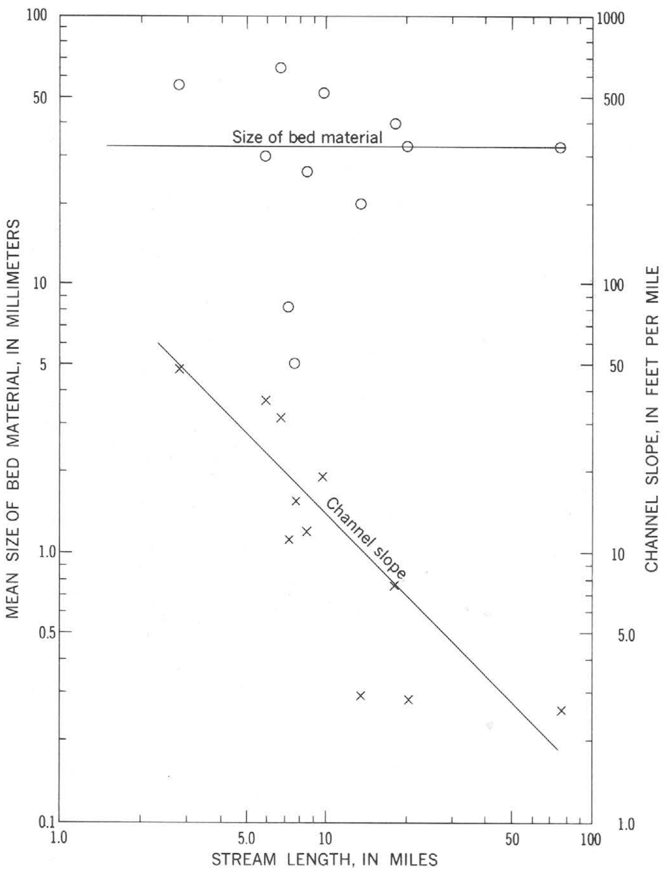


FIGURE 7.—Channel equilibrium conditions in the Elk River drainage basin, eastern Highland Rim, Tenn.

to measure the size of the normal bed material. The stream at this point is in the upper part of the St. Louis Limestone.

Downstream, as the river crosses more and more cherty rocks, the bed material coarsens, and the slope increases. At a river length of 20.7 miles, the bed material consists entirely of chert cobbles having a mean size of 32 mm. Some sandstone is carried down this far but is confined to pebbles less than 10 mm in size. The average slope, unchanged despite the increased discharge, is 2.8 feet per mile. At a river length of 77 miles, the bed material is about the same as that at 20.7 miles and has a mean value of 31 mm (fig. 6*D*). Here the material is mostly chert, probably carried down from the Fort Payne Chert. Sandstone granules less than 2–3 mm in diameter form part of the load; a small proportion consists of large slabs and boulders of locally derived limestone.

From the geomorphologist's point of view, the salient feature of the Elk River profile is the close relation between slope and the kind of material through which the stream flows. In the Pottsville Formation, of course, the slope is steep. The maximum slope is in the oolitic limestones where there is very little chemically resistant material. In this belt the steepness of slope is determined by the rate of breakup and diminution in size of the sandstone boulders that are transported downvalley from the caprock. As in Doran Cove the valley rapidly widens downstream, and the coarser transported residues of the Pottsville are stored on the cove floor. Slope rapidly decreases as the valley floor widens. The coarse Pottsville fragments are not carried beyond the outcrop of oolitic rocks. Near this boundary the size of the bed material is at a minimum. Farther downstream the chert content in the rock and soil increases, and the streambed is filled with chert cobbles. Similar conditions of channel equilibrium are maintained at least as far downstream as 100 miles. In these lower reaches, chert is supplied by tributaries and, as both drainage area and discharge increase, the slope gradually decreases.

PAINT ROCK CREEK PROFILE

Paint Rock Creek, a tributary of the Tennessee River, drains the Cumberland Escarpment to the south. It heads far back on the Plateau, and its valley cuts entirely through the oolitic limestones into the cherty limestones (fig. 9). As along the Elk River the relation between bedrock and channel slope is close, but at Paint Rock Creek the pattern of rock types along the stream is different. In the headwater part where the stream descends from the Plateau into Horse Cove, the slopes are very steep. This cove is a sink in the oolitic limestone, and the writer believes on the basis of the exposures near Princeton, Ala., that its floor is near the base of the oolitic limestones. Below Horse Cove the stream flows under ground for a short distance, but it emerges downvalley from the Tuscumbia Limestone, a chert-yielding rock. The material in the channel is chert cobbles. Channel slope averages about 6 feet per mile but declines downstream as the valley widens and discharge increases. Unlike the Elk River, Paint Rock Creek flows downdip, and as it continues downvalley it crosses progressively less cherty rocks higher up in the section. About 45 miles from its head, the stream crosses the upper contact of the Tuscumbia Limestone and again flows in the oolitic limestones.

In the lower reach in the oolitic limestones, Paint Rock Creek does not flow in a narrow valley; rather, it flows on a broad plain in which plateau remnants, capped by Pottsville Formation, are scattered at some distance from the river. Not many sandstone cobbles are carried to the river, and the channel bed is largely sand. Channel slopes in this reach are gentle, in some places less than 2 feet per mile—a lower value than that of slopes anywhere on the Elk River.

CONCLUSIONS

The gross features of the Cumberland Plateau and Highland Rim have generally been interpreted according to the peneplain concept. According to that theory the present processes of erosion cause the retreat of slopes and dissection of some areas, but the effects of vertical downwasting are minimal. Proponents of the

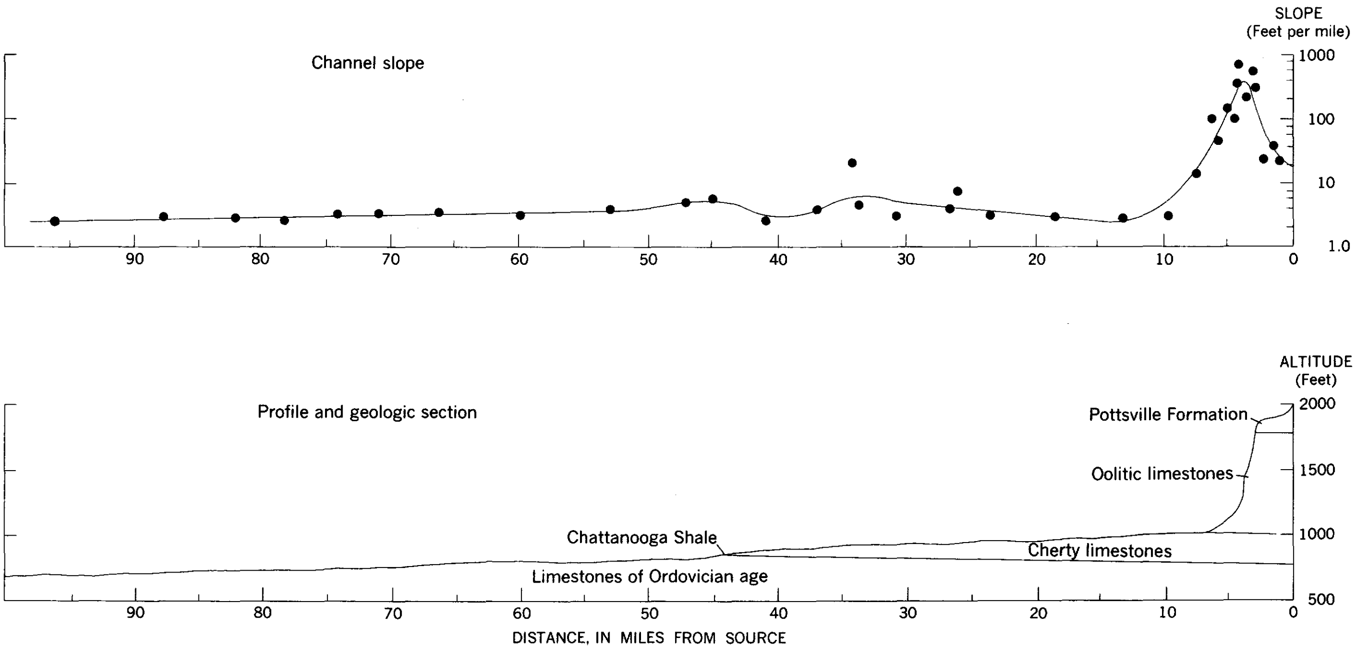


FIGURE 8.—Longitudinal profile and channel slope of the Elk River. Distances were measured along the channel and include bends.

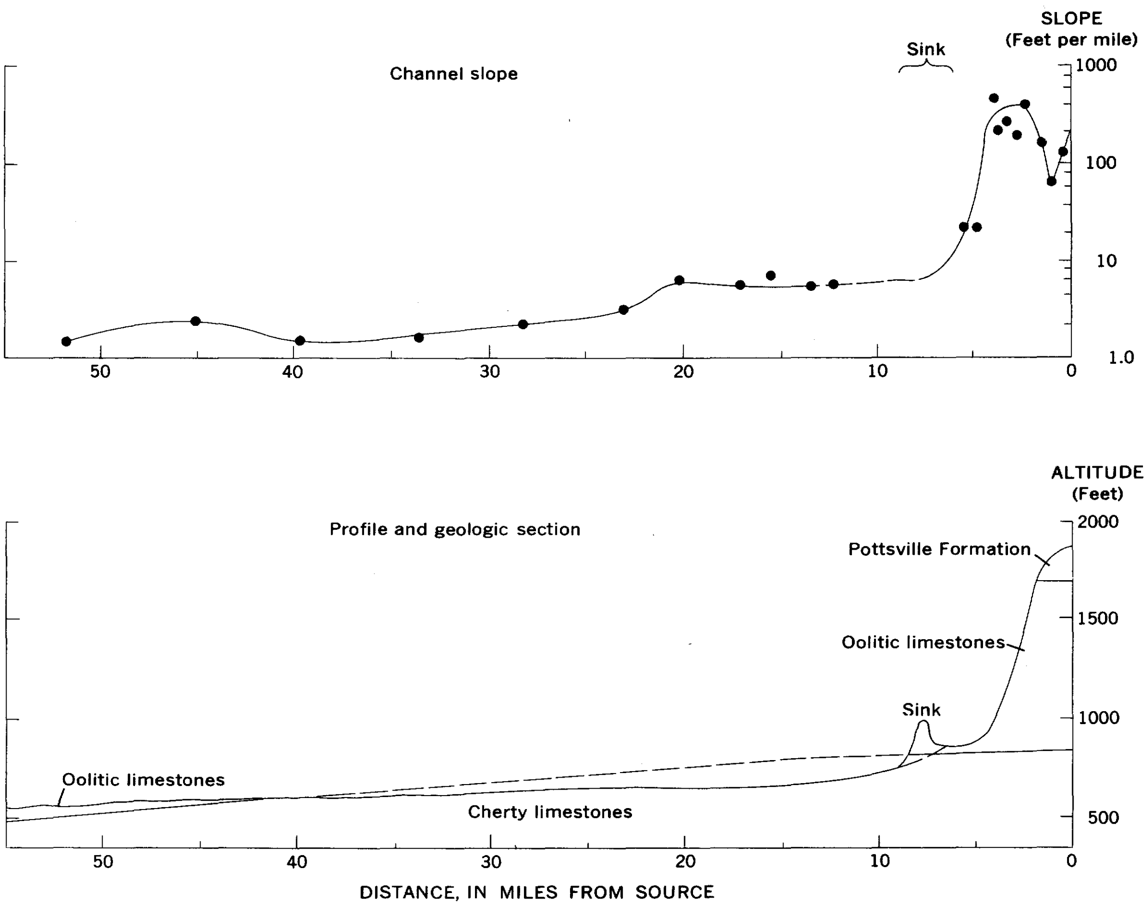


FIGURE 9.—Longitudinal profile and channel slopes of Paint Rock Creek. Distances were measured along the channel and include bends.

peneplain concept believe that large areas in the Highland Rim are remnants of the Highland Rim peneplain. The Cumberland peneplain is not as well preserved; nevertheless, the surface of the present plateau presumably corresponds closely to the original erosion surface. The interpretation requires several periods of base leveling and several periods of uplift. It also requires the preservation of exposed land surfaces for long periods of geologic time.

The alternative theory assumes that all parts of the landscape are adjusted in form to the processes that now erode them or have eroded them in the recent past. Slopes retreat headward, but they do so only as a part of the general downwasting of the whole area. Details of form change from place to place as different beds are exposed to the lowering erosion surface. No periods of base leveling are required in this interpretation. The concept makes no assumptions about the structural history of the region or about the overall relief of either past or future topography. The present topographic forms, however, are in adjustment with the ersoion process.

The distribution of surficial deposits provides a test of these alternative interpretations. If the entire Highland Rim were a peneplain, a pediplain, or any sort of stream-cut erosion surface inherited from the past, we might expect its surface to be littered to some extent with ancient cobbly and gravelly deposits, such as those now being deposited along the foot of the Cumberland Escarpment. No such distribution of gravelly deposits is present, however. There are no patches of residue from the Pottsville Formation on the Highland Rim, except at the very foot of the Cumberland Escarpment and along the large through-flowing streams. Along such streams the gravelly deposits are related to the present stream system and are diluted by locally derived materials. The local streams of the Highland Rim transport only locally derived materials. The soils of the interstream divides do not contain sandstone but do contain a fairly coarse concentrate derived from the cherty limestones. The stream channels are adjusted to carry off coarse cherty material.

The surficial deposits thus provide no evidence that supports the theory of the peneplain. They are distributed as would be expected if the entire area is downwasting and are graded as though in equilibrium with the forms of the slopes.

The equilibrium theory, in which all landscape forms are presumed to be mutually adjusted, provides a much simpler explanation for the observed relationships and for the conformity of the landscape to the geologic framework. As Chorley (1962, p. B8) pointed out, this approach emphasizes process and its relation to form rather than stage and an assumed historical development. Although the approach may seem less rewarding to geologists oriented toward study of the earth's history, the fact is that history cannot be interpreted correctly without, first, an understanding of the processes involved.

REFERENCES

Chorley, R. J., 1962, Geomorphology and general systems theory: U.S. Geol. Survey Prof. Paper 500–B, p. B1–B10.

Conant, L. C., and Swanson, V. E., 1961, Chattanooga Shale and related rocks of central Tennessee and nearby areas: U.S. Geol. Survey Prof. Paper 357, 91 p.

Fenneman, N. M., 1938, Physiography of Eastern United States: New York, McGraw Hill Book Co., 691 p.

Galloway, J. J., 1919, Geology and natural resources of Rutherford County, Tennessee: Tennessee Geol. Survey, Bull. 22, 81 p.

Gilbert, G. K., 1877, Report on the geology of the Henry Mountains [Utah]: U.S. Geog. and Geol. Survey Rocky Mountain Region (Powell), 160 p.

Hack, J. T., 1957, Studies of longitudinal stream profiles in Virginia and Maryland: U.S. Geol. Survey Prof. Paper 294–B, p. 45–97.

——— 1960, Interpretation of erosional topography in humid temperate regions: Am. Jour. Sci., v. 258–A (Bradley volume), p. 80–97.

——— 1965, Geomorphology of the Shenandoah Valley, Virginia and West Virginia, and origin of the residual ore deposits: U.S. Geol. Survey Prof. Paper 484, 84 p.

Hayes, C. W., 1899, Physiography of the Chattanooga district, in Tennessee, Georgia, and Alabama: U.S. Geol. Survey 19th Ann. Rept., pt. 2, p. 1–58.

Hayes, C. W. and Campbell, M. R., 1894, Geomorphology of the southern Appalachians: Natl. Geog. Mag., v. 6, p. 63–126.

Keith, Arthur, 1896, Description of the Briceville quadrangle [Tennessee]: U.S. Geol. Survey Geol. Atlas, Folio 33.

Malmberg, G. T. and Downing, H. T., Jr., 1957, Geology and ground-water resources of Madison County, Alabama: Alabama Geol. Survey County Rept. 3, 225 p.

Peterson, M. N. A., 1962, The mineralogy and petrology of Upper Mississippian carbonate rocks of the Cumberland Plateau in Tennessee: Jour. Geology, v. 70, p. 1–31.

Snyder, W. M., 1962, Some possibilities for multivariate analysis in hydrologic studies: Jour. Geophys. Research, v. 67, p. 721–729.

Stearns, R. G., 1954, The Cumberland Plateau overthrust and geology of the Crab Orchard Mountains area, Tennessee: Tennessee Div. Geology Bull. 60, 47 p.

——— 1963, Monteagle Limestone, Hartselle Formation, and Bangor Limestone—a new Mississippian nomenclature for use in middle Tennessee, with a history of its development: Tennessee Div. Geology Inf. Circ. 11, 18 p.

Straw, H. T., 1940, The relative relief of the Eastern Highland Rim Plateau of Tennessee; a study in the cartographical presentation of surface configuration: Tennessee Acad. Sci. Jour., v. 15, p. 372–380.

Theis, C. V., 1936, Ground water in south-central Tennessee: U.S. Geol. Survey Water-Supply Paper 677, 182 p.

Thornbury, W. D., 1954, Principles of geomorphology: New York, John Wiley & Sons, 618 p.

Wilson, C. W., Jr., 1949, Pre-Chattanooga stratigraphy in central Tennessee: Tennessee Div. Geology Bull. 56, 407 p. Wilson, C. W., Jr., Jewell, J. W., and Luther, E. T., 1956, Pennsylvanian geology of the Cumberland Plateau: Tennessee Div. Geology Folio, 21 p.

Wolman, M. G., 1954, A method of sampling coarse river-bed material: Am. Geophys. Union Trans., v. 35, p. 951–956.

U.S. GOVERNMENT PRINTING OFFICE: 1966 O—790-260