The Logan Plateau, a Young Physiographic Region in West Virginia, Kentucky, Virginia, and Tennessee

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By WILLIAM F. OUTERBRIDGE

A highly dissected plateau with narrow valleys, steep slopes, narrow crested ridges, and landslides developed on flat-lying Pennsylvanian shales and subgraywacke sandstone during the past 1.5 million years

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By William F. Outerbridge

Abstract

In the course of landslide studies of the Appalachian Plateaus, seven physiographic regions were found that could be identified by stratigraphy, structure, and type and abundance of landslides, as well as by topography, and that reflect the effects of rock control of topography across large regions.

A central area, here named the Logan Plateau, exhibits these rock-controlled attributes. The description and conclusions derived from this area can be applied to other areas of the Appalachian Plateaus.

The Logan Plateau is highly dissected with narrow valleys, steep slopes, narrow crested ridges and relief of 150–750 m. It is developed on the Breathitt and Kanawha Formations of Kentucky and West Virginia, parts of the New River and Pocahontas Formations of West Virginia, and their stratigraphic equivalents in Virginia and Tennessee. These stratigraphic units are composed mostly of subgraywacke sandstone, siltstone, shale and coal. Dips are generally about 10 m/km. Rock beds are generally flat, and faults are sparse. Regional joints are widely spaced and trend northwest and northeast. Stress relief joints are abundant. They are vertical and parallel to the contours on hillsides and extend about 10 m down from the surface. A second type of stress relief feature occurs under stream valleys, is parallel to the bedding, and is expressed as a bowing up of beds below drainage, with the formation of cavities. These two stress relief systems intersect and provide important conduits for ground water.

Residuum locally is deep, and weathering averages 56 m in depth on hilltops but is shallow along valley sides. Colluvium is the dominant surficial deposit on the flanks of hills in the Logan Plateau and is largely landslide debris. Colluvium is thinnest near hilltops and on steep slopes and thickest on the lower slopes. Landslides on the Logan Plateau are mostly debris flows and debris avalanches, but slumps occur in the colluvium. Debris avalanches and flows are common in spring and summer as direct and immediate results of torrential thunderstorms. During late winter and spring, slumps and debris flows are common.

Most streams run on bedrock. Sediment is brought to streams by creep and by landslides. Locally strip-mine debris contributes to the sediment load of the streams.

Erosion rates have been calculated for several drainage basins in and around the region. Much variation exists, both within drainage basins from year to year and between drainage basins. A reasonable figure for the erosion rate of the subgraywacke sandstone, siltstone, shale, and coal of the Logan Plateau is 100 m/m.y. (million years). Orthoquartzite surrounding the Logan Plateau is eroding at a rate of 10 m/m.y. A rectangular grid of 2-cm spacing was laid over 1:250,000-scale maps of the Logan Plateau area, and the highest point in each grid square was plotted. The points were contoured; they form an envelope surface that corresponds to a likely former erosion surface. The age of that surface is 1.5 million years. It is unlikely that any erosion surfaces in the Logan Plateau are older than 1.5 million years.

The Kentucky, Big Sandy, Guyandotte, and Kanawha-New Rivers and their major tributaries probably have been flowing along the same general courses since Tertiary time, but they have been strongly affected by the establishment and history of the Ohio River. Local lithologic conditions have caused each stream to have a different history through the Quaternary. Terraces and abandoned meanders occur along all of them. The major streams, particularly the Big Sandy River and the South Fork of the Kentucky River, have been actively deepening their valleys and increasing their drainage areas by headward extension and by stream piracy.

INTRODUCTION

The Appalachian Plateaus province is mostly a highland region underlain by generally flat lying clastic rocks. A deeply dissected landscape of steep slopes and narrow, sinuous ridges and valleys has been eroded through the flat-lying rocks. The landform development of the region reflects differences in local precipitation, base level, geologic structure and stratigraphy, and possibly local uplift.

The Appalachian Plateaus province was divided into seven sections by both Fenneman (1946) and Thornbury (1965). Fenneman (1938, p. 283) stated that "sections differ in the character of their underlying rocks, in altitude, in degree of dissection, and in the presence or absence of glaciation." On his map (1946), he characterized his units by presence or absence of glaciation, stage of erosion, and relief. Thornbury considered the geology of his regions but stated that "given a certain geologic framework, the topographic condition or expression of an area is largely determined by its geomorphic history" (1965, p. 9).

The subprovince boundaries were not firmly established because of differences of opinion of various geomorphologists on the boundary between the Cumberland Plateau and the Allegheny Plateau (fig. 1). Fenneman (1930) drew "a line between a maturely dissected Allegheny Plateau and a submaturely dissected Cumberland Plateau." Later he included the drainage basin of the Kentucky River in the Cumberland Plateau (Fenneman, 1938). In similar manner, Thornbury (1965) distinguished a Cumberland Mountains section from the Cumberland Plateau on the basis of different degrees of dissection, noting that the separation of the Cumberland Mountains and the Allegheny Mountains was arbitrary, but he did not draw a map. Both Fenneman and Thornbury used degree of dissection as a key to subdivision and found it inadequate because they referred the dissection they saw to a peneplain model and not to the response of rocks in the field to geomorphic processes.

Geologic mapping of 7.5-min quadrangles in Kentucky since 1960 and a slope stability reconnaissance throughout the Appalachian Plateaus since 1974 have provided abundant new data on the structure, stratigraphy, and geomorphology of the entire province. These studies show that bedrock units vary in lithology and thickness through the region and that the topography varies directly with the stratigraphy. The terrain can be divided into geomorphic

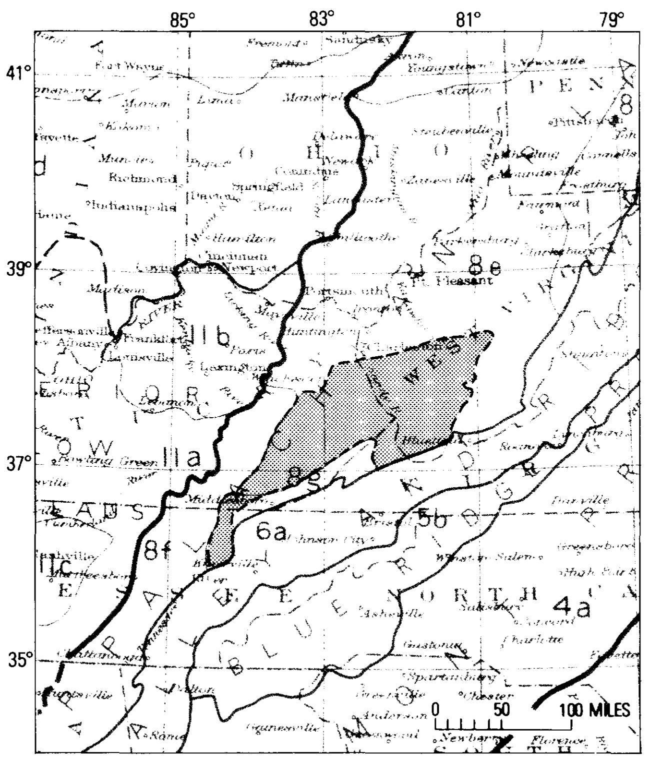

Figure 1. Kanawha section (8e), Cumberland Plateau section (8f), and Cumberland Mountain section (8g) of the Appalachian Plateaus, modified from Fenneman (1946). The unglaciated Allegheny Plateau section of Fenneman (1938) was renamed the Kanawha section by Fenneman in 1946. The Logan Plateau is shown by shaded area.

units that reflect bedrock control of geomorphic processes (Newell, 1978). During landslide studies of the region, it was found that landforms are controlled by bedrock lithology and are modified by landsliding. Streams function mainly to carry away landslide debris. The type and abundance of landslides and the slope on which they lie are controlled by bedrock (Outerbridge, 1980). Different regions in the Appalachian Plateaus can be characterized by their landslides as well as by their bedrock lithologies and topography, and the regions so delineated do not match the regions established by Fenneman and by Thornbury.

A reclassification of the Appalachian Plateaus is needed because recent mapping in the plateaus has shown that earlier classifications do not portray adequately the physiography of the province. Earlier classifications were based on the degree of dissection of the regions from assumed peneplains. This classification is based on the specific reactions of bedrock to geomorphic processes.

One of the newly recognized physiographic regions is the Logan Plateau (pl. 1), named for Logan County, W. Va. Surrounding it are the redefined Cumberland Plateau, the new Ohio Plateau, the new Parkersburg Plateau, the redefined Allegheny Plateau, the Valley and Ridge province, and the Cumberland Overthrust Block. Most of these regions are provisionally named.

A plateau is an upland area of flat-lying beds. The Logan Plateau is highly dissected and is underlain by nearly flat lying subgraywacke sandstone, shale, and coal of the Breathitt and Kanawha Formations of Pennsylvanian age and their stratigraphic equivalents in Tennessee and Virginia. The valleys are narrow, and gradients are steep; slope angles of valley sides average 26° (50 percent grade). The floors of the main valleys are at elevations between 200 and 700 m. Ridges are sinuous and narrow, rising to hilltops whose elevations range from about 450 m to about 1050 m and reach a maximum of 1103 m. The highest elevations are along the southeast side of the region and along the boundary with the Allegheny Plateau; the lowest elevations are along the northwest side of the region. Relief varies from 150 m to 750 m across the region but the median is about 300 m. The drainage network includes streams that have a dendritic pattern with many straight reaches.

In contrast, the Cumberland Plateau (pl. 1) is an area of low local relief, generally about 50–250 m, with rounded hills and wide, low-gradient, flat-floored valleys with meandering streams. Tributaries of the meandering rivers have dendritic patterns. The Cumberland Plateau is developed principally on almost flat lying orthoquartzitic sandstone of the Lower Pennsylvanian Lee Formation of Kentucky and its equivalents in Tennessee. Few landslides occur on the flat to gently sloping surfaces of the Cumberland Plateau. The boundary of the Logan Plateau against the Cumberland Plateau from the edge of the Valley and Ridge province northward to about lat 37° N. is drawn where steep hills of the Breathitt Formation rise above the gently sloping to flat surface of the Cumberland Plateau. North of lat 37° N., the boundary is drawn on the Kentucky River drainage divide.

The Ohio Plateau (pl. 1) is an area of low local relief, generally 50–250 m, with steep to gentle slopes, narrow crested to rounded ridges, and wide to moderately wide valleys. The streams have a dendritic pattern modified by meanders. Gradients are gentle, and the base level of streams is controlled by outcrops of Lee sandstone or by the Ohio River. Elevations of stream valleys range from 150 m at the Ohio River to 250 m at the head of the Licking River, and hilltops range from about 250 m near the Ohio River to 500 m at the head of the Licking River. Relief is generally about 150 m. Debris flows and debris avalanches occur near the boundary between the Ohio Plateau and the Logan Plateau, but earth flows and slumps are more abundant generally over the plateau. The boundary between the Logan Plateau and the Ohio Plateau is drawn between drainage areas controlled by orthoquartzite of the Lee Formation and those not so controlled.

The provisionally named Parkersburg Plateau (pl. 1) is an area of moderate local relief, generally of 100–250 m, with steep to gentle slopes, narrow crested to rounded ridges, and narrow valleys. Streams commonly are in a dendritic pattern with straight reaches. Stream gradients are high. Elevations of streams range from 150 to 250 m; of hill tops, from 250 to 500 m. The topography is developed on sandstone and shale generally of Allegheny and younger age. The slide-prone red shale of the Conemaugh and Monongahela Formations of Pennsylvanian age and the Washington and Greene Formations of Permian age are extensive in the Parkersburg Plateau. Earth flows and slumps are the dominant landslide types in the Parkersburg Plateau. The boundary between the Logan Plateau and the Parkersburg Plateau is drawn between the area where interbedded gray subgraywacke sandstone, siltstone, and shale are the dominant bedrock and the area where interbedded red sandstone, siltstone, and shale are dominant.

The Allegheny Plateau (pl. 1) in the vicinity of Beckley, W. Va., is an upland with hilltop elevations between 600 and 1000 m. Relief is low to moderate, generally about 100–400 m, with rounded hills and wide flat valleys developed on sandstone of the New River Formation of Early Pennsylvanian age. The streams in the vicinity of the New River have a dendritic pattern. The surface of the Allegheny Plateau adjacent to the Logan Plateau is generally stable, with few landslides. The boundary between the Logan Plateau and the Allegheny Plateau is drawn between the deeply dissected sandstone and shale of the Kanawha Formation and the sandstone flats of the underlying New River Formation.

The Valley and Ridge province (pl. 1) is characterized by straight to curvilinear ridges along resistant beds of folded rocks. Drainage lines are trellised. These features contrast sharply with the sinuous ridges and dendritic drainage pattern of the Logan Plateau. Landslides are far less abundant in the Valley and Ridge than on the Logan Plateau. The boundary between the Logan Plateau and the Valley and Ridge province is drawn between the flat-lying rocks of the plateau and the folded and faulted rocks of the mountains.

The Cumberland Overthrust Block (pl. 1) is a large synclinal area set off from the Logan Plateau by the Jacksboro, Pine Mountain, and Russell Fork faults. The core of the syncline is composed of flat-lying rocks of the same age, types, and physiographic character as the rocks of the Logan Plateau. The subprovince is distinguished by its synclinal structure and boundary faults from the Logan Plateau. In areas of high relief and along the northwest face of Pine Mountain, debris flows and debris avalanches are as abundant as on the Logan Plateau. Stratigraphic control of landslides is more apparent, and block glides occur along the southeast slope of Pine Mountain.

The features of the regions are summarized in table 1.

Precipitation ranges from 100 to 140 cm per year across the region in which the Logan Plateau is located. It is fairly evenly distributed throughout the year, varying between about 5–10 cm in October and about 10–15 cm in March. Floods are common in the spring, and torrential thunderstorms are frequent in the spring and summer. Temperature ranges from about −20°C in January to about 40°C in July but averages near freezing in January and near 25–30°C in July (National Oceanic and Atmospheric Administration, 1980).

METHODS OF STUDY

Data used in this study to characterize the Logan Plateau include bedrock stratigraphy and structure, observations of surficial deposits and slopes, topographic analysis, and erosion rates.

Data on bedrock stratigraphy and structure were obtained through the study of diamond drill cores and the mapping of 11 7.5-min geologic quadrangle maps, as well as reconnaissance throughout the area. The map showing bedrock lithology (pl. 2) was compiled and generalized from geologic maps of West Virginia (Cardwell and others, 1968), Kentucky (McDowell and others, 1981), Tennessee (Hardeman, 1966), and Virginia (Calver, 1963).

Data on surficial deposits and slopes came from Newell (1977, 1978) and from a reconnaissance study of the landslides of the Appalachian Plateaus conducted during 1977–82, as well as a detailed study of the landslides of the Hazard North Quadrangle, Ky.

Topographic data used in this study were derived from 1:250,000-scale, 100-ft contour interval maps published by the U.S. Geological Survey. From these data, a contour map of summit altitudes (the envelope map, pl. 5), another of the general altitude of the drainage net (the subenvelope map, pl. 3), and a relief map (pl. 4) were prepared. The derivative maps were prepared according to the method

Table 1. Comparison of physiographic regions in Appalachian Plateaus

Region	Structure	Bedrock type	Slope	Relief (m)	Landslides	Drainage pattern
Logan Plateau	Flat	Subgraywacke sandstone, siltstone, and shale.	Steep	150–750	Debris avalanches, debris flows.	Dendritic.
Cumberland Plateau	Flat	Orthoquartzite, siltstone, shale	Flat to gentle	50–250	Minor slumps	Do.
Ohio Plateau	Flat	Subgraywacke sandstone, siltstone, shale, and orthoquartzite.	Gentle to steep	100–250	Mud flows and slumps, minor debris avalanches and flows.	Do.
Parkersburg Plateau	Flat	Red beds	Steep	100–250	Abundant slumps and mud flows.	Do.
Allegheny Plateau	Flat	Orthoquartzite, sandstone, and shale.	Gentle to steep	100–400	Few slumps and debris flows.	Do.
Valley and Ridge province.	Folded and faulted.	Quartzite, sandstone, siltstone, shale, and limestone.	Flat to steep	0–750	Debris avalanches, flows, and slumps.	Trellis.
Cumberland Overthrust Block.	Synclinal, fault-bounded thrust fault slice.	Subgraywacke sandstone, siltstone, shale, orthoquartzite, red beds, and limestone.	Steep	200–750	Debris avalanches, debris flows, and block glides.	Trellis/ dendritic.

described by Denny (1982), except that a 5-km grid (2 cm at 1:250,000 scale and 5 mm at 1:1,000,000 scale) was used and all numbers were converted from English to metric units as they were recorded.

Erosion rates were calculated from data in Ehlke, Bader, and others (1982), Ehlke, Runner, and Downs (1982), Curtis and others (1978), Quinones and others (1981), Leist and others (1982), Gaydos and others (1982), and U.S. Geological Survey (1982). Analysis of the topography by the method of Stearns (1967) gave information on the development of the topography of the area and on the amount of material eroded. Estimated erosion rates were calculated from streamflow and suspended sediment and dissolved solids or conductivity data.

GEOMORPHOLOGY

Local relief in the Logan Plateau ranges from 150 to 750 m. Relief is highest on the southeastern side of the region and decreases northwestward. Slopes tend to be steeper where there is more sandstone. Slopes are also precipitous where streams undercut them. In general, slopes average 26° (50 percent grade) (fig. 2). Flood plains are very narrow except along major streams. Valley sides commonly are more or less linear and may follow regional joints in plan. Minor valleys and reentrants scallop the sides of linear valleys. Joint control is inferred from the straightness of some valleys and from the tendency of major streams to run in straight reaches separated by abrupt bends. Valley side slopes underlain by colluvium or bedrock meet flat, alluviated valley bottoms at a sharp angular boundary. With very few exceptions, the alluvial valley fill is less than 3 m thick and commonly is less than 1 m thick. The bottoms of the main valleys commonly are clear of colluvium except along the valley wall. The heads of most valleys are semi-bowl-shaped, and the bottom of the bowl is filled with landslide debris. Most streams run on bedrock. Terraces and abandoned meanders occur along the Kentucky and Big Sandy Rivers and other rivers but have not been studied in detail.

Flatwoods (figs. 3, 4), a unique feature in this region, is a 5-km^2 mesa standing above the surrounding highlands. Only Pine Mountain, about 6 km to the southeast, stands higher than Flatwoods, by about 60 m. The highest point on Flatwoods is 868 m, and the relief on the surface of the mesa is about 110 m. The lowest parts of Flatwoods are about 60 m above the tops of surrounding hills. Flatwoods is capped by sandstone, shale, and coal and is now being reduced in elevation by strip mining for coal. The bedrock is weathered to a depth of about 60 m; this depth of weathering combined with the mesa landform strongly indicate that Flatwoods is a remnant of an old erosional surface of the Logan Plateau.

The Logan Plateau is drained by the Cumberland, Kentucky, Big Sandy, Guyandotte, and Kanawha-New Rivers, which are tributaries of the Ohio River. The Logan Plateau is a region of active downcutting, and most of the rivers and their tributaries are entrenched into bedrock.

Most of the sediment carried by streams is brought to them by creep, debris flows, debris avalanches as defined by Sharpe (1938), and slumps. The process helps maintain the steepness of the outsides of entrenched meanders (Newell, 1978) or, more generally, of any slope with a stream at its base. Any stream flowing along the side of a valley receives steady contributions of debris due to creep and episodic contributions due to slumps in colluvium and bedrock. Debris flows and debris avalanches are fairly common in the spring and summer as direct and immediate results of torrential thunderstorms. The response time of small streams to heavy rain is very short, and flash floods carry much of the new alluvium away immediately. Larger streams have alluvial fan deposits where higher gradient tributaries enter

Figure 2. View northwestward from Flatwoods Lookout Tower, Pike County, Ky., showing typical Logan Plateau topography.

them. As much as 7 m of sediment has been reported at one locality in the Tug Fork (Huddle and Englund, 1966), but most of the river bottoms have a thin cover of sand less than 1 m thick. Sandstone ledges crop out in the bottoms of most of the rivers.

Estimated erosion rates of streams in and around the Logan Plateau are shown in table 2, and the locations of basins drained by those streams are shown on plate 2. The annual erosion rate is the sum of the annual discharges of dissolved, suspended, and bed loads from a drainage basin divided by the area of the basin. The dissolved solid discharge is routinely taken as a function of the specific conductance of the water in a stream (U.S. Geological Survey, 1982). Regression equations have been devised to relate dissolved solid load and specific conductance, but where no such equation is available the specific conductance is multiplied by a rule-of-thumb factor of 0.65 (U.S. Geological Survey, 1982) to obtain an estimate of dissolved solid load. The dissolved solid load is then multiplied by the amount of water passing the measuring point to obtain the dissolved solids discharge. The result is expressed in cubic feet of sediment and is divided by the area in square miles of the watershed to obtain an erosion rate for dissolved solids.

Suspended sediments are sediments held in suspension by the turbulence of the stream. Suspended sediment discharge is estimated by multiplying the water discharge in cubic feet per second by the suspended sediment concentration in milligrams per liter and the factor 0.0027 (U.S. Geological Survey, 1982). The result is expressed in tons and must be divided by an appropriate specific gravity to obtain a volume of rock. A specific gravity of 2.4 for Pennsylvanian sandstone, shale, and coal was derived from data in Clark (1966) and used in this study. The volume is divided by the area of the watershed to obtain a suspended sediment erosion rate.

Bed load is the part of a stream's load that is dragged, rolled, or bounced along the stream bed. Much of the bed load moves only at high water. Bed load generally is not measured, but where it has been measured in the Logan Plateau (Curtis and others, 1978; U.S. Geological Survey, 1982) the components have been sand size or smaller. Observation of stream beds in eastern Kentucky shows fairly abundant gravel, cobbles, and boulders, as well as trash.

Sources of error in the estimation of erosion rates due to dissolved solids, suspended solids, and bed load are numerous and important. As the data for the Coal River,

Figure 3. View eastward from Flatwoods Lookout Tower showing contrast in topography between top of Flatwoods mesa and the rest of the Logan Plateau. Pine Mountain stands in the background at right.

W. Va. (table 2), show, no one measurement on a stream is very significant. It happens that the values estimated for the Coal River correlate well with the price of coal, which was high in 1974, 1978, and 1979. But the estimates also vary with the weather for the year and are higher for wet years than for dry ones. New major construction or strip mining will increase the estimated erosion rate for the drainage in which it occurs, but as such activity ceases the erosion rate drops back to more normal levels.

There is a likely major source of error in the estimate of the rate of erosion due to dissolved solids. Dissolved solids are added to a stream mostly by inflow from groundwater. The volume of inflow of groundwater changes more slowly with time than the volume of surface water, and the concentration of dissolved solids in groundwater varies little from day to day, so that the dissolved solids concentration is lower when the stream is high and higher when the stream is low. But not all of the groundwater leaving the drainage basin flows in the stream. Wyrick and Borchers (1981) determined that stress relief fracturing, including arching under the valley bottom, provides conduits for significant flows of groundwater. In the stream they studied, which flowed over a waterfall near the lower end, streamflow was 11 times greater below the falls than above in times of low flow and 6 times greater during high flow. Underflow in the basins tabulated in table 2 is unknown but may also be a large fraction of the stream flow.

One can believe that the products of human activity would tend to increase the concentration of dissolved solids in streams, and there is evidence that in the vicinity of major sources, such as mines and factories, they do. But there is so much overlap in the ranges of dissolved solids concentrations for surface water and groundwater that it is necessary to specify pollution in terms of particular ions, and the amounts do not seem to have a significant effect on denudation rates. At Fishtrap and at Dewey Dams in Kentucky (pl. 2), where underflow is blocked, the dissolved solids load of the streams is about one-tenth of the suspended sediment load.

The conductivity of rainwater is less than 20 micromhos per centimeter (Ehlke, Bader, and others, 1982), which may represent a dissolved solid content of as much as 13 parts per million. Annual rainfall is greater than 1 m, so 0.013 mm of solids per meter of rain might be washed through the system and be recorded as an erosion rate of 13 m/m.y.

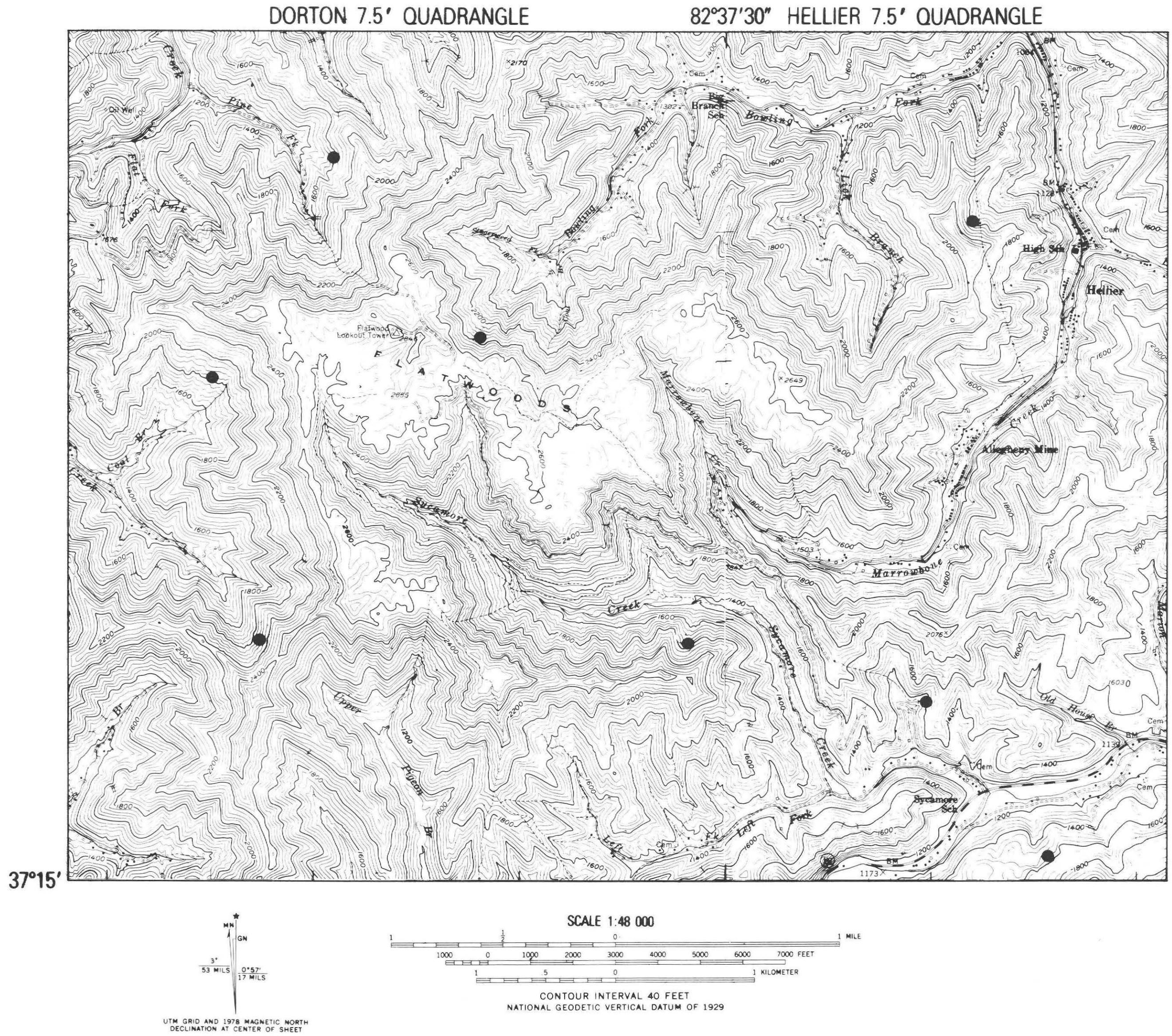

Figure 4. Part of the Logan Plateau including Flatwoods. Note that Flatwoods has a classic mesa form. Note also the characteristic landslide topography (shown by solid circles) in the large hollows bounding Flatwoods. Map from U.S. Geological Survey, Dorton, Ky., Quadrangle (1954, photorevised 1978), and Hellier, Ky.-Va. Quadrangle (1954, photorevised 1978).

Suspended sediment discharge can be fairly accurately estimated. It can be assumed that the amount measured in the stream is the entire amount. But there is no certainty that the discharge measured is the same as the discharge 200 years ago or more. In areas of active strip mining, it is not. On Caney Fork near Gulnare (pl. 2, loc. 20; table 2), for instance, sediment yield per unit area was about 100 times greater in October-November 1975 than in the same period in 1974 although the increase in runoff was only fourfold (Curtis and others, 1978). The area disturbed by strip mining doubled, from less than 0.5 percent to 1 percent of the drainage area. Observations of streams in areas of strip mining show that within a year after the onset of strip mining, streams draining the area begin to aggrade their channels. Sediment is dominantly sand size but ranges up to boulder size. Aggradation continues until the influx of mine debris is reduced or eliminated, and then the stream clears its channel. The cycle can be completed in about 20 years. The Big Creek drainage area, for instance, was mined intensively by strip, auger, and underground methods in the 1950's and early 1960's. By 1967 the overbank spoil was covered by grass and young trees, and by 1974–75 the suspended sediment yield per acre-foot of runoff, as reported by Curtis and others (1978), was the lowest in the Fishtrap Lake basin. One may, therefore, avoid overestimating the erosion rate by simply avoiding drainages with recent active mining. The same applies to drainages affected by recent roadbuilding and other heavy construction.

Table 2. Estimated rates of erosion in selected drainage areas, in meters per million years
[--, no data; do, ditto]

Drainage area and measuring point	Upstream area in km²	Years of record	Erosion rates: Suspended sediment	Erosion rates: Dissolved sediment	Erosion rates: Combined	Reference	Principal rock types in drainage, and remarks	Map number (see pl. 2)
West Virginia								
Coal River at Tornado	2230	1974	115	--	--	Ehlke, Runner, and Downs (1982).	Gray sandstone, siltstone, and shale; some red sandstone, siltstone, and shale near mouth. Heavily mined (Kanawha, Allegheny, and Conemaugh Formations).	1
		1975	83	--	--			
		1976	24	--	--			
		1977	76	--	--			
		1978	121	--	--			
		1979	135	--	--			
Mean			92	4.66	97			
Indian Creek at Fanrock	105	1974–76	12	14	26	Ehlke, Bader, and others (1982).	Resistant sandstone, siltstone, and shale of the New River Formation.	2
Guyandotte River near Baileysville.	798	1969–76	54	477	531	do	Same, heavily mined	3
Clear Fork at highway 16 bridge.	321	1974–76	36	387	423	do	Same, heavily mined	4
Guyandotte River at Logan	2165	1975–76	30	39	69	do	Gray sandstone, siltstone, and shale in a region of active mining.	5
Guyandotte River at Branchland.	3175	1975–76	41	38	79	do	Gray sandstone, siltstone, and shale of the Kanawha and Allegheny Formations.	6
Mud River near Milton	663	1975–76	30	11	41	do	Gray sandstone, siltstone, and shale of the Allegheny Formation and red sandstone, siltstone, and shale of the Conemaugh and Monongahela Formations.	7
Virginia								
Levisa Fork at Big Rock	769	1974–75	100	12	112	Curtis and others (1978).	Gray sandstone, siltstone, and shale of Breathitt Formation, heavily mined.	8
Conaway Creek at Conaway ...	19.2	1974–75	284	58	342	do	Same, active heavy mining	9
Kentucky								
Card Creek at Mouthcard	10.8	1974–75	1089	20	1109	do	Same	10
Feds Creek at Fedscreek	30.0	1974–75	53	14	67	do	Breathitt Formation, very little active mining.	11
Big Creek at Dunlap	24.7	1974–75	72	18	90	do	Same	12
Island Creek near Phyllis	6.27	1974–75	131	8	139	do	Active mining	13
Lick Creek at Lick Creek	17.4	1974–75	253	20	273	do	Breathitt Formation, active mining ...	14
Millers Creek near Phyllis	4.35	1974–75	1532	22	1554	do	Same, extremely heavy mining	15
Grapevine Creek near Phyllis.	16.0	1974–75	102	22	124	do	Same, almost no mining	16
Levisa Fork near Millard (Average basin yield).	1004	1974–75	129	12	141	do	Same, locally heavily mined	17
Johns Creek near Meta	146	1975	325	22	347	do	Same	18
Raccoon Creek near Zebulon ..	38.3	1975	175	.9	176	do	Same, very little mining	19
Caney Fork near Gulnare	9.69	1975	422	6	428	do	Same	20
Brushy Fork at Heenon	52.8	1975	1147	11	1158	do	Same, extensive active mining	21
Buffalo Creek near Endicott ...	16.1	1975	1185	16	1201	do	Same	22
Johns Creek near Van Lear ...	520	1975	204	19	223	do	Same, locally heavily mined	23
Middle Fork of the Kentucky River at Hyden.	523	1976–78	95–131			Quinones and others (1981).	Breathitt Formation	24
		1980–81	40	26	66	U.S. Geological Survey (1982).	Same, in a dry year	24
Rockcastle River at Billows ...	1564	1979–80	7.4	9.22×10^{-3}	7.4	Leist and others (1982).	Orthoquartzite of Lee Formation and some sandstone and shale of Breathitt Formation.	25
Tennessee								
Emory River near Oakdale	1979	1979–80	4	34	38	Gaydos and others (1982).	Same, river cuts limestone in lower part of gorge.	26

The proportion of the suspended sediment load contributed by domestic sources is a function of population density. Much of it is direct effluent from homes and is fairly constant in volume from day to day. A liberal allowance for suspended sediment contribution might be 1 kg per person per day. The population density is about 23 people per square kilometer. The contribution then is 8.4 metric tons per km^2 per year. Dividing by 2.4, the assumed specific gravity of the rock in the region, yields a volume of 3.5 m^3 of rock to remove from each square kilometer and comes down to an erosion rate of 3.5×10^{-6} m/yr or 3.5 m/m.y. that can be attributed to human activities.

Sources of error, then, include a random variation, dependent at least in part on the weather, which can result in an error of half an order of magnitude in any single erosion rate estimate. In addition the amount of dissolved solids leaving a drainage can be an order of magnitude larger than whatever value is calculated from stream flow because of unmeasured underflow. Where the underflow is blocked, as at a major dam, data control is better. Human activities raise the indicated erosion rate for dissolved solids, but the amount is only locally measurable. Dissolved solids in rainfall might raise the indicated erosion rate, but they seem to be lost along the way—some of the dissolved solids erosion rates are less than the estimated contribution from rainwater. Estimated erosion rates for suspended sediments are affected by disturbance of the surface, but drainages with such disturbances can be observed and avoided. The contribution from domestic activities is small compared to other sources of error and may be discounted. The bed load is unmeasured but if measured would increase the erosion rate.

Overall, considering the amounts and directions of error and uncertainty, it appears that most estimates of erosion rates are too low and that order of magnitude figures like 10 m/m.y. and 100 m/m.y. are the most reasonable way to express erosion rates for lengths of time of interest to geologists. Exceptions exist for such data as those of Curtis and others (1978), in which all the sediment coming into the reservoirs could be accounted for and there was no significant underflow at the dams. The erosion rates, 141 m/m.y. at Fishtrap Dam and 223 m/m.y. at Dewey Dam, are probably fairly accurate numbers for current erosion rates but are high for historic rates owing to contributions of sediment from mining and construction. The rates are consistent with those found by Ahnert (1970) for areas of high relief.

The operation of all these sources of error notwithstanding, it should be noted that as data on erosion rates accumulate they tend to group about specific values. Rates of erosion published by Hack (1980, 1965) for large areas of heterogeneous rock types tend to group around 50 m/m.y. Coates and Naeser (1981) found the same rate in clinkered stone and shale of the Powder River Basin. I find about 100 m/m.y. in subgraywacke sandstone, siltstone, shale, and coal of Pennsylvanian age but about 10 m/m.y. on orthoquartzitic sandstone of Pennsylvanian age. These erosion rates suggest strongly that peneplains, if they ever existed, could not have lasted very long, that Flatwoods will be eroded away fairly soon, and that Pine Mountain owes its prominence to the orthoquartzite of the Lee Formation, which forms the crest and southeast side of the mountain.

STRATIGRAPHY

Orthoquartzitic sandstone of the Lee Formation is distributed in discontinuous, extensive bodies that decrease in age westward at and within the base of the Breathitt Formation and within the top of the Pennington Formation (fig. 5, pl. 2). These sandstone bodies, about 150 km long, 50 km wide, and as much as 100 m thick, have been considered to be sandbars (Horne and others, 1971) and channel fill deposits (Rice and others, 1979). Foreset beds are conspicuous in most outcrops. Conglomeratic sandstone is abundant in the lower parts of channel fills. The sandstone is at least 90 percent quartz and has been mined for glass sand near Paintsville, Ky., and at the northeast end of Pine Mountain on the Kentucky-Virginia border. The sandstone is generally resistant to erosion and forms prominent cliffs, although locally it is leached and friable. Orthoquartzitic bodies of the Lee Formation are interbedded with dark gray shale, siltstone, and even-bedded subgraywacke sandstone of the lagoonal facies of the Breathitt Formation.

The Breathitt Formation (Kanawha Formation of West Virginia) and the Pocahontas and New River Formations of West Virginia are a westward-thinning wedge of subgraywacke sandstone, siltstone, shale, and coal that can be divided into three facies—lagoonal, lower delta plain,and upper delta plain (Horne and others, 1971). The oldest rocks, on the eastern side of the wedge, were deposited in a narrow basin. Younger beds were deposited in successively wider zones to the west. The beds most distant from the sediment sources were dark-gray shale containing rare marine fossils interbedded with thin siltstone and sandstone beds. The dark-gray shale generally lies on and is interbedded with orthoquartzitic sandstone of the Lee Formation and is included in the lagoonal facies.

The lower delta plain facies is composed of medium-gray shale, subgraywacke sandstone in both channel and quiet-water deposits, siltstone, and coal in very extensive beds. Two widespread but generally very thin marine units, the Kendrick Shale Member and the Magoffin Member, occur in this sequence, which forms the greatest part of the Breathitt Formation.

Near the top of the preserved section and nearest the sediment sources in older parts of the section is the upper delta plain assemblage. This consists of thick channel fill deposits of locally conglomeratic, subgraywacke sandstone and thick coal beds, siltstone, and shale. This sequence begins just above the Magoffin Member in the main part of

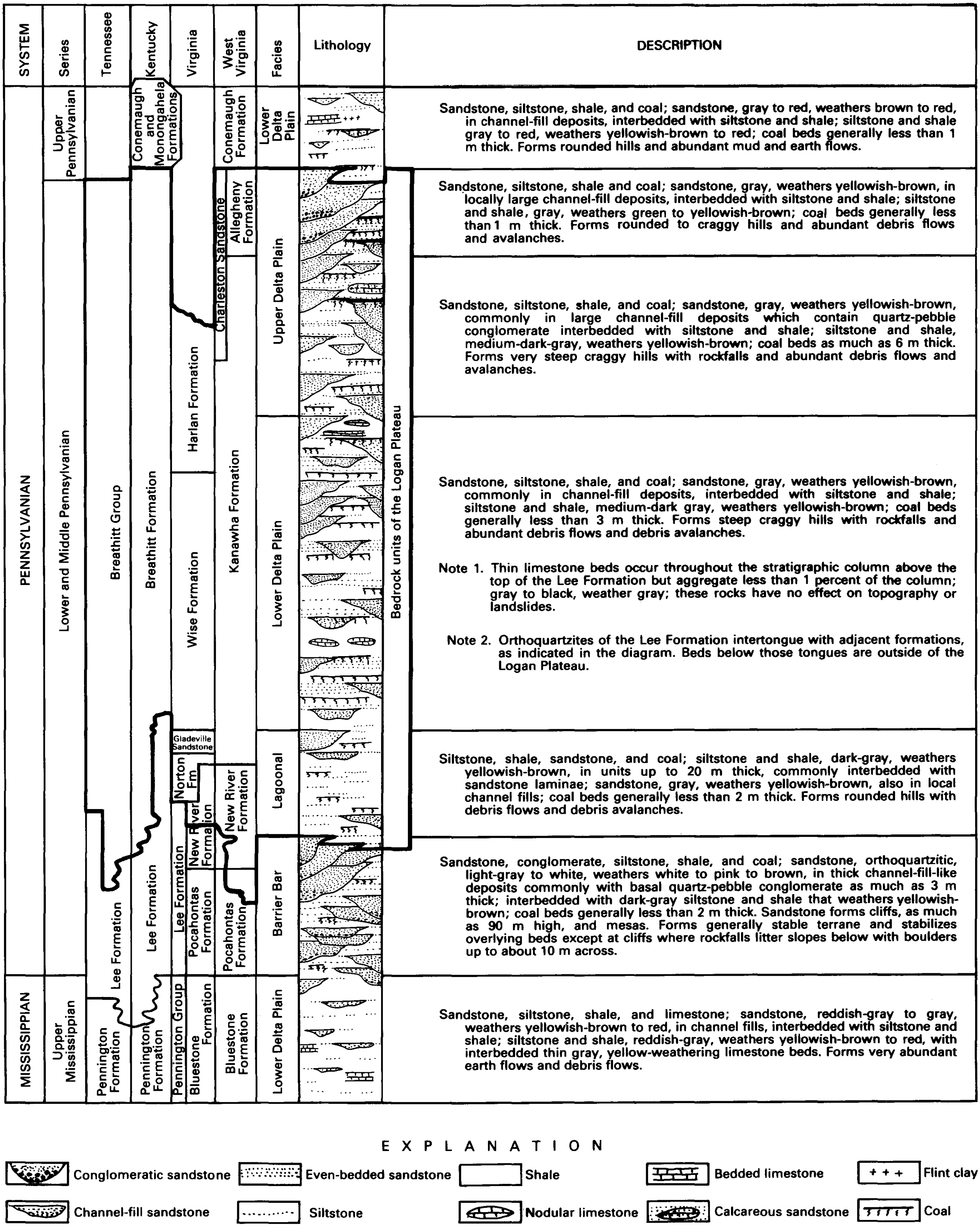

Figure 5. Generalized stratigraphy of the Logan Plateau.

the basin and extends to the base of the Allegheny age rocks. Sandstone in the Lower and Middle Pennsylvanian section decreases to the south, southwest, and west, as shown by Newell and Rice (1977), but increases northeastward. In the vicinity of Summersville, W. Va., sequences of shale become thin in the Breathitt-Kanawha section, and the characteristic topography of the Logan Plateau disappears as the section becomes much more than half sandstone.

Channel fill sandstones crop out along mountain tops in the Allegheny age rocks in Martin, Perry, and Breathitt Counties, Ky. Where outcrops are more continuous, siltstone and shale are dominant, sandstone is generally even bedded, and thick clay, fossiliferous chert, and limestone are present; all suggest a return to a lower delta plain environment.

Sandstone, siltstone, and shale, some red, of the Conemaugh Formation cap hills in the northwestern part of the Logan Plateau but are not abundant enough to influence the topography.

STRUCTURE

The Pennsylvanian rocks of eastern Kentucky, southern West Virginia, Virginia, and Tennessee lie in a broad shallow syncline. On the east side of the syncline, Mississippian and Pennsylvanian age rocks are in gradational contact (Arkle and others, 1979), but beginning in the middle of the basin an unconformity truncates increasingly older rocks northwestward across Kentucky and westward across West Virginia. The Pennsylvanian age rocks are deposited on the Pennington Formation of Mississippian age on the east side of the basin and on the successively lower Newman Limestone and Borden Formation to the west.

Dips are gentle, about 10 m/km. Minor anticlines occur in several parts of the larger syncline and bring orthoquartzite of the Lee Formation to the surface.

Faults are rare in the Logan Plateau and have no significant effect on the topography. Regional joints in the Logan Plateau are about 10 m apart and trend northeast and northwest. Stress relief joints result from the removal of compressional stress on underlying rocks by the erosion of overlying rocks. Where intersected by road cuts, the joints tend to be nearly vertical, to extend only a few meters from the surface, and to be spaced 1 m or less apart. They run parallel to valley walls and along the centerlines of valleys. Beneath the valley floors, horizontal fractures, mainly along bedding planes, connect vertical fractures along the valley walls with those along the valley centerlines. The stress release joint system is the principal conduit for ground water in the Logan Plateau (Wyrick and Borchers, 1981).

SURFICIAL DEPOSITS

Distribution of Residuum

Residuum in this area consists of thoroughly rotten and commonly friable sandstone and shale that has weathered to soft clay. It occurs in small areas on ridge crests and hilltops throughout the region. On some sandstone flats, such as the one crossed by the Perry-Letcher County line just north of the North Fork of the Kentucky River, residuum is as much as 26 m thick, according to a core log (Alvord, 1970), and weathering extends to a depth of 100 m. Residuum is much less abundant than on the Cumberland and the Allegheny Plateaus.

Depth of Weathering

Weathering is shown in drill core as a change in sandstone color from N–7 gray to orange and brown in the 5YR to 10YR hue range (Goddard and others, 1948). The range of depth of weathering in 15 drill cores (Huddle and Englund, 1966; Alvord, 1970) drilled in the tops of hills scattered over eastern Kentucky is from 30 to 100 m, and the average depth of weathering is 56 m. Depth of weathering is greater where sandstone forms a greater portion of the geologic section and is less where shale is a greater portion of the section. Shale is less permeable and may inhibit weathering by blocking the groundwater circulation. In deep road cuts across ridges and spurs, staining extends along joints and bedding planes in sandstone, but in general weathering is very shallow along valley sides.

Soils

The dominant soils in the region, as shown on U.S. Soil Conservation Service maps of Kentucky and West Virginia (1973, 1975), are deep to moderately deep, well drained gravelly or stony soils formed in loamy gravelly to stony colluvium from sandstone, siltstone, and shale. The normal slope range is 20–60 percent. The soil pH is in the range of 4–5. Soil permeability is 5–12 cm/hr, and the water capacity, the approximate amount of capillary water held in soil wet to field capacity, is about 1–2 mm/cm of soil.

Colluvium is the dominant surficial deposit in the region and covers all but the steepest hillsides. Colluvium is thinnest near hilltops and on very steep slopes; it is thickest near the bases of slopes and especially in the heads of valleys. Newell (1977) mapped colluvium extensively in the Kentucky River Basin.

Landslides

Recent mapping in the Logan Plateau has shown that landslides are ubiquitous and characterize the region. Debris flows and debris avalanches are the dominant types. No preferred orientation has been observed for either debris flows or debris avalanches.

Little debris accumulates on slopes of 33° or more. Dingles, small wooded valleys, which occur along almost every slope, concentrate the debris and provide conduits for debris avalanches. Crags break loose from sandstone beds on the slopes and are concentrated in the dingles. The dingles that contain many crags are called cragdingles. Debris avalanches are common on such slopes, but debris flows are rare. Slopes have a complicated microtopography of sandstone crags that support benches of varying slopes depending on the proportions of coal, shale, siltstone, and thin-bedded sandstone in the rock beneath the slope. An irregular cyclic repetition of beds is characteristic of the stratigraphy of the region, so beds of the same rock type crop out repeatedly along the slope. Debris developed on each bench moves down to the next by creep, slope wash, and flowage.

Imbrication and remobilization of debris flows make delineation of any one flow difficult. The largest slides on the Logan Plateau are two on Windrock Mountain, above Frost Bottom, near Oak Ridge, Tenn., where debris flows dropped 600 m and extended 3000 m, forming a deposit as much as 500 m wide. Flows with an area of as much as 20 hectares are common. Flows covering more than 20 hectares are less common.

Debris avalanches are linear features as much as 10 m wide and about 1 km long. Debris avalanche deposits occur as steep cones at the mouths of dingles. Slumps occur in the toes of both debris flow and debris avalanche deposits where they have been oversteepened or oversaturated. Debris flow and debris avalanche deposits are essentially continuous along the lower slopes in the region for tens to hundreds of kilometers, so that a mountainside without an old landslide cover is unusual. Bedrock exposures are limited to stream beds, steep slopes and cliffs, especially those just above rivers, and narrow ridges. Earthflows are rare to absent on the Logan Plateau.

Derivative Maps of the Logan Plateau and Surrounding Area

In order to emphasize significant topographic features of the region, three derivative maps were prepared. The subenvelope map (pl. 3) shows present stream gradients; the steeper gradients indicate where stream erosion is proceeding more actively. The relief map (pl. 4) shows the depth of dissection between the present erosion surface and the surface shown by the envelope map. The envelope map of the Logan Plateau and surrounding area (pl. 5) defines a surface that can be considered a former erosion surface (Stearns, 1967).

Most of the major topographic features shown on the envelope map are similar to those that exist now. One exception is the line of depressions extending southwest in the Ohio and Cumberland Plateaus. They occur in more easily eroded rocks overlying less easily eroded rocks (pl. 5) at the base of a broad shallow syncline flanking the Jessamine Dome. The three little depressions lying just to the northwest are in a comparable lithologic situation but are stratigraphically lower and structurally higher on the east flank of Jessamine Dome. These depressions can have at least three possible origins. They could be caused by local erosion lowering the hilltops, or by subsidence along the axis of the larger depressions, or by continued uplift of the Jessamine Dome. I am inclined to favor the erosional origin but cannot dismiss the structural ones.

Drainage on the former erosion surface was divided into the westward-flowing Cumberland, Kentucky, Red, and Licking Rivers and the northward-flowing Big Sandy, Guyandotte, and New-Kanawha Rivers. The course of the Cumberland River is not well defined, and the contours suggest a drainage pattern much different from the present one. Much of the area now drained by the South Fork of the Kentucky River was drained by tributaries of the Cumberland River, and the Cumberland apparently did not cross Pine Mountain. It is likely that the main stream of the river had not yet worked its way across the orthoquartzite of the Cumberland Plateau (pl. 2). In the Kentucky River basin, the South Fork hardly shows, but topography indicates drainage lines clearly associated with the Middle and North Forks. The Red River valley has no obvious topographic expression. The Licking River valley has very little topographic expression. Both the Red and the Licking Rivers flow over thick sections of orthoquartzite and have been delayed in the erosion of their upstream reaches. The area they drain appears to be part of a broad upland area of low relief. Elevations drop into the Big Sandy drainage area.

The Big Sandy and Guyandotte Rivers drain to a pre-Ohio River system, probably the Teays-Mahomet, from a well-developed drainage basin. The basin extends through an area of high relief almost to the Valley and Ridge province and climbs sharply at the head of the drainage to the level of the Allegheny Plateau. The New River Gorge is not expressed on this map, possibly because it was too narrow or because it had not been cut. The present Ohio River is not expressed on this map.

A prominent topographic rise trends northeast across West Virginia and lines up with Pine Mountain. It is breached in the middle of the map by the Big Sandy and Guyandotte River valleys. The breach coincides with a southwestward gradation of quartzite to subgraywacke on the northeast side of the breach (pl. 3) and is limited on the southwest by the barrier formed by Pine Mountain.

The subenvelope map (pl. 3) shows elevations and gradients of the present drainage (Denny, 1982) and can be considered a representation of the surface that would result if erosion went to completion (Stearns, 1967). Steeper gradients are associated with more active streams and indicate to some extent which basins are expanding.

The Kentucky River gradients in the North and Middle Forks steepen greatly as the rivers cut into the high hills near Pine Mountain. Such gradients are not obvious on the South Fork, which is cutting headward much more rapidly than the other two forks but through lower hills and the shales of the lower part of the Breathitt Formation. It is likely that erosion in the North Fork is inhibited by outcrops of orthoquartzite in the riverbeds (pl. 2). The Red and Licking Rivers are controlled by thick orthoquartzite (pl. 2). They have fairly gentle gradients on the upland and flow at altitudes generally well above 150 m. The Levisa Fork of the Big Sandy River flows 100 m below the Licking River, in part because the head of the Licking River lies against a lower reach of the Levisa Fork but also because the Levisa Fork has a shorter run to the Ohio River and has no orthoquartzitic sandstone to cross on the way. The Tug Fork and the Guyandotte River are in the same situation, and all of these rivers are eroding headward very rapidly. The Tug Fork has already cut into the Valley and Ridge province. The New-Kanawha River has a low gradient in its lower reach, but it steepens as the river flows over orthoquartzite ledges at the west end of the New River Gorge.

The relief map (pl. 4) of the Logan Plateau and surrounding areas was constructed by contouring the differences between the high and low points in each 25-km^2 grid cell. It displays the distribution of local relief across the region and represents an approximation of the amount of downcutting of the streams from the surface described by the envelope map to their present level; it does not imply that the envelope surface has been lowered.

Relief in the Logan Plateau is generally more than 150 m and reaches 750 m; roughly half the region has more and half has less than 300 m. The highest relief is in the Crab Orchard Mountains, where stream gradients are steepest. From there the zone of higher relief extends east-northeastward from the end of Pine Mountain to the northeast end of the region, coinciding with the thickest section of subgraywacke sandstone, siltstone, shale, and coal. The section thins northwestward and the relief decreases. Depression contours are either on or upstream from areas of orthoquartzite or thick sandstone.

The deep soil development and saprolite on sandstone along the ridges in the region suggest that ridge tops are a zone of no erosion [x_c of Horton (1945)]. Downcutting is concentrated at the streams. The geometry of the stream valley requires that the amount eroded be half that which would be removed if the envelope were reduced to the level of the subenvelope. From these facts and from the erosion rate it is possible to calculate an age for the envelope surface.

If the top of a ridge is fixed and erosion is concentrated under an adjacent stream, a triangle can be described having apices at the ridge crest, the point above the creek at the envelope surface, and a point directly below on the creek. The vertical leg is approximately equal to the relief. Moving the triangle a very small distance upstream or downstream generates a prism. The volume of the prism is the horizontal distance from the stream to the ridge times the thickness of the prism times half the relief and is also the volume of rock eroded in a given time. Half the relief divided by the erosion rate equals the age of the envelope surface, which is 1.5 Ma. Almost all the surface of the Logan Plateau is younger than 1.5 Ma. There are no Tertiary or Cretaceous erosion surfaces.

History of Drainage Development Since Late Tertiary Time

Base level of the upper Cumberland River is 250 m above sea level, established by the elevation of the point at which it crosses orthoquartzite of the Lee Formation at Cumberland Falls, Ky. At present the river flows over the Rockcastle Conglomerate Member, near the west edge of the Cumberland Plateau. Quaternary glaciation probably had no climatic effect on the upper Cumberland River.

The base levels of the Kentucky, Big Sandy, Guyandotte, and Kanawha-New Rivers have been affected by events in the history of the Ohio River, which has been given by Ray (1974). The establishment of the Ohio River in Nebraskan time forced the Kentucky River to adjust its base level to the changing levels of the Ohio, resulting in the establishment and deepening of a gorge across the limestone plateau of central Kentucky. When the headward-migrating nick point reached the Pennsylvanian rocks cropping out on the Cumberland escarpment, it was not impeded because there the orthoquartzite of the Lee Formation is thin. The nick point continued cutting back into the South Fork of the Kentucky River unimpeded.

The boundary between the Kentucky and Cumberland River drainages is marked by active stream piracy by the Kentucky River tributaries and by distinctly lower stream valley bottoms on the Kentucky River side of the divide. Good examples of such piracy occur in the Barbourville-Manchester area, Kentucky. Near Bush, Ky. (figs. 6, 7) (Hima and Blackwater, Ky., Quadrangles), the Laurel River flows at an elevation of about 354 m in a wide valley with gentle slopes cut in subgraywacke sandstone and shale of the Breathitt Formation. It has been beheaded by a small tributary of Horse Creek, which flows at about 310 m and which enters Goose Creek just south of Manchester. Near the site of the beheading, the newly acquired part of the small tributary drops from about 360 m in the former Laurel River valley to 311 m in the tributary valley in a distance of 305 m. The rocks in the area dip to the southeast at about 20 m/km. In the same general area (pl. 6) (Hima and Fount, Ky., Quadrangles), Collins Fork of Goose Creek has reversed the flow of a long reach of Little Richland Creek and is within 11 km of capturing the Cumberland River at Barbourville, Ky. Stream captures in the Fount Quadrangle may in part be a result of tectonic activity along the White Mountain fault zone (Ping and Sergeant, 1978).

The valleys of the South Fork of the Kentucky River and its tributaries are generally narrow, except near Manchester, Oneida, and possibly Booneville, where the river crossed thick sandstone and has widened its flood plain above the sandstone while cutting a channel through it.

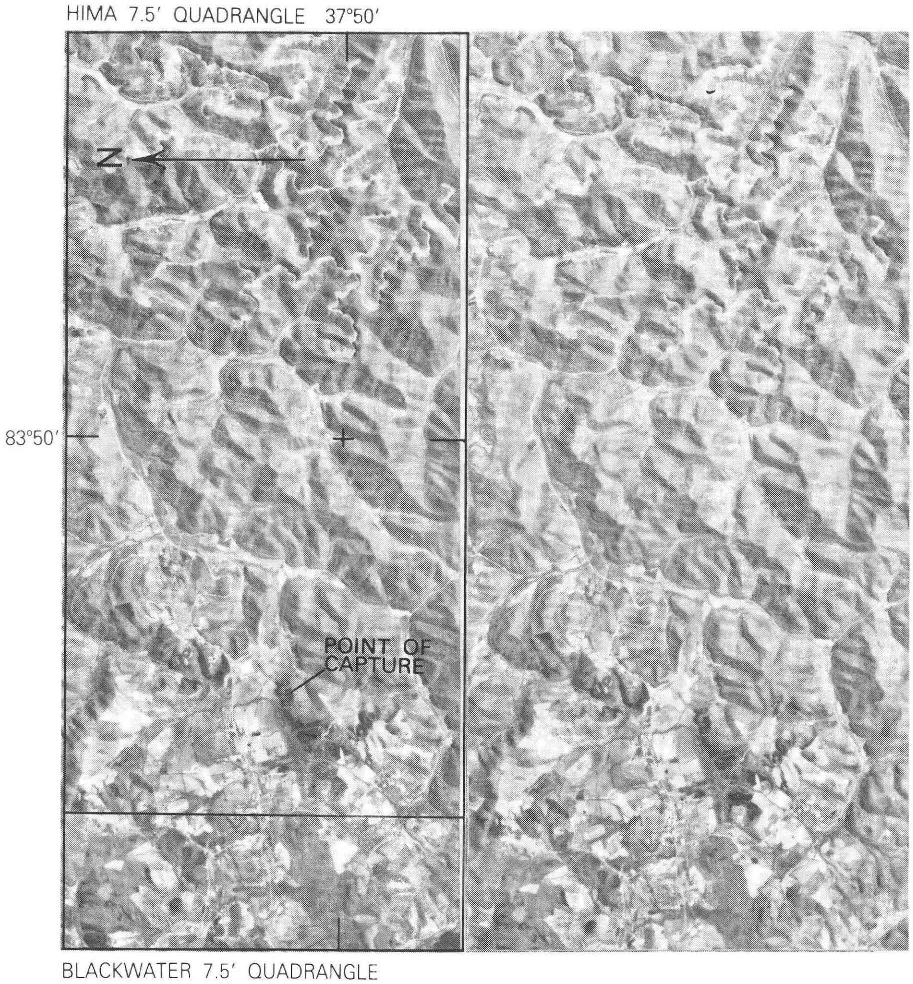

Figure 6. Stereograph of the area near Bush, Ky., showing the advance of the Kentucky River drainage against the Cumberland River drainage. For names of features see figure 7. Scale of imagery about 1:80,000.

The Middle Fork and the North Fork of the Kentucky River branch just above Beattyville, Ky. Many terraces and abandoned meanders occur in the lower reaches of the Middle Fork. Its drainage area is bounded by the drainage areas of the South and North Forks of the Kentucky River and by Pine Mountain; the Middle Fork is not increasing its drainage area.

The North Fork of the Kentucky River flowed across a tongue of the Corbin Sandstone Member of the Lee Formation just east of Beattyville, Ky., at an elevation of about 274 m. By the time the North Fork completed its gorge through the Corbin Member, it had also cut a wide flood plain at about 274 m and developed a set of large meanders. Traces of the temporary base level extend as far upstream as Hazard, Ky.; 274 m is comparable to the level of Kentucky River terrace gravels south of Winchester, Ky., which are as high as 284 m and as low as 213 m. The river likely began cutting through the orthoquartzite ledge after beginning its adjustment to the Ohio River. Many terraces and abandoned meanders occur along the North Fork of the Kentucky River.

Tributaries of the North Fork flow at lower elevations than those of the Licking River to the north, so the North Fork tributaries are extending headward at the expense of the Licking River tributaries. The process is slow because there is not much difference between the elevations of the streams involved.

A reverse situation exists between the Kentucky and the Big Sandy River basins, as in the Handshoe Quadrangle, Ky. (fig. 8). Quicksand Creek in the Kentucky River basin flows at about 354 m, the divide between the creeks is at about 393 m, and Saltlick Creek in the Big Sandy basin flows at about 274 m. The Big Sandy basin is expanding at the expense of both the Kentucky River basin and the Licking River basin.

The Big Sandy has a large drainage basin, and its channel to the Ohio River is the same as its channel to the preglacial Teays River valley. It does not cross orthoquartz-

Figure 7. Stream piracy and advance of the Logan Plateau against the Cumberland Plateau. Note the great difference in topographic type between the Logan Plateau and the Cumberland Plateau. Heavy line shows boundary between the two regions. This is one of the few places where a sharp boundary can be drawn. Triangles show points of piracy. Map area covers a part of figure 6. Base from U.S. Geological Survey Hima (1979) and Blackwater (1979), Ky., 7.5-min Quadrangles.

ite of the Lee Formation. Well-developed stream terraces flank the river and its major tributaries 240 km or more upstream from Ashland. The Big Sandy has been systematically expanding by capturing drainage area. Where the Big Sandy drainage basin bounds the Kentucky River drainage, the Big Sandy tributaries flow at a lower elevation than the Kentucky tributaries. The Pound River, a tributary of the Russell Fork of the Levisa Fork of the Big Sandy, is pirating drainage area from the head of the Cumberland River at Flat Gap on the Kentucky-Virginia border, while other tributaries of the Russell Fork are actively cutting back the plateau formed on the Gladeville Sandstone, at the expense of the Powell River. The Russell Fork is extending its drainage area near Big A Mountain at the expense of the Clinch River. The Levisa Fork of the Big Sandy is eroding headward across Sandy Ridge, also at the expense of the Clinch River. The Dry Fork of the Tug Fork of the Big Sandy has crossed Sandy Ridge and entered the Valley and Ridge province, cutting off the head of a tributary of the Clinch River. Just northeast of there, orthoquartzitic sand-

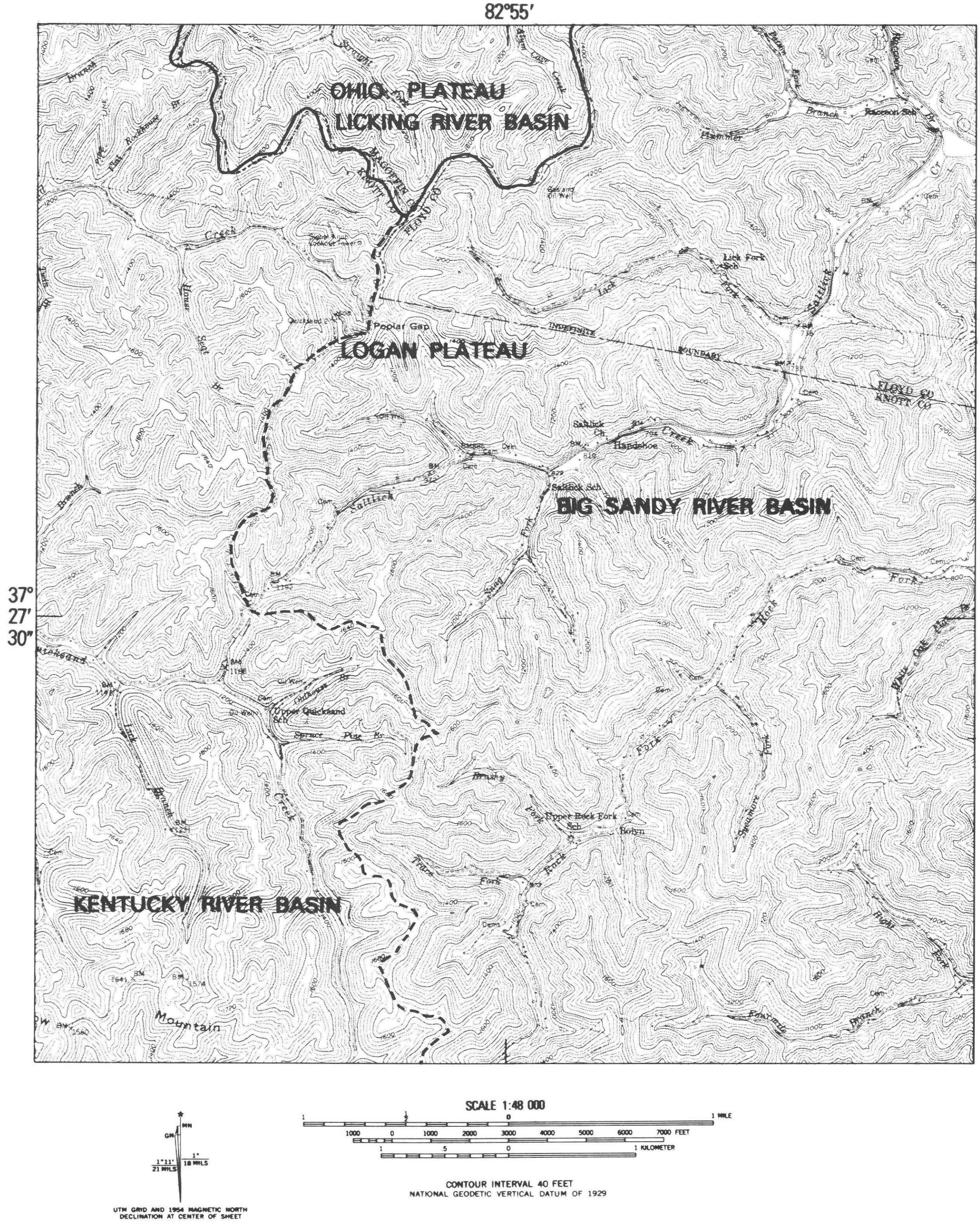

Figure 8. Part of the Handshoe 7.5-min Quadrangle, Ky. (1954), showing differences in relief and elevation of valley bottoms at the junction of the Kentucky, Licking, and Big Sandy River basins. Straight Fork and Alum Cave Fork in the Ohio Plateau join to form the head of the Licking River. Solid line is boundary between Logan and Ohio Plateaus; dashed line is boundary between Kentucky and Big Sandy River basins.

stone of the New River Formation is exposed on the southeast side of the syncline. The orthoquartzitic sandstone outcrop inhibits headward erosion by the Tug Fork and by Elkhorn Creek and helps make a boundary for the Logan Plateau.

The Guyandotte River cuts across the valley of the preglacial Teays River. Since its establishment, the Guyandotte River has extended across the subgraywacke sandstone and shale of the coal basin to the edge of the plateau area between Princeton and Beckley, W. Va., where the orthoquartzite of the New River Formation crops out. Orthoquartzite outcrops at the east edge of the Logan Plateau inhibit erosion by the headwaters of the Guyandotte and help bound the Logan Plateau.

The New-Kanawha River, which crosses the Logan Plateau at its eastern end, flows in a gorge comparable in depth to the other major valleys in this region. The major change in the river since the establishment of the Ohio River has been the rerouting of the Kanawha River from the Teays valley to the present valley, with a 60-m drop in elevation as the river graded to the Ohio. The Kanawha River has formed a floodplain of about the same width as the Teays valley, in the same kind of rocks (the Conemaugh Formation), since the rerouting. The flood plain narrows upstream and pinches out at Smithers, W. Va.

Where the Gauley River joins the New River and forms the Kanawha River, the streams run on bedrock. Tributaries to the New-Kanawha are generally short and steep. The Gauley River, a major tributary, drops 300 m in 40 km from the boundary of the Logan Plateau near Summersville, W. Va., to its junction with the New River.

In spite of the relatively homogeneous structure and stratigraphy of the Logan Plateau, each of the rivers draining it has a completely different history. The histories depended on the distance to the Ohio River from the edge of the Logan Plateau, the original size of the river, and local stratigraphy in each river basin. The almost flat bedrock structure permitted the development of a dendritic drainage pattern.

The abandoned valley of the preglacial Teays River is about 58 m above the present Ohio and Kanawha Rivers; 58 m is the net change in base level of the Big Sandy, Guyandotte, and Kanawha Rivers. The old Kentucky River flowed 92 m above its present level at its junction with the Ohio River. A net change of as little as 58 m does not seem enough to account for the very active headward erosion that is a feature of the Logan Plateau and that was in progress before the establishment of the Ohio River. Uplift of the region to the east and southeast might help account for some of the erosional activity.

The next major event in the Logan Plateau will probably be the capture of the Cumberland River at Barbourville by Collins Fork of Goose Creek, a tributary of the South Fork of the Kentucky River. Already floods on the Cumberland River reach altitudes greater than 299 m, and the altitude of the divide separating the Kentucky and Cumberland River drainages is only 311 m.

SUMMARY AND CONCLUSIONS

Ongoing slope stability studies in the Appalachian Plateaus have shown a correlation among bedrock type, relief, and landslide types consistent with the idea that rock control of geomorphic processes produces characteristic topography and surficial deposits, which can be used to delineate physiographic units. The Appalachian Plateaus province is being divided into new physiographic regions on that basis. One of these regions is the Logan Plateau, which lies between the Cumberland and the Allegheny Plateaus and is also bounded by the Ohio Plateau, the Parkersburg Plateau, the Valley and Ridge province, and the Cumberland Overthrust Block.

The Logan Plateau is a highly dissected plateau developed on nearly flat lying subgraywacke sandstone, shale, and coal of the Breathitt, Kanawha, and parts of the New River and Pocahontas Formations of Pennsylvanian age and their stratigraphic equivalents in Tennessee and Virginia. The valleys are narrow and occupied by streams that have a dendritic pattern with many straight reaches. Gradients are steep. Valley sides are steep, with slope angles averaging 26° (50 percent grade). The floors of the main valleys are at elevations between 200 and 700 m. Ridges are sinuous and narrow, rising to hilltops whose elevations range from about 450 m to a maximum of 1103 m. Highest elevations are along the southeast side and along the boundary with the Allegheny Plateau. Lowest elevations are along the northwest side.

Landslides on the Logan Plateau are extensive and consist of debris flows and debris avalanches. Their deposits are continuous over tens to hundreds of kilometers of hillside. Earth flows, abundant in other provinces, are rare to absent on the Logan Plateau. Each newly recognized physiographic section is characterized by a different suite and abundance of landslides. The type and abundance of landslides are dependent on the underlying bedrock.

The erosion rates are variable, depending on geologic and social conditions in each drainage basin, are subject to possibly very large errors in the measurement of dissolved solids discharge, and may be underestimated. An order of magnitude figure of 100 m/m.y. can be considered reasonably accurate for the rate of erosion of the rocks of the Logan Plateau. The orthoquartzite surrounding the Logan Plateau is being eroded at a rate of about 10 m/m.y., and as a result the Cumberland, Ohio, and Allegheny Plateaus are growing as the rocks of the Logan Plateau are stripped from the orthoquartzite.

The envelope and subenvelope surfaces are descriptive and hypothetical. They converge as the grid size decreases or the point density increases. The subenvelope surface shows present stream gradients. It also shows the surface that might eventually form if all the streams suddenly stopped downcutting and began valley widening until all the divides were gone, a fanciful and unlikely event. The relief surface is a contour map of the amount of relief in each grid square. Distribution of relief can reflect local differences in stratigraphy, structure, and topography. The envelope is a hypothetical surface, which becomes more generalized as the grid size is increased and the point density is decreased. It is drawn on the highest point in each grid square; it represents a surface that includes those high points and is an older surface than the present one.

The grid size used in this report is 5 mm at a scale of 1:1,000,000, so that on plates 3, 4, and 5 there is a control point every 5 mm, on average. A comparison of the modern topography shown on the base map with that shown on the 1:250,000 sheets of the same area indicates that the topography at 1:1,000,000 is highly generalized, so much so that the envelope map is probably a more accurate representation of the older surface than the topographic map is of the present one.

It is possible to construct envelope, relief, and subenvelope maps from base maps of any scale, and a series of envelope maps can be organized and calibrated against erosion rates to show the development of the present landscape.

An envelope map drawn on a 5-km grid, with corresponding subenvelope and relief maps, shows a surface much like the present one, except that the drainage system has been somewhat modified, the Ohio River established, and, possibly, the New River Gorge established, since the time represented by the envelope surface. The surface is about 1.5 million years old. Such an age makes the suggestion that the Logan Plateau contains peneplains representing Cretaceous and Tertiary erosion cycles untenable. It is more likely that erosion has continued steadily, possibly since the Cretaceous, and that almost all traces of any pre-Pleistocene surface have been eroded away.

Recognition of the Logan Plateau solves the problem of the definitions of surrounding physiographic regions and allows all of the subregions of the Appalachian Plateaus to be defined by the objective criteria of stratigraphy, structure, and the response of rocks to geomorphic processes.

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