Geomorphology and Forest Ecology of a Mountain Region in the Central Appalachians

GEOLOGICAL SURVEY PROFESSIONAL PAPER 347

Prepared in cooperation with the
Harvard Forest, Harvard University

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By JOHN T. HACK *and* JOHN C. GOODLETT

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GEOMORPHOLOGY AND FOREST ECOLOGY OF A MOUNTAIN REGION IN THE CENTRAL APPALACHIANS

By John T. Hack and John C. Goodlett*

ABSTRACT

The area studied, mostly in the headwaters of the Shenandoah River, Augusta and Rockingham Counties, Va., includes about 55 square miles of densely forested mountain land and has an average relief of about 1,500 feet. It is part of an area that in June 1949 was subjected to a violent cloudburst which damaged large tracts on slopes and bottom lands. Most of the area is underlain by flaggy arkosic sandstone and interbedded reddish shale of the Hampshire formation of Devonian age. The highest ridges are capped by massive sandstone of the Pocono formation of Mississippian age. In most of the area the rocks dip gently to the southeast but in the northwestern and southeastern parts they are folded into synclines that localize northeastward-trending ridges.

Topography is remarkably uniform and the slopes are graded to regular forms that may be described in simple mathematical terms. Because of a high bifurcation ratio between streams of different orders, almost half of the area is composed of first-order valleys. Each of the first-order valleys may be subdivided into five different parts based on the convexity or concavity of the contours. Each part, because of its geometric form, receives water downslope at a different rate. The driest area on which the contours are convex outward (from the mountain) is called the "nose" and presumably receives the least moisture by flow from the slope above. The side slope has straight contours and hypothetically receives somewhat greater runoff. The hollow above the stream head is an area of concentration of the drainage lines in which the discharge of storm runoff is inferred to increase downslope at a rate greater than the square of the distance. It merges with the channelway, a narrow strip running down the valley axis between steep side slopes. In the channelway, runoff increases downstream in proportion to the 1.6 power of the distance. The channelway at some places is bordered by a narrow strip of concave-upward slope that because of its geometric form receives somewhat more runoff than the side slopes above. In valleys larger than the first and second order the channelway is so broad that the stream channel itself is bordered by bottom lands many times larger. All of the bottom lands are subject to erosion or deposition during floods of various frequencies.

The stony and bouldery soils of the mountain slopes were sampled at many localities by measuring the diameters of individual particles selected at points on a grid pattern. The mean size of the particles on the surface of the ground was found to vary markedly from one part of a valley to another and to increase roughly with the runoff concentration inferred from the topography. The texture of debris is fine on noses and coarse in channelways and hollows. Mean size ranges from less than 1 mm on some noses to over 250 mm in some hollows. In the channelway the size generally decreases to about 100 mm and remains nearly constant in a downstream direction. Standard deviation or sorting of the particles narrows as drainage area increases.

Fields of large, angular quartzite blocks are conspicuous features of some side slopes and noses. They generally are present where massive quartzitic sandstone of the Pocono formation crops out in an exposed location such as a ridge top or nose, and where the sandstone is underlain by relatively soft shale. In these places boulders have slid down, forming a mantle on the slope below.

The vegetation of the area includes about 45 species of trees, 25 of which are closely related in their local distribution to moisture conditions. Concentration of runoff related to topographic forms is a particularly important factor. The close relation between the vegetation, the landforms, and the texture of the soil mantle is shown by the analysis of sample plots in seven first-order valleys, on several ridges, and on the flood plain of the Little River. Vegetation was further studied by the preparation of a forest map on which the vegetation is classed in three units based on the presence or absence of a few species. Unit 1, the northern hardwood forest, defined by the presence of yellow birch, basswood, and sugar-maple, or any one of the three, occupies moist environments such as hollows and bottomlands. Unit 2, the yellow pine forest, defined by the presence of pitch-pine and table-mountain pine, or either one of the two, and by the absence of the species that define unit 1, occupies relatively dry sites such as ridges and noses. Unit 3, the oak forest, defined by the absence of all of the above species, occupies intermediate sites, especially side slopes. Each of the three forest types contains many other characteristic species, especially oaks that are also affected by topographic position.

The ground cover of shrubs and herbaceous plants varies in composition in a manner similar to that of the trees. The form of the forest also changes in relation to topography and moisture, for the trees grow larger and taller in the hollows than on noses and side slopes. The distribution of the three forest types is thought to coincide with the duration of moisture in the ground through the growing season. Environmental factors that affect moisture directly also affect the physiological processes of the plants. The relation is both direct and indirect, and no cause and effect relation between moisture regimen and species distribution is implied. Topographic position on the slope is an important factor in the moisture regimen, but so also are geologic structure, soil texture, exposure, and altitude.

The violent cloudburst flood of June 1949 that caused severe erosion in the Little River valley afforded an opportunity to study the importance of extremely low frequency floods as agents

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of erosion and as factors in forest ecology. During this storm, which probably lasted only a few hours, rainfall in excess of 9 inches fell on an area centered over Buck Mountain. The runoff produced dozens of debris avalanches on the upper mountain slopes, enlarged most of the channelways, and reworked the debris on the bottom lands of many larger valleys and in places removed the forest cover on the entire valley floor. The high rates of runoff were effective in eroding mountain slopes, sorting surficial debris, transporting debris, and producing terraces, alluvial fans, and cones. It is believed that such floods, though rare, occur frequently enough to exceed in importance, as erosive agents, all intervening lesser floods that do not damage the forest. The floods are also an important element in the life history of the forest; they provide open spaces for the growth of trees that require open sky, thus keeping the species composition in a state of flux.

A special study was made of asymmetric topographic forms in the area. Mountain slopes on the average are steeper facing the northeast and southeast quadrants. Asymmetry of the slopes is accompanied by differences in soil texture and vegetation. The differences are believed to be due to moisture conditions as determined by geologic structure and by exposure. In drainage areas of similar size the steeper slopes correlate with the finer textured soils and the more open forest floor that are characteristic of the northern hardwood forest type.

Inasmuch as the present topography and distribution of the vegetation can be understood in terms of observable processes active today or in the recent past, neither peneplanation nor progressive biological succession need be called upon in order to explain their characteristics. On the contrary, the regularity of the forms and their close relation to the geology and vegetation argue in favor of more uniformitarian concepts.

INTRODUCTION

The ridges of the central Appalachian Mountains are densely forested. In some places areas as large as 50 to 100 square miles are uncultivated, without roads, and uninhabited. Slopes, summits, and valley bottoms alike are tree covered. The forest contains both needle-leaved and broad-leaved trees, but is chiefly an oak forest. There is, however, great variability in the forest cover involving dozens of species. Study of the vegetation and its relation to geology and topography demonstrates that the distribution of many kinds of plants is dependent not only on differences in the bedrock and local climate, but to a large extent on the processes of erosion and the topographic forms that are produced by them. The mountains are undergoing active erosion at the present time. Concentrations of boulders associated with the headward erosion of valleys are forming and moving downslope. Conversely the vegetation itself is an important factor in the erosion of this area. Furthermore, it is clear that avalanching and sliding of debris during torrential rains is an important mechanism in the erosion of these areas.

During the spring and summer of 1955 the writers undertook a detailed study of an area of about 55 square miles in this forested region. The area has an average relief of about 1,500 feet, and the highest peak is Reddish Knob, 4,397 feet in altitude. The area is drained by the Little River, which is a small headwater of the North River, a tributary of the Shenandoah. The topography is typical of the longitudinal sandstone ridges of the Valley and Ridge province in Virginia and West Virginia. The Little River area was selected for study, however, because it contains hundreds of conspicuous landslide scars and severely damaged valley bottoms formed during a single cloudburst in June 1949. Study of this flood-damaged area was supplemented by work about 15 miles to the south on Crawford Mountain, an area of similar geology but undamaged by the flood, and in the Palo Alto area in West Virginia.

The location of the areas studied is shown on the index map (fig. 1). The Little River area is shown on the McDowell and Parnassus quadrangles of the U.S. Geological Survey; it may be reached by road from Bridgewater, Va. Crawford Mountain is north of a road connecting Buffalo Gap with the Calfpasture valley and is reached from Staunton, Va.; it is shown on the Craigsville quadrangle of the U.S. Geological Survey. Both areas are in the Dry River District, George Washington National Forest.

The vegetation and geology were surveyed and studied jointly by the writers. Aerial photographs were used for interpretation; some of these photographs were taken especially for this purpose during March 1955 and have a scale of 1:10,000. The interpretation of the photographs was supplemented by ground traverses, detailed vegetation counts, and planetable maps of small areas.

The work was done under the joint auspices of the U.S. Geological Survey and the Harvard Forest of Harvard University, Petersham, Mass. The writers are indebted to Prof. Hugh M. Raup, director of the Harvard Forest, for his support and suggestions relating to the botanical work, and to colleagues of the Geological Survey who have contributed valuable ideas and criticisms.

BEDROCK GEOLOGY

The Little River drains an area underlain entirely by sandstone and shale as shown on the geologic map (pl. 1). The structure is dominated by a broad anticlinal arch with resistant beds of the Pocono formation forming the upper slopes of the highest ridges. The geologic map (pl. 1) was prepared mostly by inspection of aerial photographs, but was checked in the field along the course of traverses made for other purposes. The location of the igneous rocks, which include a dike and a sill, were verified in the field, and the fracture zones shown on the map were visited in several places. Exposures of contacts are few because of the ever-present

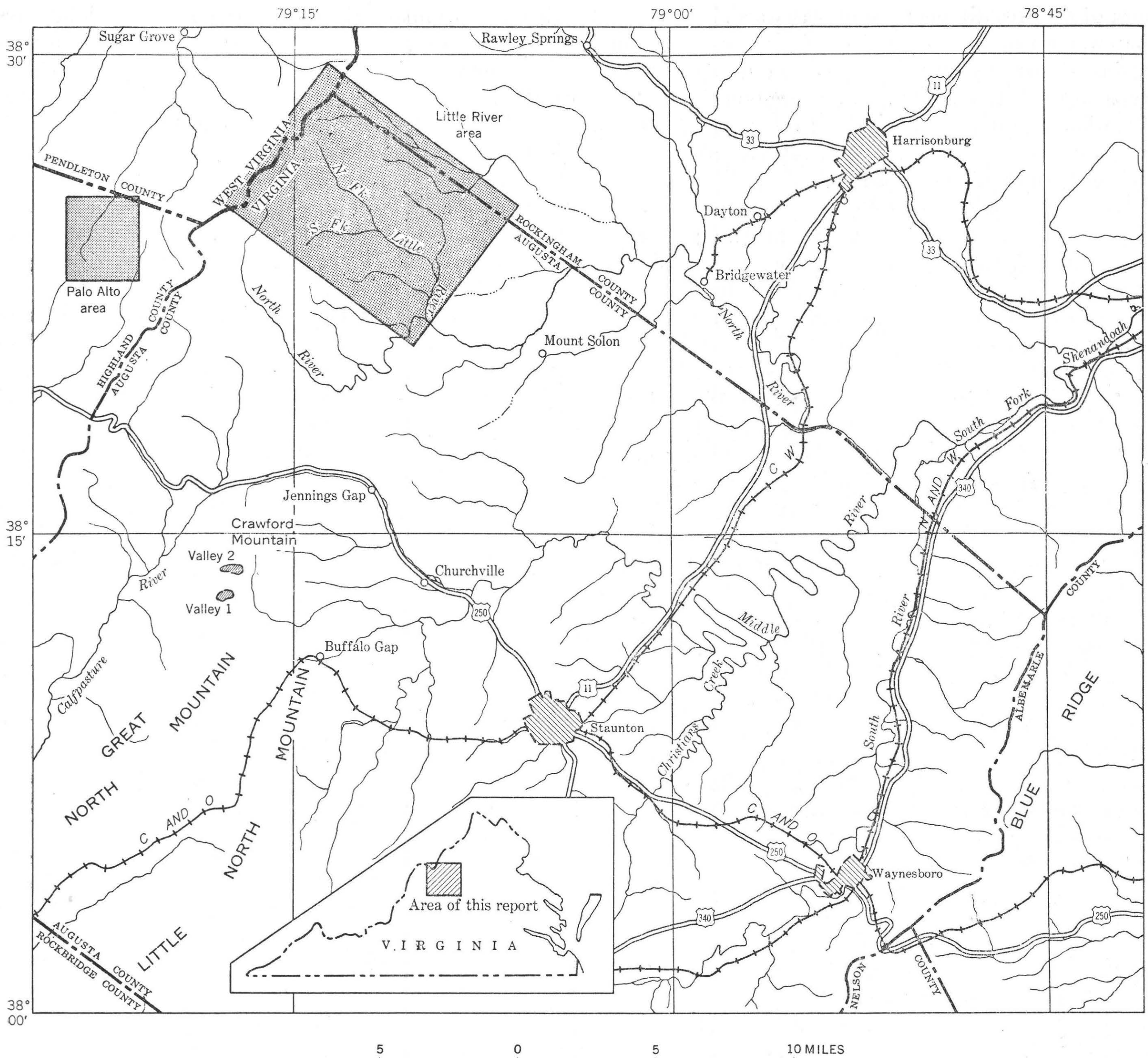

Figure 1.—Index map of the upper Shenandoah Valley region in Virginia, and an adjacent area in West Virginia showing the location of the areas studied.

mantle of soil and rubble, and the reliability of the boundaries is not high. The Hampshire formation, alone, is relatively well exposed because the soil mantle has been removed by numerous landslides.

Hampshire formation.—The Hampshire formation of late Devonian age (Butts, 1940, p. 335) has the largest outcrop area. It is predominantly red to reddish-brown arkosic sandstone, generally thin bedded or in thin flags. The sandstone is interbedded with rather massive shale or mudstone of the same or slightly darker color. Although in comparison with the calcareous rocks of Cambrian and Ordovician age that crop out in the Shenandoah Valley, the Hampshire is a resistant formation; it is relatively nonresistant as compared with the underlying Chemung and overlying Pocono formations. This is perhaps because the sandstone beds are flaggy, relatively thin, and being arkosic, weather more readily. The formation yields loamy soil that appears to permit the sliding of debris on the steep slopes. The avalanche scars formed during the storm of June 1949 are confined to this formation. Many of the thin standstone beds are permeable. Because the rocks in most of the area dip gently southeastward, it is inferred that water running down the northwest-facing slopes against the dip enters the many sandstone aquifers, and seeps through the mountain to emerge on the opposite side where the slope is inclined with the dip. As shown on pages 34–38 "with-dip slopes" are considerably moister than "against-dip slopes."

Pocono formation.—The Pocono formation of Mississippian age (Butts, 1940) overlies the Hampshire formation and forms most of the higher summits of the area. The base of the Pocono as mapped by the writers is the first massive sandstone bed in the section above the main body of reddish rocks. This definition corresponds to that of Woodward (1943, p. 511). The unit is well defined and is exposed along the ridge road that follows the Virginia–West Virginia State line. North of Reddish Knob a sandstone bed containing coarse quartz grains is exposed in a quarry above a red shale at an altitude of about 3,950 feet, and is considered by the writers to be the base of the Pocono. The base of the Pocono as shown on the "Geologic Map of West Virginia" (Stose, 1932) is roughly in the same position. This unit, however, obviously was not used by Butts as the base of the formation, as shown by the fact that the "Geologic Map of the Appalachian Valley in Virginia" (Butts, 1933) does not show the Pocono formation in the vicinity of Reddish Knob. The contact chosen by the writers is significant from the geomorphic viewpoint because the sandstone beds above it break into larger, tougher blocks than those beneath. This fact has a pronounced influence on the topography, for the basal beds of the Pocono are the principal ridge-makers.

In the Little River area the Pocono may be divided into two parts. The lower part, best exposed near Reddish Knob, consists predominantly of yellow to yellowish-brown shale but also contains several massive sandstone beds that are cut by widely spaced joints and that break on exposure into large blocks. These basal shale and sandstone units also crop out along the crest of Timber Ridge and Buck Mountain, where they are of exceptional interest because the sandstone beds have many open fractures and weather to blocks. Because they rest on soft impermeable shale they form reservoirs for ground water; this is reflected by the plant cover. Blocks derived from the sandstone bluff form concentrations of coarse rubble on the shale slopes below.

The upper part of the Pocono formation, exposed in the eastern part of the area, consists of massive sandstone with some interbedded shale and carbonaceous layers. These rocks are very resistant to erosion and underlie long gentle dip slopes such as those on the southeast side of Sand Spring Mountain. Their resistance is apparently due to the fact that joints are widely spaced, and the intervening coarse sandstone bed fractures with difficulty and is virtually inert chemically. Where the dip of the sandstone beds is gentle, large areas of overlying rock have been stripped off, leaving a tableland of dry sand and sandstone boulders. Small swamps and ponds known locally as bear wallows occur in a few places on these tablelands; some are atop the highest ridges in the region.. The wallows probably have formed where ground water is perched on a lentil of shale or shaly sandstone.

Intrusive rocks.—Two bodies of igneous rock were found in the area. A vertical dike of syenite is prominently displayed on aerial photographs. It extends a distance of at least 6 miles from a point southeast of Big Ridge to a point northwest of the West Virginia State line, outside of the mapped area. The dike was seen in outcrop at only three places, which are indicated on plate 1 by a cross, but its trace on the ground can easily be followed as a consequence of its effect on the vegetation. The forest growing on the dike contains tree species, such as sugar-maple,[1] that usually grow in a relatively moist environment. Large boulders of syenite are numerous in channels downstream from the dike and become especially abundant near the outcrop. In valley 4 (pl. 1), numerous syenite boulders were found on the side wall of the valley on the trace of the dike. The ground at this place is boggy. Presumably the boulders are in place or very nearly so, and the ground is moist because the syenite acts as a dam against the flow of ground water.

The dike rock, an aegirite syenite, has been examined by Charles Milton, of the Geological Survey, who describes it (written communication, March 29, 1956) as a rather fine-grained greenish-gray rock with sparse black biotite flakes and numerous pinkish vuggy schlieren.

> In section, it consists essentially of untwinned alkalic feldspar with abundant needles of aegirine. Rarely the feldspar shows porphyritic development, with Carlsbad twinning.

A sill of diabase of the variety teschenite was uncovered in a trench on the slope north of the junction of the North and South Forks of the Little River. The topography and vegetation at this outcrop are described in detail on page 45, and the outcrop is shown in figure 24. The sill is less than 5 feet thick. It is generally not exposed, though boulders are found on the streambeds. One other exposure of this rock was found in a tributary of the North Fork half a mile to the west of the first outcrop. The area underlain by the sill may be considerably more extensive than shown.

[1] Scientific names of plants mentioned in the text by their common names are given in table 1.

According to Charles Milton (written communication, 1956)—

The rock of the sill is a coarse-textured brownish gray rock with conspicoous dark phenocrysts of hornblende. In thin section, the euhedral brown hornblendes are zoned and strongly pleochroic. A few large turbid apatites are present. The matrix is essentially feldspar and analcite.

The age of the intrusive rocks is not known; however, as they intrude the Hampshire formation they must be at least as young as latest Devonian. The dike in addition cuts what is here called basal Pocono after Woodward (1943), and although the writers found no fossils in these rocks presumably they are Mississippian, and the dike rock is at least as young as Mississippian.

Structure.—At the east end of the area the rocks are folded into a sharp overturned syncline. Narrow Back Mountain is composed of overturned Pocono and Hampshire strata. To the west the structure opens out into a broad gentle anticlinal arch whose axis trends northeastward. As the highest point of the arch is in the western part of the area most of the rocks underlying the Little River basin have a gentle southeastward dip. In the vicinity of the State line the dip is steeply westward, and Reddish Knob lies on the east limb of a narrow but open syncline. Southwest of Reddish Knob a stripped surface on a resistant sandstone bed in the Pocono formation makes a synclinal valley occupied by the head of the North River. (See pl. 1.)

The area is crossed by at least three fracture zones that are readily seen on aerial photographs. These zones affect the vegetation so strongly that in places, as in the headwaters of the North Fork, they can be seen on the vegetation boundaries of plate 1. Here a narrow strip of vegetation, of the kind ordinarily found in a moist environment, crosses a dry sandstone ridge. The fracture zones were visited in the field at a number of localities, and no evidence of differential movement in the rocks was observed. The northwestward-trending joint system in the area is very strong, and presumably similar fracture zones are numerous.

TOPOGRAPHY

TOPOGRAPHIC FORMS OF FIRST-ORDER MOUNTAIN VALLEYS

The topography of the Little River basin and the surrounding mountains is regular and may be subdivided into valleys of different orders. The regularity of the topography is ultimately related to the uniformity of the geology, as the bedrock consists in most of the area of alternating sandstone and shale beds. In terms of the descriptive system of Horton (1945, p. 286–300),[2] the drainage density or the ratio of the length of the stream channels to the area drained by them is 8. The main stream, the Little River, is a fifth-order stream. The bifurcation ratio is approximately 4, whereas the length ratio is 2.4. In the lowlands of the Shenandoah Valley to the southeast the bifurcation ratio is 3.2, whereas the length ratio is 2.4. Comparing the two, the differences mean that in the mountains a larger proportion of the total area is occupied by valleys of lower order. The calculation can be made using a formula derived from one of Horton's (Hack, 1957, p. 66) that in this mountain region in an area drained by a fifth-order stream, 44 percent of the total area is occupied by the slopes of first-order valleys, whereas in a typical lowland area drained by a stream of the same order only about 33 percent of the area is occupied by first-order valleys. In the Little River area, then, a description of the slopes of first-order valleys is a description of almost half the area.

The first-order valleys are similar in form. They have amphitheaterlike heads, steep side slopes with slightly convex-upward profiles and narrow channelways with little or no bottom land along the valley axes. Though studies of valley forms have been made in seven valleys, a single first-order valley on Crawford Mountain cut in the Chemung formation of Devonian age (Butts, 1940) is chosen as an example for purposes of description. This valley was mapped in the summer of 1954 with planetable and alidade and is shown in figure 2. It is referred to in this report as valley 1. Note that the outline of the valley extends to the ridge crest on either side. The lower end of the map is incomplete, as it is 700 feet farther downstream to the junction with another stream. As shown in figure 2, the area of the valley may be subdivided into five parts, which represent a classification of slopes on the basis of geometric form. The vegetation boundaries are roughly coincident with the boundaries of the valley subdivisions and thus give reality to the classification. The slope classification also reflects the hypothetical behavior of runoff or seepage water as it moves downslope, and is either concentrated or dispersed depending on the contour of the surface. Where other factors do not become so important as to mask the effect of slope forms on runoff,

[2] The terms introduced or used by Horton in his descriptive system include the following: (a) The drainage density is the ratio of the length of the stream channels to the area drained by them in miles per square mile; (b) the bifurcation ratio is the ratio of the number of streams of one order to the number of streams of the next higher order; and (c) the length ratio is the ratio of the average length of streams of one order to the average length of streams of the next lower order. Valley and stream orders are numbered by Horton from small to large; that is, a valley having no tributaries is a first order valley; a valley having one or more tributaries of the first order is of the second order; and a valley receiving one or more tributaries of the second order is of the third order and so on.

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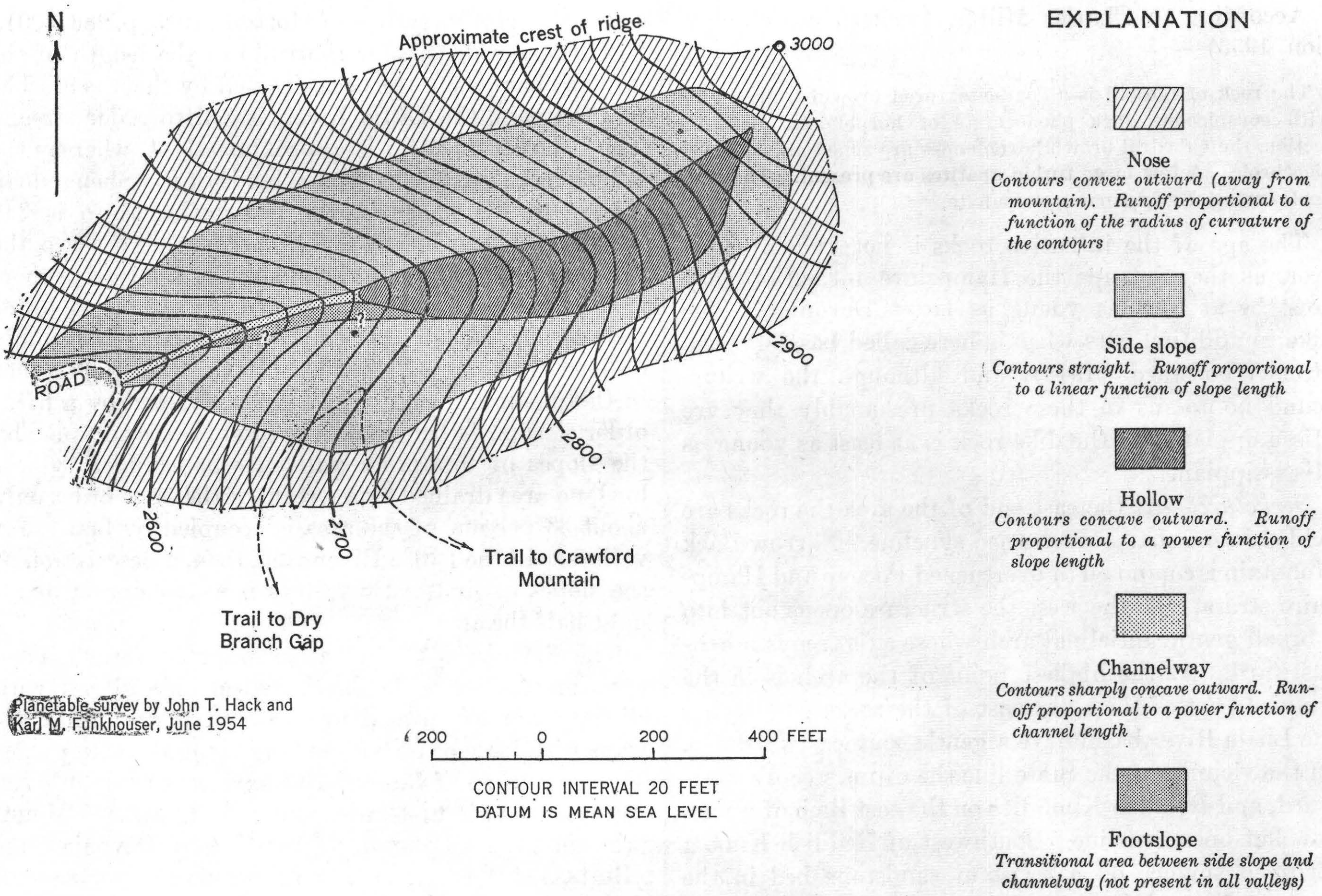


FIGURE 2.—Contour map of upper part of valley 1, on the west side of Crawford Mountain, showing the classification of slope areas used in this report. See figure 1 for location.

the vegetation distribution can largely be explained in terms of the different postulated moisture regimes. However, no actual measurements of moisture or runoff have been made by the writers.

Nose.—The first area, the driest part of the valley, includes the ridge crests and the nearby slopes on either side. It is defined as the area in which the contours are convex outward (away from the mountain). Within this area any water running downslope tends to diverge. If the ground were imagined to be an impervious, smooth surface lacking any channelways, the amount of runoff crossing any place during a rain would be proportional to a function of the radius of curvature of the slope contour. The sharper the curvature of the nose, the less runoff. Only an infinitesimally small fraction of the water passing over any part of this slope can have come from the top of the slope.

Side slope.—Inside the nose area is an area in which the slope has no curvature and the contours are straight or nearly so. There may be minor indentations, of course, such as the one on the north side of the lower part of valley 1. In the side-slope area the flow of water over the ground (assuming no channelways and no infiltration) must be proportional to the length of the slope. This amount of runoff is considerably higher than the runoff on a nose and as a result, where other factors are similar, the side slope is presumed to be an environment with greater moisture.

Hollow.—The central part of the valley contains the stream head, an area in which the contours are concave outward (away from the mountain). At every point in this area the slopes converge toward the stream. At every point the amount of water passing over the surface is proportional to a quantity considerably greater than the slope length. In valley 1, for example, proceeding down the axis of the valley within the hollow, the drainage area increases in proportion to the 4.5 power of the slope length. In some hollows the rate of increase is even greater. As a consequence the hollow is a moist area and the moisture in the ground increases toward the stream. In some large hollows during the spring months water can be heard running beneath the rubble on the floor of the hollow. As would be expected, the vegetation not only reflects the greater moisture within the hollow but also the greater instability of the debris mantle. The hollow may be thought of as a transitional area between the head and side slopes of the valley and the stream channel. In figure 3, drainage area is plotted against slope length in order to show the changes in rate of increase in and along the axis of valley 1.

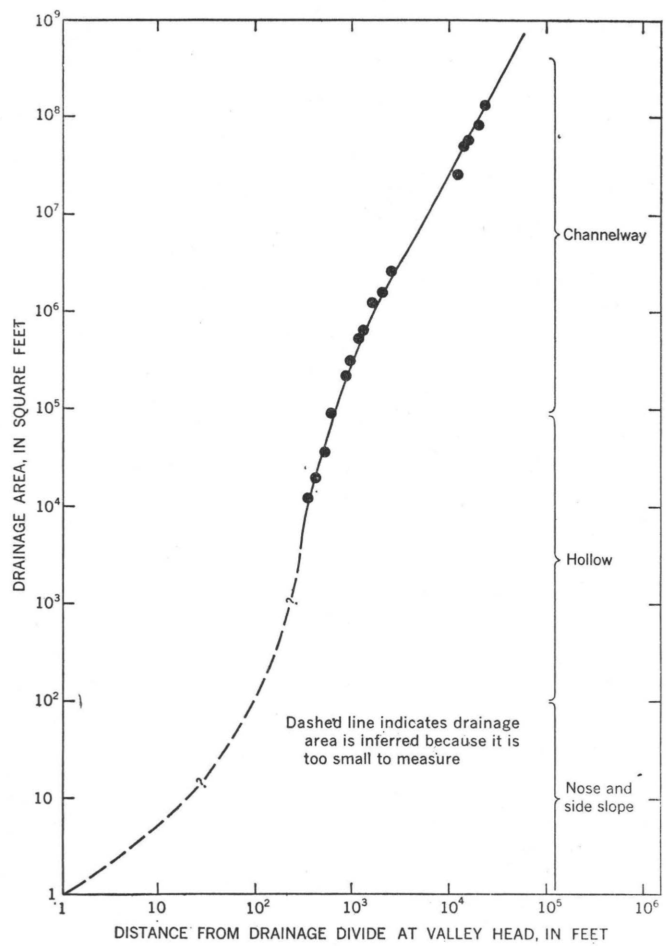


FIGURE 3.—Graph on logarithmic coordinates showing the increase in drainage area with increasing distance from the valley head. Data are from valley 1.

Channelway or valley floor.—The lower end of the valley is occupied by the stream channel itself. This is a narrow strip consisting only of the channel and in places a narrow flood plain or terrace. The catastrophic flood of June 1949 greatly enlarged most of the first-order channels of the Little River area, in many places gouging out areas of side slope. The channel is therefore bordered by steep banks in places 15 to 20 feet high and in places by an overhang. In undamaged areas, however, such as valley 1, the channel in most places is bordered directly by the side slopes, or by a gentler slope called the foot slope, described below. In the stream channel intermittent flows of water prevent the growth of trees and shrubs. The channel bottom is armored with coarse rock fragments as described in an earlier report (Hack, 1957, p. 82). In the channelway the moisture is obviously greater than it is in the hollow. The rate of increase of drainage area as one proceeds downstream, however, is considerably less (see fig. 3). Drainage area in these mountains varies, but in general the area increases along the valley axis in proportion to the 1.60 power of the channel length.

Foot slope.—In some places the channelway is bordered by a slope that is gentler than the side slope. This area is characterized by contours that are concave outward, like the hollow. As in the hollow, based on topographic form alone, the environment is inferred to be moister that the side slope, as every point on the foot slope must receive moisture that is gathered from a segment of the side slope above of some finite width. The 1949 flood in the Little River basin took out most of the foot slopes in first-order valleys; foot slopes in second- and third-order valleys are wider, and they were not entirely removed. In places the foot slopes contain remnants of old channelways, preserved like terraces. In places they consist of detritus derived from the side slope above and which has accumulated next to the channel because of a long period of lateral cutting on the opposite side of the channel. Foot slopes are not present along the entire valley. In small valleys the side slope commonly abuts directly on the channel.

SLOPE PROFILES

Enough measurement has been made of ridge crests and the upper slopes of mountains to permit a few general observations on their shape and comparison with the slopes of hills in areas of lesser relief. Early in these investigations a convenient method of slope measurement was discovered. It was found that the convex profiles of hills and ridges can generally be fitted to straight lines if they are plotted so that the center of the coordinate system is at the center of the ridge, or hilltop; the logarithm of the fall or vertical distance from the ridgetop to a point on the slope is plotted on the ordinate, and the logarithm of the slope length, defined herein as the horizontal distance from the hilltop to the same point on the slope, is plotted on the abscissa. When plotted in this manner the profiles of many hills and mountaintops can be approximated by simple power functions of the form

$$\log H = \log C + f \log L$$

or

$$H = CL^f$$

where H is the fall from the ridge center,
L is the horizontal distance or slope length,
and C and f are constants.

The coefficient C is generally a very small fraction, and the exponent f is a number larger than 1, generally smaller than 2. Figure 4 is a typical graph of this kind on logarithmic graph paper showing the profile of a hill in the Martinsburg shale area near Staunton, Va.

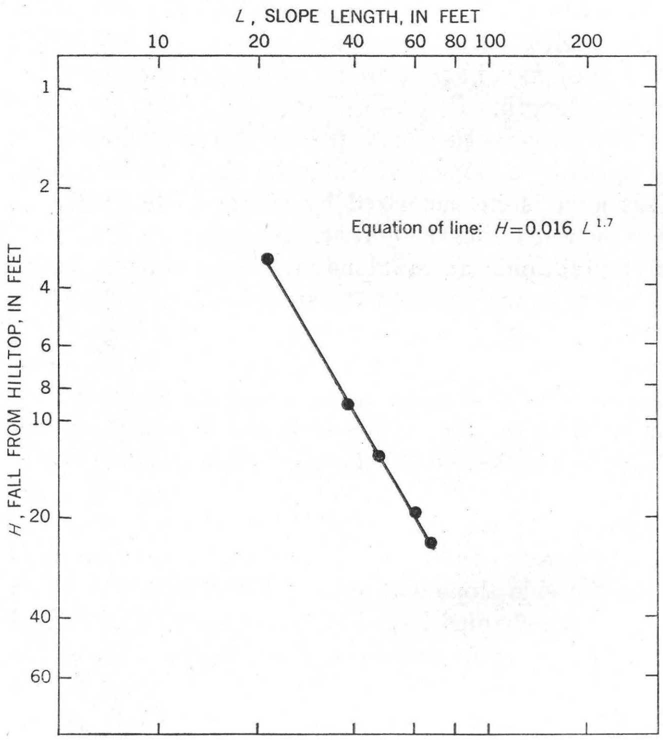


FIGURE 4.—Graph on logarithmic coordinates showing the profile of a side slope typical of valleys eroded in the Martinsburg shale. Data were measured on a hill southeast of Staunton, Va.

Not all hill slopes, of course, attain such perfection of form. It has been noted that variations in the soil or bedrock commonly produce variations in surface form that show up strikingly in such graphs, as breaks in the slope of the line even though they are scarcely noticeable on the ground. The advantage of plotting slopes in this manner is that it facilititates the comparison of convex slope profiles from one place to another. The equation of the line includes both the curvature and steepness of the line. The coefficient, C, may be defined as a coefficient of steepness for it defines the fall, H, at a given slope length for a slope with a curvature, f. The exponent f is determined by the rate of change of slope, or curvature of the hill. This principle is illustrated in figure 5 by a comparison of profiles plotted on logarithmic scales with the same profiles plotted on normal or arithmetic scales. Note that curves A and B, having lower exponents than curves E and F, are sharper at the top, but much less curved lower down. Curves B and F have higher coefficients than their corresponding pairs A and E. As the arithmetic graphs show, curve B, with a higher coefficient than A, is the steeper of the two. Similarly curve F is steeper than E.

Hill or ridge slopes near the crests have been measured at many localities in Maryland and Virginia on several kinds of rocks and in areas of different relief and plotted in the manner described. In figure 6 the values of the coefficients and exponents of profiles at 27 localities are compared. The localities are divided into three groups: (a) localities on the coastal plain where the average relief ranges from 50 to 100 feet per square mile and where slopes are eroded in unconsolidated sand, silt, and gravel; (b) localities in the Shenandoah Valley of Virginia where the slopes are cut on rocks such as limestone and shale, and where the relief averages from 150 to 400 feet per square mile; and (c) localities in sandstone areas west of the Shenandoah Valley, including Crawford Mountain and the Little River basin, where the average relief in places exceeds 1,500 feet per square mile. It is noteworthy that the total range in curvature as defined by the exponents is between 1.2 and 2. The coefficients of steepness range from 0.001 to 0.8. In general the steep profiles are comparatively straight and the gentle ones are curved, though there is quite a large variation away from the general average.

A clearer picture may be obtained by plotting typical profiles on arithmetic coordinates as shown in figure 7. This diagram has been constructed by drawing curves whose equations have exponents and coefficients that are determined by the line drawn through the points of figure 6. This line represents an average of the profiles at the localities measured, and progresses from the profiles of mountains on the left to the profiles of coastal-plain hills on the right. The mountain profiles on the average have coefficients larger than 0.05. These profiles are steeper than the others throughout their length. They are more peaked, or more sharply curved at the top, and are straighter at lower altitudes. Some of the slopes measured, of course, depart markedly from the average. One of the profiles on the coastal plain with an extraordinarily high degree of curvature (2) is shown by a dashed line. Nevertheless we are probably justified in the generalization that the average slope profile in a Devonian sandstone area such as the Little River basin has a sharp crest but is relatively straight below the crest, and is steeper throughout than the average slope profile in the lower country where the rocks are softer.

Thus far only convex slopes near the crest have been considered. What of the form of slopes in the hollows and the lower side slopes near the channelways? Valley

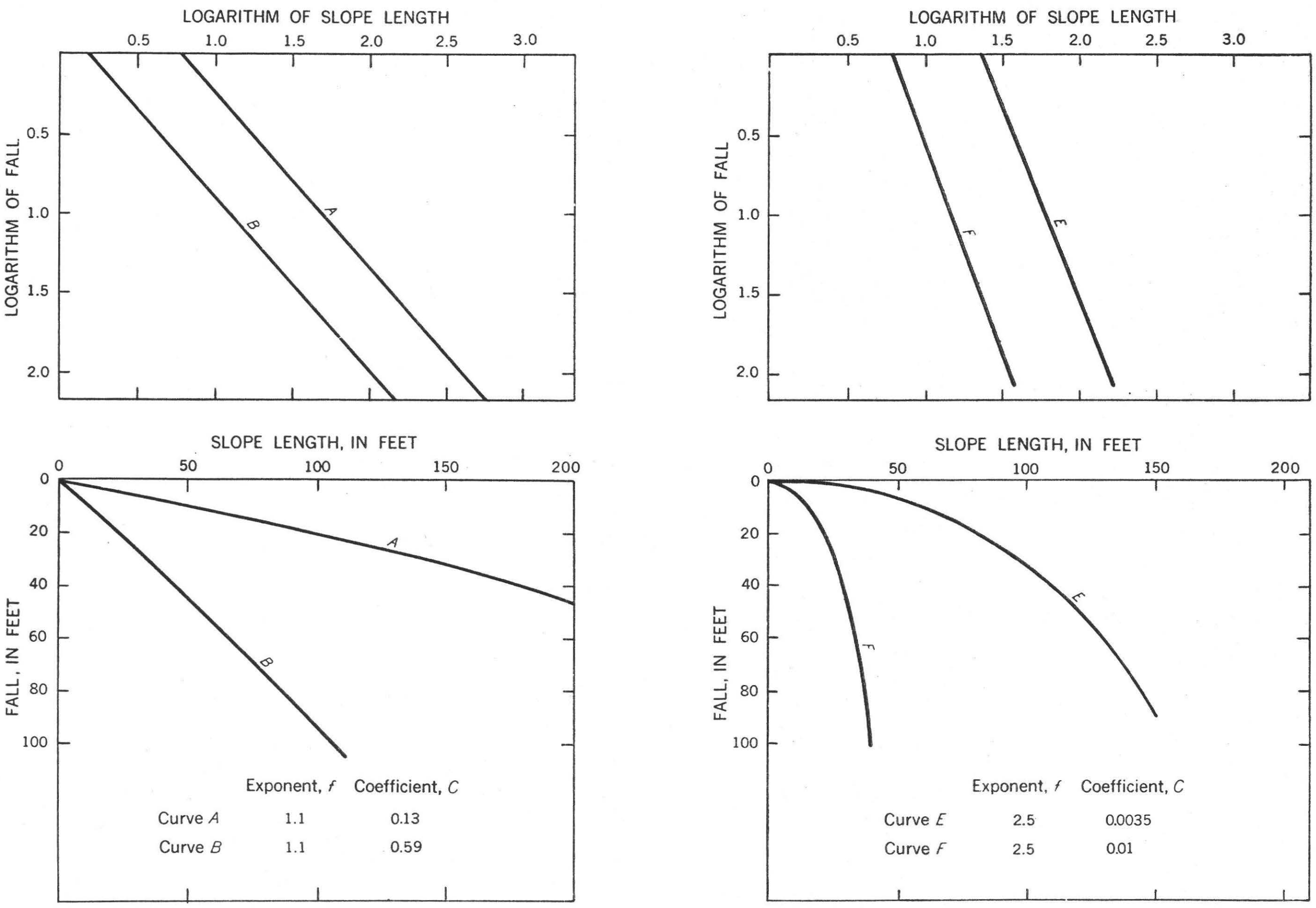


FIGURE 5.—Graphs of four typical slope profiles having different coefficients and exponents. Plotted on logarithmic coordinates (above) and on ordinary arithmetic coordinates (below).

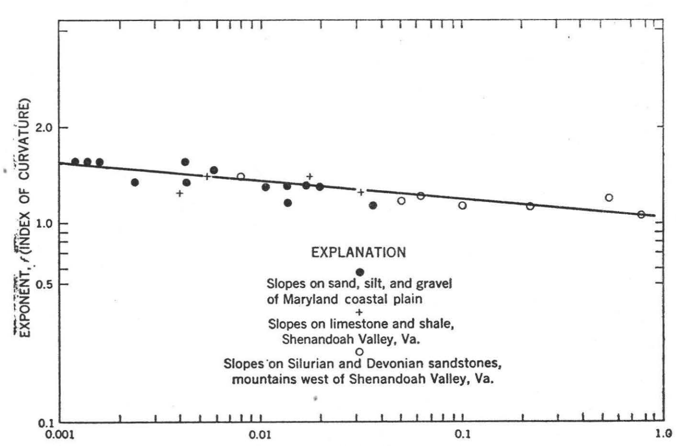


FIGURE 6.—Graph on logarithmic coordinates showing coefficients and exponents of measured slopes at 27 localities in the Potomac watershed in Virginia and Maryland.

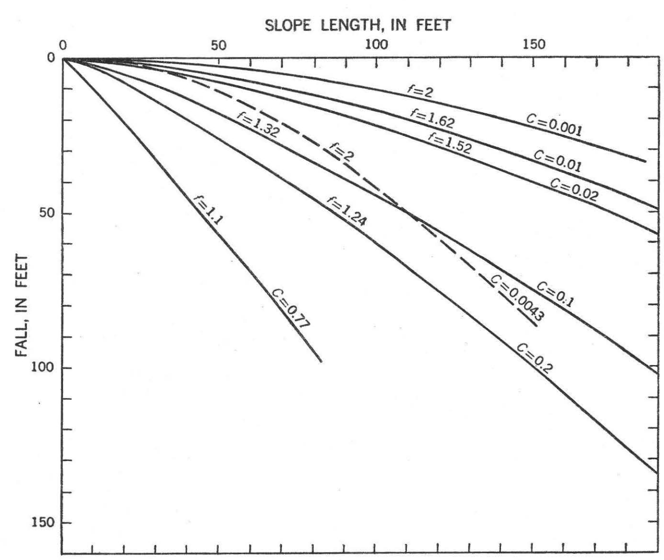


FIGURE 7.—Graph on arithmetic coordinates, showing typical slope profiles based on exponents and coefficients read from the trend line shown in figure 6. Note that the slopes having high coefficients (C) and low exponents (f) are steeper and more sharply curved at the top. Dashed line represents slope having a high exponent (2) but a coefficient higher than the average for slopes having that exponent.

1 on Crawford Mountain serves as an example. In figure 8, three slope profiles in valley 1 are plotted on logarithmic scales. Profile *A* is taken from the crest of the mountain down the valley axis, through the hollow and along the channelway. Its slope changes from convex to concave. Profiles *B* and *C* are measured from the noses on either side down the side slopes to the channel. Both are on convex slopes. All three profiles have the same exponent (approximately 1.23) but profile *B*, down the north-facing side, is noticeably gentler than the other two. In profile *A*, the central profile, the initial convex slope form is maintained up to a distance of at least 300 feet from the origin. At this point the profile begins to change in curvature from convex to concave, and at 700 feet the profile is represented by an entirely different line having an exponent of 0.75. The point or zone at which this change takes place is called the inflection point. On Crawford Mountain the inflection point corresponds roughly with the beginning of the channel. This statement, however, may not be applied to all valleys. On the coastal plain in unconsolidated deposits the channelway in some places is well defined some distance above the inflection point, and the position of the inflection point in relation to drainage area and its rate of increase may be complicated by many factors.

Side slopes are typified by profiles *B* and *C* shown in figure 8. They end abruptly at the channelway at slope lengths (measured horizontally from the crest of the

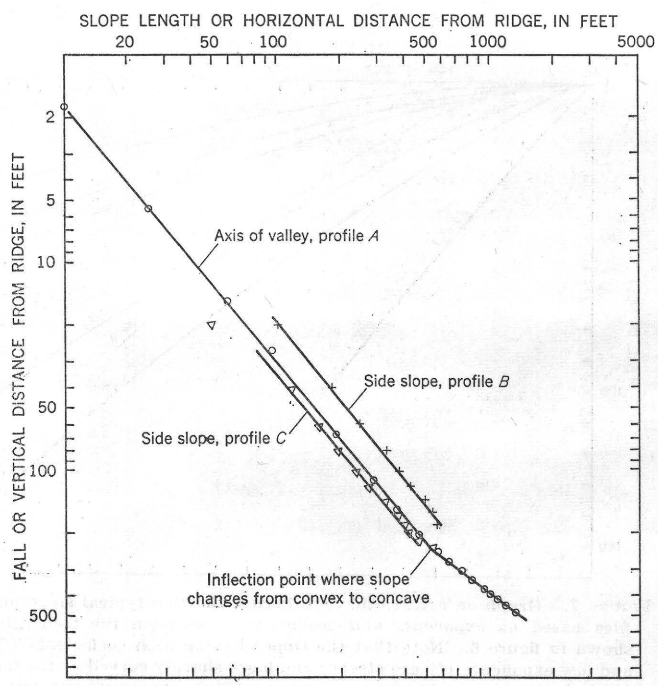


FIGURE 8.—Graph on logarithmic coordinates showing three profiles in valley 1 on Crawford Mountain.

noses) between 500 and 600 feet, without passing through an inflection point. The graph shows quite clearly that there is no appreciable change in form of the slopes as the channelway is approached. Both slopes continue to steepen throughout their length. On many long slopes, however, the form does change as the channelway is approached. The slope may become straight as incipient or shallow hollows are formed on the lower slopes. Presumably convex slopes can attain only a certain length beyond which average runoff is sufficient to remove material from the surface so as to form a hollow, and eventually another valley.

The length of the side slopes of first-order mountain valleys is of course limited by the height of the ridge crests between the valleys. The form of the topography is such that the ridge crest or line of intersection of the side slopes of two adjacent valleys descends from a point above the hollow to the junction of the two streams below at a rate similar to that of the channelways. Careful examination of the contours in the Little River area (on Buck Mountain, pl. 1, for example) shows that the relief from the channelway to the ridge crest in a direction at right angles to the contours is 200 to 400 feet. The crest can attain a greater height above the channelway only if the average gradient of the side slope is increased, or if the slope length is increased.

FORM OF VALLEYS OF HIGHER ORDER

In the Little River basin (pl. 1) the valley of the principal stream, which begins on Reddish Knob and joins the North River below Grindstone Mountain, is a valley of the fifth order. The South Fork of the Little River is a fourth-order valley, and there are five third-order valleys, which include Big Run, Hog Run, Coal Run, and Stony Run. Third-order valleys are the smallest valleys that have bottom lands of any appreciable width. Their bottom lands are narrow and average about 100 feet; about one-quarter to one-half of this width is normally taken up by the river channel. Channel banks are characteristically low, in general less than 5 feet high, but there is a wide range in bank height. Terraces or multiple bottom lands are rare in valleys of this size, the single valley flat generally being bordered by steep side slopes. In places, especially on the inside of bends in the channel, there are gentle foot slopes that are concave upward.

The South Fork of the Little River, a fourth-order valley, has a bottom over 400 feet wide. Terraces are also rare along this stream. The single bottom, as will be shown on page 52, is of complex origin, with many local irregularities formed by the work of rare but intense floods.

The main stem of the Little River, a fifth-order valley, attains a bottom width of over 1,000 feet in places. A few narrow terrace remnants border this valley, but like the smaller valleys the valley floor is mostly a graded plain close to a constant height above the stream. The valley is clearly of complex origin, however, as it is broken by numerous abandoned channels and floodways that form an anastamosing pattern. Normally the river channel occupies only a small part of the valley bottom, but in many places the flood of 1949 reworked the entire bottom.

The longitudinal profiles of mountain valleys in this region, as exemplified by the Little River basin, have a remarkable regularity of form. When the long valley profiles are plotted so that the stream length (distance from the head of the stream) is on the abscissa and the altitude of the channel on the ordinate, the profile is approximated by a logarithmic curve, of the form

$$B=C-k \log L$$

where B is the altitude,
L is stream length,
and k and C are constants.

Three typical streams of the area are plotted in figure 9. The profiles approximate straight lines on semilogarithmic coordinates. As argued in an earlier report (Hack, 1957, p. 73), streams whose profiles follow such a logarithmic curve have bed material that approximates a uniform size all along the channel length. This is more or less true of many of the streams in the Little River basin. The bed material consists of boulders of sandstone derived from the Hampshire and Pocono formations that have undergone but little rounding or wear within the drainage basin. The stream bed material consists of a lag concentrate of the coarser fragments. Its average mean diameter is about 100 mm.

The slopes enclosing the valleys of third-, fourth-, and fifth-order streams are partly side slopes like those of first-order valleys and partly the noses on spurs between tributary valleys of lower order. As is well shown on the topographic map (pl. 1) side slopes join the valley bottom at a sharp angle, in many places forming cliffs. Such cliffs form where the stream is eroding the bottom of the slope by lateral corrasion or has done so in the recent geologic past. Such vertical or nearly vertical cliffy slopes are more abundant in large valleys than they are in first-order valleys, where the process of lateral corrasion is apparently less important. Cliffs are, of course, most common where the bottom of the side slope is composed of relatively resistant beds and are uncommon at the interbedded shaly horizons.

The topography between valleys of higher order is composed of a branchwork of lower order valleys separated from each other by ridge crests. Since the channelways, hollows, and side slopes are graded in a similar and regular manner, the ridges too are graded in a regular manner. Like the valleys, the ridges may be grouped into ridges of several orders. They bifurcate in a manner inverse to that of the valleys. The ridge crests between first-order valleys have steep longitudinal profiles, whereas the main ridges that form major divides between larger streams have gentle longitudinal profiles. The profiles are roughly parallel to the master streams that separate them. Thus the crest of Buck Mountain slopes southeastward roughly parallel to the slope of the North and South Forks of the Little River. The ridges that branch outward from the main ridge have much steeper crests that are similar in steepness to the first-order valley bottoms. The crude parallelism of stream channel and ridge crest is illustrated in figure 10 by a comparison of the long profile of Hog Run with that of the ridge immediately west of Hog Run.

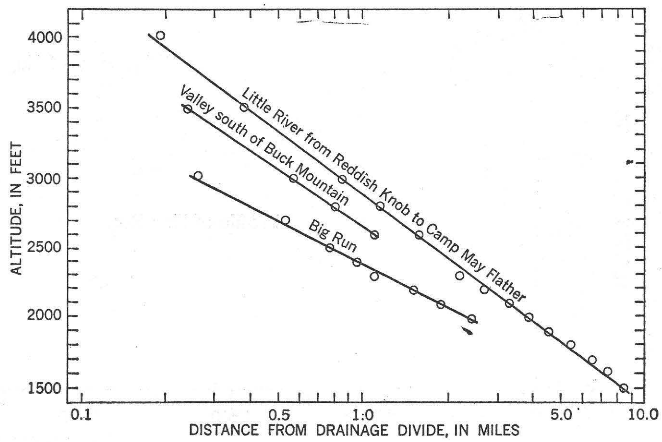


FIGURE 9.—Graph on semilogarithmic coordinates showing longitudinal profiles of three stream channels in the Little River area.

The writers' observations in the Little River area appear to be similar to Strahler's observations in the Verdugo Hills, Calif., an area of somewhat less relief, but having steeper slopes (Strahler, 1950). The Verdugo Hills have the same concave-upward forms in the hollows, referred to by Strahler as "hoppers." As in the Little River area the long profiles of the ridge crests and channels are roughly parallel, though the difference in altitude between them averages only 100 feet (Strahler, 1950, p. 802). Most of the valleys in the Verdugo Hills are V-shaped, and side slopes intersect the channelways in sharp angles. Strahler has made a careful analysis of this feature and notes that concave-upward profiles at the base of side slopes occur where the stream channel impinges against the opposite bank. This observation agrees with observations of the writers relating to foot slopes (p. 7). Strahler regards the

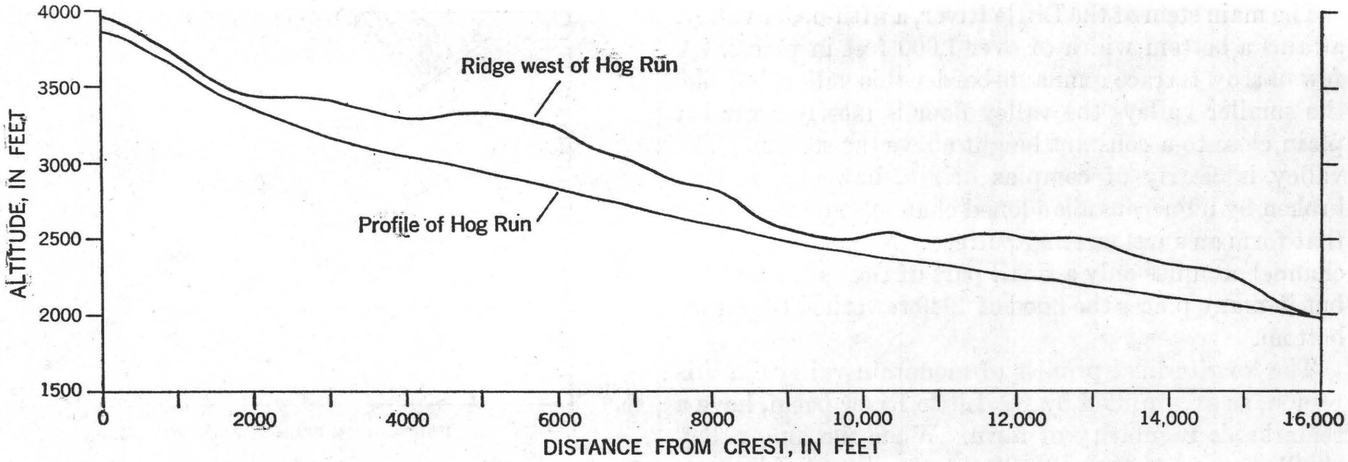


FIGURE 10.—Longitudinal profiles of Hog Run, a north tributary of the Little River and the ridge crest to the west of Hog Run.

slope forms of the Verdugo Hills as equilibrium forms. The orderliness of the forms of the Little River area lead the writers to the same conclusion.

The present analysis of slopes in the Little River area results in two conclusions that should be emphasized. Most important is that slopes should be thought of as functional parts of a single organic unit, the valley. Statements or inferences relating to the form or origin of slopes must be considered in relation to their position within the valley. Concave-upward slopes, for example, are of universal occurrence in the hollow, that is, in the vicinity of the stream head, but are uncommon farther down, even in close proximity to the channel.

The measurements of convex-upward slopes made in connection with this study have shown that there are clearly defined differences in form between the ridge tops or head slopes of mountain areas underlain by resistant rocks and those of lowland areas underlain by less resistant, more easily weathered rocks. In general, the mountain tops are more peaked, and their slopes straighter than lowland forms.

MANTLE OF SURFICIAL DEPOSITS

The mountains of the Little River basin that typify large areas of mountainous terrain are mostly covered by a thin mantle of loose debris. The debris is generally stony, but in some areas it ranges from stony loam to blocky rubble. The mantle is thin, measured in terms of a few feet. In places it may be 10 or 20 feet thick. Here and there, where relatively hard strata of sandstone intersect the slopes or ridge crests, bedrock in the form of cliffs or rocky protuberances penetrates the mantle. In some places these ledges are broken into accumulations of large angular fragments. The total area of rock outcrop is, however, small, less than 5 percent, in comparison with the total surface area. The debris mantle consists of the material loosened from the bedrock by weathering, moved downward by creep, and sorted by the action of flood runoff.

Variations in texture of the surficial mantle have been measured in the field, mapped, and studied in relation to both the vegetation and topography. In this mountainous area, mass movement in the form of rock falls and creep is by no means the only process that moves the surface debris and erodes the slopes. Transportation by running water, especially during intense rainfall, is also a process of major importance.

METHOD OF STUDY

Crude estimates of the mean particle size of material on the ground surface were made at many places. The estimation was based on the areal or grid sampling procedure used in estimating sizes of river gravel (Wolman, 1954, p. 951, and Hack, 1957, p. 48). A tape was stretched across the area where a measurement was desired, and a pointer thrust in the ground at predetermined regular intervals. Whatever particle the pointer first touched was tallied according to size class. From the tally a cumulative size-distribution curve could be constructed. Mean size, standard deviation, and other parameters were calculated using the assumption that the size distribution was logarithmic normal, an assumption that has been found to be approximately correct where sufficient data were available to determine the distribution. At most of the localities a grid of only 20 points was considered sufficient to give a crude estimate of size. In these samples four size classes were tallied as follows: Less than 2 mm; 2 to 50 mm; 50 to 230 mm (length of hammer handle); and 230 mm to the largest boulder in the sample.

In valley 1 on Crawford Mountain somewhat less crude estimates were made, using samples of 100 grid points and more size classes. Where the pointer touched material finer than 2 mm (too fine to be selected and measured as individual particles) bulk subsamples of the soil were collected. All the subsamples collected at a single locality were combined into one lot that presumably was representative of the material finer than 2 mm at that locality. This material was analyzed in the laboratory by standard methods. The bulk analysis was combined with the field measurements of the larger particles to obtain a crude estimate of the total range and distribution of sizes. In making the estimate by combining the two kinds of data, the point pebble counts were not converted to weight as they might have been. In view of the crudity of the sampling procedure such a refinement was considered unnecessary. As shown by the data in figure 12, the mean sizes estimated by counts of 20 agree roughly with mean sizes estimated by counts of 100 at adjacent localities.

For the purposes of this study the samples composed of 20 grid points provided an adequate description of the surficial mantle. The method of estimation is capable of distinguishing between only those deposits having wide differences in texture. The larger the standard deviation (a measure of the range of sizes in the sample), the less accurate the estimate. In general the differences that can be resolved by measurement of 20 particles can also be detected by eye. The advantage of the measurement is that it can be compared with samples at other places.

SURFACE MANTLE ON OPEN SLOPES

In general, as the slope length and drainage area increase, coarseness of the debris on the ground increases and its standard deviation or range in size decreases. Figure 11 shows two samples obtained by combining grid and laboratory analyses representing widely different types of surface mantle. The ground surface at locality A on a nose, where the drainage area and slope length were very small, contains a wide range in sizes. The material might be classed as a stony loam on the basis of its appearance. On the other hand, at locality 616 in the hollow the material is well sorted and would

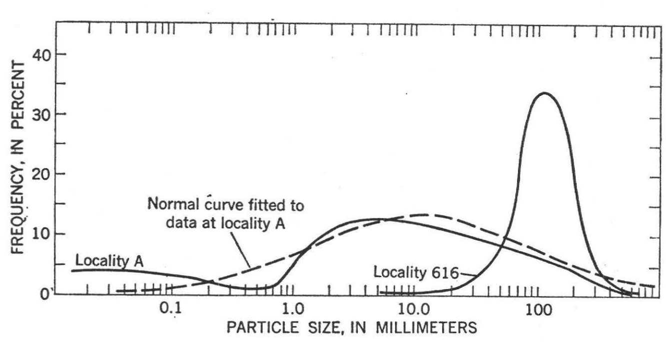


FIGURE 11.—Frequency curves showing size distribution typical of particles on the ground surface in a hollow (locality 616) and on a nose (locality A).

resemble a coarse stream gravel except that the fragments are somewhat more angular and weathered.

Figure 12 shows the mean sizes at sample localities at various points in valley 1. Loamy material with mean size less than 25 mm is almost wholly restricted to noses and side slopes, whereas coarser material is entirely restricted to the hollow and channelway. Extreme contrasts in size occur in many places as shown just above the roadway at altitude 2,570 feet, where a sample on the steep side slope is only 5 mm in mean size, contrasting with 70 mm in the channelway. In general, the size increases sharply between the side slope or nose and the hollow. It reaches a maximum near the base of the hollow and then decreases slightly downstream. This pattern of size distribution is repeated in valley after valley, both on Crawford Mountain and in the Little River area. Block fields found at certain geologic horizons, and described on page 15, are exceptions and in some places form coarse, well-sorted debris accumulations on side slopes and noses.

In stream channels, as was shown in an earlier paper (Hack, 1957, p. 58), channel slope is one of the important factors related to size of the debris on the channel bottom. On open valley sides, however, this is not the case. Side slopes with gradients exceeding 30° may have material on the surface as fine or finer than ridge tops or flat noses. On such open valley sides the coarseness of the debris tends to be related in part to the proximity of outcrops of resistant beds upslope from where coarse boulders originate, and in part to slope length or drainage area. Drainage area, and consequently the amount of runoff, appears to be the predominating factor determining size, for many of the larger hollows contain sandstone boulder fields in which some boulders measure 4 meters in diameter but the average diameter is 0.2 to 0.3 meters. It may be, however, that for a given drainage area or slope length the size increases in proportion to slope.

A primary valley containing a large hollow on the northwest side of Reddish Knob (pl. 1, valley 3) is shown in figure 13. This valley was surveyed by the writers (see also fig. 15); the surficial debris was divided into three size classes, which were estimated by eye, and mapped. The area shows well the relation of texture of debris to the topography. The coarsest debris is confined to the hollows; upper slopes are mantled by stony loam. Side slopes have a large variability in ground texture. Areas of smooth ground alternate with areas of coarse boulders elongated in a direction parallel to the slope. Some of these form swatches of boulders that extend downslope for hundreds of feet. In places these show evidence of instability and represent small slides or active mass move-

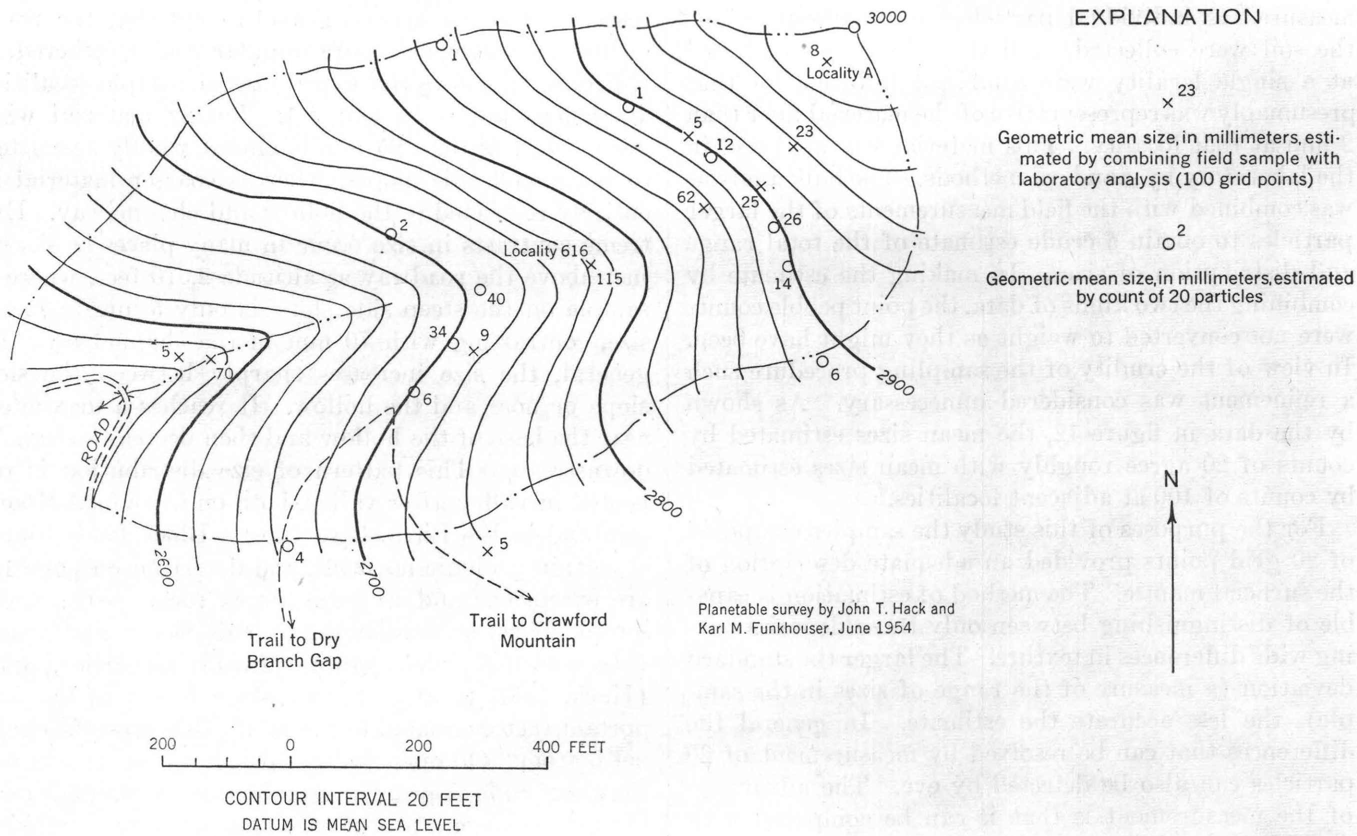


Figure 12.—Map of valley 1 on Crawford Mountain, showing mean size, in millimeters, of particles on the ground surface at various localities.

ment. The hollow is mantled entirely by coarse blocks that increase in size downslope toward the stream channel. This area shows abundant evidence of great moisture in the ground by its dense growth of water-loving trees and herbaceous plants.

In hollows, the drainage area contributing runoff to any point on the ground is enormously greater than on the side slope, and the size of the debris on the ground is far greater. In valley 1, on Crawford Mountain as shown in figure 3, drainage area in the hollow increases to 100,000 square feet, whereas on the adjacent slope the drainage area is much less and cannot greatly exceed the slope length (amounting to 400 or 500 feet). This represents a drainage area in the hollow over 200 times that on the side slope. The amount of water that drains from so large an area during an intense rain has a considerable capacity for geologic work, and is probably adequate to account for the removal of the fine fractions from the debris mantle.

In the channelway the drainage area continues to increase, but in this portion of the valley the slope generally decreases so that the competence of the stream does not necessarily increase, and may decrease. In the Little River area the size of debris in the channelway decreases from a maximum attained in the hollow to a figure somewhat below (in places one-half) the maximum, and then remains about constant farther downstream.

The change in character of the surface debris in relation to drainage area is shown in figure 14, based on data from seven first-order valleys. The points represent only localities that are along the valley axis above the channelway. No localities on side slopes or in the channel are included. Drainage areas were measured on an enlargement of a standard topographic map published at a scale of 1:62,500. The sample points were located in the field by measurement with a surveyor's chain from a point on the ridge crest. Considerable error is involved in the estimate of drainage area because of the small scale of the maps. Because of the error involved in the estimates of both particle size and drainage area, the lines drawn on the graph have limited significance. Nevertheless, the data indicate that as one approaches the channelway and as drainage area increases, the size of the debris on the ground increases. The sorting of the debris also improves, partly through a loss of fine-grained material and relative increase of the coarse. The exact slope of the line in the

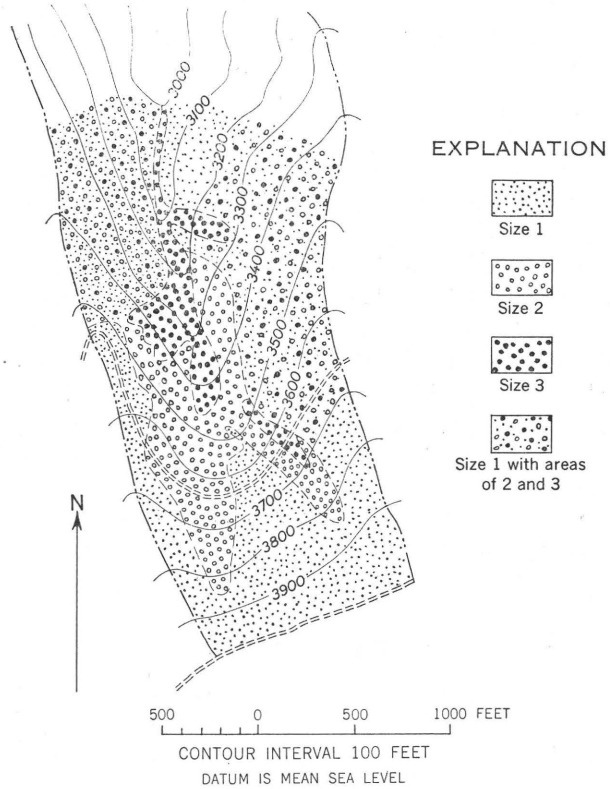


Figure 13.—Sketch map of valley 3, northwest of Reddish Knob (pl. 1), showing the distribution of coarse- and fine-surface debris. Contour lines are enlarged from the U.S. Geological Survey's topographic map of the Parnassus quadrangle, Virginia, and at this scale are only diagrammatic. Many details are omitted.

Size 1: Boulders separated by areas of sandy and silty soil. Footing smooth and firm. Surface debris ranges in mean size from 1 to 50 mm.

Size 2: Little or no fine-grained material exposed at surface of ground. Medium-size boulders and cobbles predominate. Ground bumpy but footing not difficult. Surface debris ranges in mean size from 50 to 150 mm.

Size 3: No fine-grained material on surface. Ground entirely large boulders. Footing difficult and deep holes common. Boulders may be covered with moss and humus. Surface debris ranges in mean size from 150 to 350 mm.

upper graph of figure 14 may not be significant, but as drawn it is 0.5. Certainly the data indicate that the gradient is less than 1 and larger than 0, thus the curve is parabolic and is asymptotic to a line parallel to the abscissa (drainage area). The rate of increase of size of debris is greatest at small drainage areas where presumably runoff first concentrates. The rate of increase gradually diminishes, probably approaching zero somewhere near the beginning of the channelway. At this point the size is at a maximum, for it is known from other data that in the channelway the size of material diminishes slightly until it reaches a more or less constant figure.

These observations apply only to certain mountain valleys and slopes. They do not apply to the soil-covered slopes of primary valleys in lowland country. Studies of such valleys made by Hack indicate that they are not similar to mountain valleys in all respects, and that the processes forming them and their geometry may be somewhat different.

BLOCK FIELDS

Fields of sandstone blocks or boulders in some places are unrelated to hollows, and they occur on side slopes and noses where very resistant sandstone or quartzite is underlain by relatively unresistant rock, such as shale. At least two such contrasting horizons occur in the Little River area along the ridge forming the West Virginia–Virginia boundary (pl. 1). A massive sandstone about 50 feet thick forms the base of the Pocono formation. It is underlain by thick reddish shale that constitutes the highest bed in the Hampshire. The sandstone outcrops are broken along joint planes into large angular blocks and, on the slopes below, the shale is covered by a residue of similar blocks that have worked down

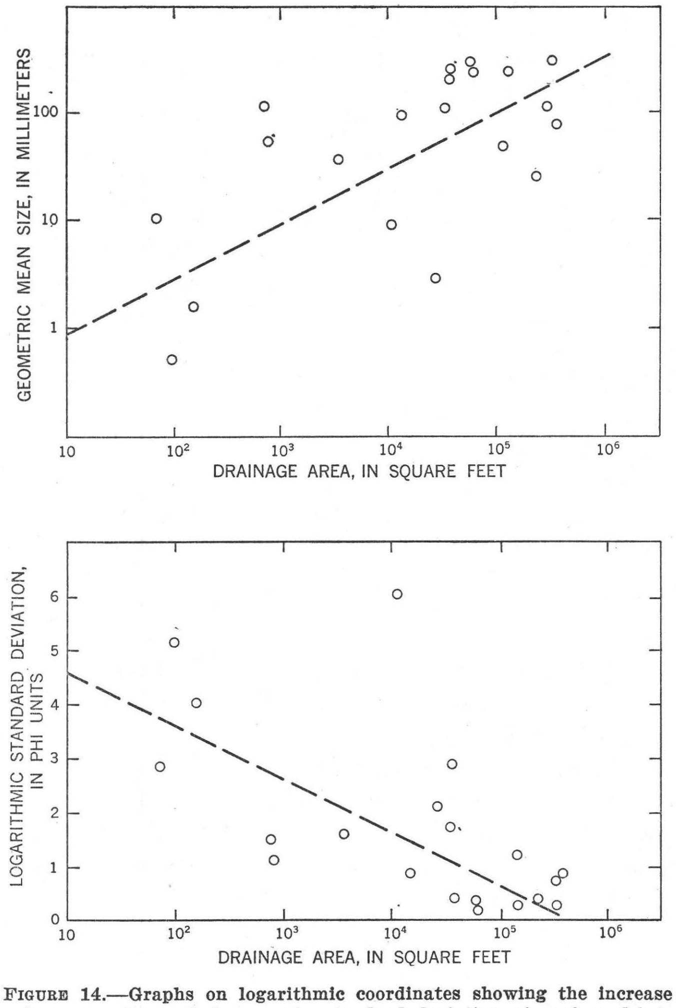


Figure 14.—Graphs on logarithmic coordinates showing the increase in mean size, and decrease in standard deviation of surface debris in relation to increasing drainage area. Data are from 20 localities in 5 hollows. In computing the standard deviation in phi units the logarithm to the base 2 of the size class, in millimeters, is used.

from above. Accumulations of blocks at this horizon are common at several places along the base of the Pocono formation. They generally contain central areas that are bare of trees.

Another similar horizon is 500 feet higher in the geologic section where a bed of massive sandstone overlies a thick section of shale within the Pocono formation. Block fields occur all along the sandstone outcrop but are most common on the ridge, either because they are in an exposed position or because there is a better opportunity on a ridge for the preservation of such a residual accumulation. A large block field (locality 804, pl. 1) northwest of Reddish Knob was examined and is shown in plate 2*A*. This block field lies athwart the crest of a ridge that trends northward and that has an elliptical shape and a radius of about 200 feet. Slopes on either side of the ridge average over 32°. The block field extends farther down the slope on either side into hollows where the block field is tree covered and has gentler slopes of about 26°. A sample of the block field indicates the mean size of the boulders on the ridge crest is 240 mm. The standard deviation is only 0.5 phi units. This means that about 99 percent of the boulders are larger than 75 mm and smaller than 780 mm. Fine-grained material is completely absent and in places there are open spaces in the block field in which one can look down at least 10 feet. The lower part of the field with gentler slopes appears to be thinner because there are no deep openings between the blocks.

The size and texture of the block fields are very similar to the coarsest debris on the floor of hollows. This is shown by comparing of a view of the debris in the hollow of valley 3 (pl. 2*B*), with a view of the block field at locality 804 (pl. 2*A*). The geometric size of the blocks is virtually the same, measuring 220 mm on the floor of the hollow as compared with 240 mm for the block field. The boulders in both are of sandstone of the Pocono, but in the hollow the debris has been moved considerably farther down the mountain and overlies the Hampshire formation. The blocks on the floor of the hollow appear to be considerably less angular than those in the block field. This difference in roundness can be seen in the photographs. The roundness of the boulders in the hollow is probably due partly to weathering and to repeated abrasion by sand washed over them during times of very high runoff. The roundness is not necessarily caused by movement of the boulders themselves.

VALLEY BOTTOMS

The valley bottoms of first- and second-order streams are almost wholly occupied by the stream channel itself. They are floored by coarse boulders that are generally somewhat smaller in mean size than those in the hollow. The material in the hollows is slightly rounded; the debris in the channel is noticeably more rounded and the rounding increases as the valley becomes larger. Valleys of the third and larger order are floored by rather wide bottom lands, and the stream channel itself occupies a larger proportion of the valley floor. In both the Little River area and the Crawford Mountain area the material in the channels ranges in size from 60 mm to 160 mm. Channels of these larger valleys generally have banks less than 5 feet high, though there is considerable variation. The lowlands between the channel and the valley side slope are floored with sand, gravel, and boulders. Sand covers the largest area, with here and there boulders or areas of boulders projecting through it.

The material forming the floor of the Little River valley is described in detail on page 51, in connection with the description of the 1949 flood.

WEATHERING

Evidence of weathering in the surface mantle is of interest because of its bearing on the stability or history of the landforms on which it appears. Though systematic observations involving trenching and sampling for laboratory analysis were not made, some information relating to weathering profiles can be given. Oxidation of the shaly bedrock to depths of 3 feet was observed in roadcuts in a saddle on the crest of Crawford Mountain. Weathering was also observed in the extensive clay pits of the North Mountain Brick Co. These pits are located on the end of a shale ridge along the Chesapeake and Ohio Railway a few miles south of Crawford Mountain. The pits expose shale, both on the nose and side slope. On the nose the shale is oxidized and its color altered from greenish to pinkish to a maximum depth of about 12 feet. On the side slope no oxidation, as evidenced by a change in color, was observed, and the difference between nose and side slope was marked. The weathered shale on the nose has different shrinkage properties from the unweathered greenish shale, suggesting that its mineralogy is different. The differences in weathering between side slope and nose may be a result of the differences in moisture conditions between the two, or, as seems more likely, it may be a reflection of different rates of movement of material by creep and wash, the nose being the more stable. These conditions may, of course, be quite local.

In general, soil-profile development is weak. Many exposures of surficial materials were observed in the Hampshire formation in the cuts produced by debris avalanches, and in them the soil is apparently without a profile—at least a visible one. The writers were also impressed by the rarity of tree blowdown mounds such as are abundant on similar rock formations in the mountains of northern Pennsylvania (Denny and Goodlett, 1956, p. 59). Blowdown mounds were seen occasionally during traverses. An extensive field of mounds is on a foot slope adjacent to the channel of Hog Run, an environment that is relatively stable. Areas of blowdown mounds are also in a few places on side slopes. Their general absence is thought to be evidence of the instability of the ground surface. Probably motion of soil material and truncation of the bedrock by various forces of erosion is rapid enough, except in a few places—notably on noses and perhaps foot slopes—to keep pace with the formation of blowdown mounds as well as well-developed soil profiles.

VEGETATION

The Little River basin is almost completely forested. There are small areas of recently cutover lands, and a few open fields can be seen in the flood plain of the Little River. A considerable area was denuded of trees by the flood of June 1949, particularly on the valley floors (pl. 1).

The forest cover consists largely of second growth less than a hundred years old, with occasional small stands containing large, old trees. About 40 species of trees (table 1) grow in the area, of which about 30 are of sufficient size at maturity to form the crown canopy of the forest. The geographic distribution of about 20 of the tree species is closely related to the topographic form of the slopes, 10 species are almost ubiquitous, and the remaining 10 species occur with such low frequency that attempts to characterize their habitats do not seem desirable.

TABLE 1.—*Scientific and common names of plants*
[Nomenclature follows that of Fernald, 1950]

Common name	*Scientific name*
Trees	
Ash:	
Mountain-ash	*Pyrus americana* (Marsh.) DC.
White ash	*Fraxinus americana* L.
Basswood	*Tilia americana* L.
Beech	*Fagus grandifolia* Ehrh.
Birch:	
Black birch	*Betula lenta* L.
Yellow birch	*lutea* Michx. f.
Butternut	*Juglans cinerea* L.
Cherry:	
Black cherry	*Prunus serotina* Ehrh.
Pin-cherry	*pensylvanica* L. f.
Chestnut	*Castanea dentata* (Marsh.) Borkh.
Cottonwood	*Populus deltoides* Marsh.
Cucumber-tree	*Magnolia acuminata* L.
Dogwood, flowering	*Cornus florida* L.
Elm, American	*Ulmus americana* L.
Gum, black	*Nyssa sylvatica* Marsh.
Hemlock	*Tsuga canadensis* (L.) Carr.
Hickory:	
Pignut	*Carya glabra* (Mill.) Sweet
Shagbark-hickory	*ovata* (Mill.) K. Koch
Hop hornbeam	*Ostrya virginiana* (Mill.) K. Koch
Locust, black	*Robinia Pseudo-Acacia* L.
Maple:	
Mountain-maple	*Acer spicatum* Lam.
Red maple	*rubrum* L.
Striped maple	*pensylvanicum* L.
Sugar-maple	*saccharum* Marsh.
Oak:	
Black oak	*Quercus velutina* Lam.
Chestnut-oak	*Prinus* L.
Red oak	*rubra* L.
Scarlet oak	*coccinea* Muenchh.
Scrub-oak	*ilicifolia* Wang.
White oak	*alba* L.
Pine:	
Pitch-pine	*Pinus rigida* Mill.
Table-mountain pine	*pungens* Lamb.
Scrub-pine	*virginiana* Mill.
White pine	*Strobus* L.
Sassafras	*Sassafras albidum* (Nutt.) Nees
Shadbush	*Amelanchier* sp.
Spruce, red	*Picea rubens* Sarg.
Sycamore	*Platanus occidentalis* L.
Tulip-tree	*Liriodendron Tulipifera* L.
Willow	*Salix* sp.
Witch-hazel	*Hamamelis virginiana* L.
Shrubs and herbs	
Black cohosh	*Cimicifuga racemosa* (L.) Nutt.
Blueberry:	
Deerberry	*Vaccinium stamineum* L.
Low blueberry	*vacillans* Torr.
Low sweet blueberry	*angustifolium* Ait.
Checkerberry	*Gaultheria procumbens* L.
Dutchman's-pipe	*Aristolochia durior* Hill
Fern:	
Christmas fern	*Polystichum acrostichoides* (Michx.) Schott
Maidenhair-fern	*Adiantum pedatum* L.
Marginal shield-fern	*Dryopteris marginalis* (L.) Gray
New York fern	*noveboracensis* (L.) Gray
Spinulose wood-fern	*spinulosa* (O. F. Muell.) Watt
Fetter-bush	*Pieris floribunda* (Pursh) B. & H.
Grape	*Vitis* spp.
Greenbrier	*Smilax* spp.
Huckleberry	*Gaylussacia* spp.
Maple-leaved viburnum	*Viburnum acerifolium* L.
May-apple	*Podophyllum peltatum* L.
Minnie-bush	*Menziesia pilosa* (Michx.) Juss.
Mountain-laurel	*Kalmia latifolia* L.
Raspberry, purple-flowering	*Rubus odoratus* L.
Virginia creeper	*Parthenocissus quinquefolia* (L.) Planch.
Wild sarsaparilla	*Aralia nudicaulis* L.
Wood-nettle	*Laportea canadensis* (L.) Wedd.

The relation between species composition of the forest and topography is reflected in the form or appearance of the forest stands. For example, from a vantage point in early summer an observer might note the following three subdivisions of the forest landscape. First, a brownish-green needle-leaved forest of uniformly short stature that mantles most of the noses and many of the side slopes; the ground cover is brushy and dense. Second, a slightly yellowish-green broad-leaved forest that mantles most of the straight slopes; the trees are rather widely spaced, and the ground cover brushy. This kind of forest alternates with the third category which appears as a dense dark-green broad-leaved forest that grows mostly on valley floors and in hollows, but may extend up the side slopes. Here the pronounced globose crowns of individual trees project well above the general level of the canopy. The ground cover is not brushy. This forest extends on to the flood plains of large streams, where it becomes a mixed needle-leaved and broad-leaved forest.

Study of the forest showed that these form categories could be defined in terms of the presence or absence of a few species of trees. This fact provided a basis for three vegetational units defined in terms of species, and reflecting differences in the form of the forest. The usefulness of these units was greatly enhanced when ground reconnaissance showed that two of the three units could be identified on large-scale, high-quality aerial photographs. The vegetation map of the Little River drainage basin (pl. 1), compiled largely from aerial photographs, shows the distribution of the three vegetational units.

The units are based on the assumption that the objective description of vegetation requires the mapping of the distribution of species. Species are concrete units of vegetation, whose presence or absence can be recognized and verified by any trained observer. The forest types were therefore defined in terms of the presence or absence of a few tree species. Boundaries between types could be drawn easily on the ground and thus mapped. Validity of boundaries rests on the fact that many tree species show pronounced discontinuities in their distribution within small horizontal distances, presumably the result of topographic diversity, and, therefore, habitat diversity.

Forest stands containing sugar maple, basswood, or yellow birch, or any combination of these species, constitute one unit. Stands that lack these species can be subdivided into two units on the basis of presence or absence of pitch-pine and table-mountain pine. These three units contain many other species of plants, some of which may overlap two or all three of the units. The most common associated tree species are included in the map explanation of plate 1.

The three units are summarized in the following key:

	Unit	Forest type
Sugar-maple, basswood, and yellow birch, or any one of the three, are present	1	Northern hardwood.
Sugar-maple, yellow birch, and basswood are absent;		
pitch-pine and table-mountain pine, or either one of the two, are present	2	Yellow pine.
pitch-pine and table-mountain pine are absent	3	Oak.

Because the species characteristic of unit 1, and many of the associated trees and other plants, are important components of the deciduous forest of the northeastern United States, this unit is referred to as the "northern hardwood" forest type. Unit 2, because the characteristic species—pitch-pine and table-mountain pine—belong to the general category of hard or yellow pines, is referred to as the "yellow pine" forest type. Unit 3 generally is characterized by the presence of several species of oak and is referred to as the "oak" forest type.

A recent map of the major forest types of Virginia (Forest Survey Staff, 1941), published at a scale of 1:1,000,000, shows most of the Little River area mantled by "Shortleaf–Pitch Pine–Hardwoods," with a small area of "White Pine–Hardwoods" confined to the valley of the North River. This map is not accompanied by definitions of the forest types, but, as defined by Lotti and Evans (1943) and Craig (1949), who included the forest type map in his report, the "Shortleaf–Pitch Pine–Hardwoods" type includes both the yellow pine and oak forest types used in the present study. A third forest type, the "cove hardwoods," is "found in areas too small to be shown" on the forest type map of Virginia (Lotti and Evans, 1943, p. 7). This forest type, along with the "White Pine–Hardwoods" type, is roughly the equivalent of the northern hardwood type used in this paper.

Fortunately two of the units (northern hardwood and yellow pine) can be identified and their areas outlined on the aerial photographs used in this study. The area remaining is mantled by the oak forest type. All of the tree species used to define the forest types in the field (legend of pl. 1) cannot be identified on the photographs. However, field study showed that the forest types could be outlined on the photographs because the presence of the characteristic species affected the appearance of the forest. The interpretation probably has local validity only. On 1:10,000-scale photographs taken in March 1955 (see pl. 4) the three forest types appear as follows:

Yellow pine forest type:
- Individual tree crowns gray to dark gray, small, globose, fine grained, distinct; shadows dark, rounded to elliptical; low density stands; uniformly short height creates coarse, stippled appearance.

Northern hardwood forest type:
- Individual tree crowns light to medium gray, large, irregular, canopy deep and irregular (multistoried), fluffy; shadows medium; maximum height stems, trees closely spaced. When present in stands, white pine and hemlock can be distinguished as follows:
  - White pine, individual crowns large, globose, dark gray; shadows black and irregular in outline.
  - Hemlock, individual crowns large, globose, dark gray; shadows dark gray, pointed.

Oak forest type:
- Uniformly very light gray, individual crowns vague in outline, shadows indistinct; often has appearance of a pile rug.

The deciduous trees were leafless when photographs were taken in March 1955 and also when the northern hardwood and oak forest stands were studied in early April 1956. The field study disclosed that the distinction between the types visible on photographs resulted from differences in branches and branching habits of the trees. The oak trees, predominant in the oak forest stands, have crooked, heavy branches that tend to diverge widely from the axis of the main stem and result in the pile-rug texture seen on photographs. The trees in the northern hardwood stands, on the other hand, have upsweeping branches of generally smaller diameter that create the fluffy texture seen on the photographs.

The reliability of the central part of the forest-type map (pl. 1) is believed to be good. Botanical data obtained from study of forests on the ground agree with the photo interpretation. The central part of the map was field checked in April 1956. The margins of the map were prepared by means of photographs at a scale of 1:20,000. This part of the map was not field checked, and the reliability is probably fair to good.

The distribution of the species that define the forest types shows a high degree of coincidence with the distribution of other components of the landscape that can be readily recognized and described. The relation between forest types and topography, as shown on plate 1, is particularly strong. The northern hardwood forest occupies the flood plains of the larger valleys, extends as a narrow thread up the floors of the smaller valleys, and in first-order valleys enlarges into a tadpole-shaped area in the hollows at the valley heads. The yellow pine forest, on the other hand, is extensive on the ridges and noses and the sandy plateaus underlain by the Pocono formation. Coincidences are also apparent between the distribution of forest types and slope orientation, soil texture, and the nature and attitude of the bedrock. The relation between slope orientation and the distribution of forest types is so obvious that, like topography, it is readily apparent on plate 1 and on figure 15. For example, the northern hardwood forest extends much farther up the side slopes and occupies the hollows more extensively on the northeast-facing slopes than on the southwest-facing slopes. As will be explained in some detail in the pages following, it is believed that many of these relations are largely controlled by a common environmental factor—the distribution of moisture in the ground.

FORESTS OF FIRST-ORDER VALLEYS

Detailed studies of the vegetation, soil, and topography were made in several first-order valleys, including two valleys on Crawford Mountain (valleys 1 and 2, fig. 1), two valleys on the side of Reddish Knob (valleys 3 and 8, pl. 1), two valleys on Buck Mountain (valleys 6 and 7, pl. 1), and a valley near Grooms Ridge (valley 9, pl. 1). These valleys have different geologic conditions, exposures, and altitudes, and together they furnish a sample of a wide variation of vegetation. All the valleys reveal a relation between topography and vegetation, inasmuch as the vegetation in the hollows differs from that on the noses and side slopes. This effect is marked in valley 3, for example, but is much less so in valley 1, and is only slight in valley 9.

VALLEY 3

Valley 3, northeast of Reddish Knob, was studied in more detail than the others, and serves as an example of a first-order valley in which the effect of topography on the distribution of the vegetation is marked. The head of this valley is at an altitude of 4,000 feet, and its axis has a north-northwest exposure. The valley heads in the Pocono formation, but the lower part is cut into the Hampshire formation. The hollow and much of the side slopes are floored with cobbles and boulders of large size, which were transported from the massive Pocono sandstone that crops out in the valley head. The distribution of vegetation in the upper part of the valley is shown in figure 15. It was compiled by means of a series of traverses down and across the valley, using the three units described on page 18. A comparison of this figure with figure 13 shows a high degree of coincidence between the distribution of the sizes of rock fragments and the distribution of northern hardwood and oak forest vegetation units. These distribution patterns in turn show a high degree of coincidence with topographic form.

Vegetational data in valley 3 were also recorded by blocks 50 or 100 feet in length from a continuous sample 20 feet wide and 1,350 feet long that traversed the up-

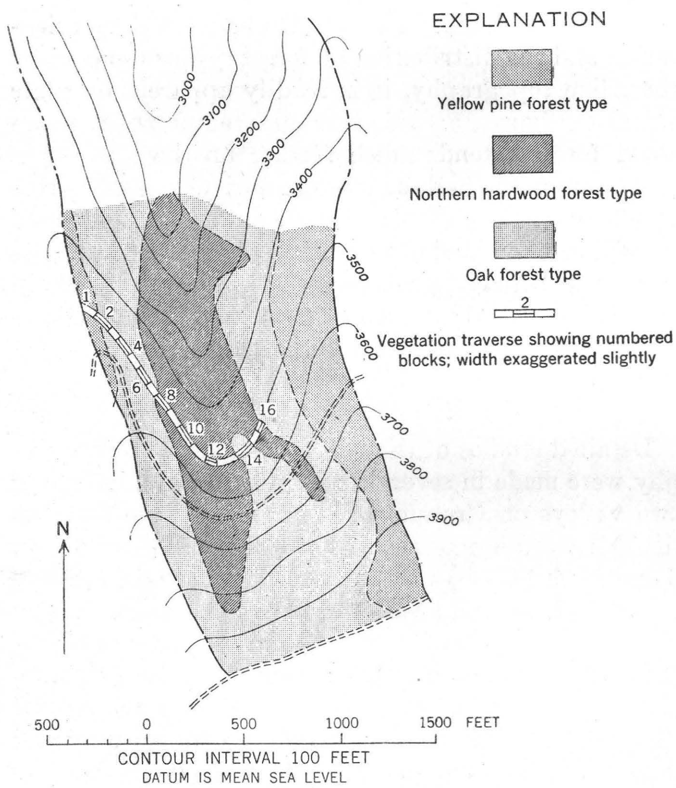


Figure 15.—Sketch map of valley 3, northeast of Reddish Knob (pl. 1), showing the distribution of the forest types and the location of the vegetation traverse. Base same as figure 13.

per part of valley 3 from the western nose eastward along the contours across the hollow (fig. 15). All tree stems having diameters of 2 inches or more, 4.5 feet off the ground, were recorded by species. These data provide detailed descriptions of the mapped forest types and show some of the range of variation within a single type.

The basal area[3] of each block was calculated from the traverse notes. The percentage of basal area provided by each species is shown by block in table 2*A*. Progressing from block 1 to block 16, the topography changes from a nose (block 1) to a side slope (blocks 2–7) to a hollow (blocks 8–16), and the drainage area of the slope above the blocks increases immensely. As shown in the table, the composition of the forest changes abruptly at the hollow from oak forest to northern hardwood forest.

Thirteen kinds of trees were tallied along the traverse. Table 2*A* shows that none of the 13 species occurs in every block. Seven kinds of trees—pignut, basswood, sugar-maple, hop hornbeam, yellow birch, witchhazel, and mountain-maple—are restricted to blocks 8–16, located in the hollow; however, none of these seven species grows in block 14. In this traverse, chestnut-oak occurs only in blocks 1, 2, and 4, located on the nose and side slope. Five tree species—red oak, striped maple, red maple, black birch, and black locust—occur both in the hollow and on the side slope. Of these five species, only red oak and black birch constitute as much as 50 percent of the basal area in any block; none of them constitutes as much as 50 percent of the basal area of a single block that is located in the hollow. In the traverse, only red oak occurs on the nose, the side slope, and in the hollow.

The diversity of the forest growing in valley 3 thus can be described in terms of presence or absence of tree species. Furthermore, it can be demonstrated that the species having highly local distribution within the valley constitute a large part of the stands (table 2*B*). For example, of the seven species restricted to the hollow, basswood, sugar-maple, and yellow birch each constitutes more than 50 percent of the basal area in at least one block. The combined basal area value of these three species in blocks located in the hollow that are classed as northern hardwood forest type ranges from 56.5 to 100 percent. This means that the species selected to characterize the northern hardwood forest type generally constitute most of the basal area of the stand.

In this traverse, the forest growing on the nose and side slope is of the oak forest type. However, immediately outside of block 1 the forest growing on the nose contains both pitch-pine and table-mountain pine, and is mapped as yellow pine forest type (fig. 15). Block 14, located in the hollow, lacks yellow birch, sugar-maple, and basswood, and is classed as oak forest type. Here red oak comprises most of the basal area. Block 14 contains a low ridge that divides the axis of the main hollow, in block 12, from the axis of a secondary hollow in block 15.

The oak forest type, defined in terms of absence of five species, is necessarily an "ashcan" forest type that is highly variable in species composition. In general, this forest type consists largely of oaks. For example, oaks constitute from 47 to 100 percent of the basal area in blocks 1–4 and 7. However, in the eight blocks classed as oak forest in the traverse, the combined basal area value for all kinds of oak ranges from 2 to 100 percent. Thus blocks 5–7 and 14 support forest in which oaks make up less than half of the basal area.

Because basal area combines stem diameter and number of stems, it gives no measure of size of stems. In other words, a large number of small stems may have the same basal area as a few large stems. In the traverse, the trees that constitute the forest canopy, or overstory, range in diameter from 6 to 20 inches or more.

[3] Basal area as used in this paper is the sum of the cross-sectional area of the trees (measured at "breast height"; that is, 4.5 feet off the ground surface) in a unit area, expressed in square feet. Basal area thus provides a quantitative description of the forest. It is used by foresters as a measure of stand density or stocking, and is correlated with volume of wood and growth.

TABLE 2.—*Vegetation data for valley 3, by block*

[Blocks are areas 50 or 100 feet long measured from a continuous sample 20 feet wide and 1,350 feet long]

	Nose	Side slope						Hollow								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A. **Species composition of the forest, showing proportions of total basal area in each block, in percent**																
Chestnut-oak (CO)	89.2	89.8		70.8												
Red oak (RO)	10.8		83.0	17.3	12.5	2.0	47.1			6.3			29.1	40.0		
Striped maple (St)		5.1	5.7	1.3	25.0	12.2	41.1		7.7	4.7	3.5		1.5	35.3	3.3	
Red maple (RM)		5.1	11.3	4.0		2.0	5.9	2.8	1.1					4.4		
Black birch (BB)				6.6	50.0	82.8	5.9				37.8			20.2		
Black locust (BL)					12.5	1.0		30.1	15.4							
Pignut (PG)								10.5					10.5			
Basswood (BA)								27.3			56.5					
Sugar-maple (SM)								29.4	16.5	66.6			35.8			
Hop hornbeam (HH)									1.1							
Yellow birch (YB)									58.2	22.2		77.9	21.0		96.7	100.0
Witch-hazel (WH)											.7					
Mountain-maple (MM)											1.4	22.1	2.2			
B. **Summary of the above data to emphasize predominance of species by block**																
Percent																
75–100	CO	CO	RO			BB						YB			YB	YB
50–74				CO	BB				YB	SM	BA					
25–49					St		RO St	BL BA SM			BB		RO SM	RO St		
10–24	RO			RO	RO BL	St		PG	BL SM	YB		MM	PG YB	BB		
1–9		St RM	St RM	St RM BB		RO RM BL	RM BB	RM	St RM HH	RO St	St WH MM		St MM	RM	St	
C. **Number and location of trees by species larger than 20 inches in diameter at breast height (4.5 feet off the ground surface)**																
Number																
1				CO				BL BA SM	YB	SM	BB		RO SM			YB
2						BB										

In the oak forest type growing on the nose and side slope the large overstory trees (more than 10 inches in diameter) are red oak, chestnut-oak, and black birch. In the northern hardwood forest type growing in the hollow the large overstory trees are basswood, sugar-maple, yellow birch, black birch, pignut, and red oak. Twelve of the stems were greater than 20 inches in diameter (table 2*C*). Note that the trees of largest diameter include the species used to characterize the forest types.

Nine of the twelve trees of largest diameter grow in the hollow. Although different kinds of trees are involved, this fact suggests that the rate of diameter growth, and perhaps maximum diameters, are greater in hollows than in other parts of first-order valleys. For example, red oak occurs in six blocks outside the hollow and in three blocks within the hollow. However, red oak of a diameter greater than 20 inches was found only in block 13, in the hollow. This does not constitute conclusive evidence because detailed data on ages of the trees are lacking.

Not only are the trees of greatest diameter concentrated in the hollow, but the amount of wood per unit area as expressed in terms of basal area is somewhat greater in the hollow. Although basal area is highly variable from block to block (table 3), the blocks having the highest basal area are located in the hollow (blocks 8, 11, and 13).

TABLE 3.—*Basal area, in square feet, of trees along traverse in valley 3, and analyses of the basal area data*

Block	Basal area	Block	Basal area
Nose and side slope:		Hollow:	
1	4.026	8	12.501
2	3.414	9	7.963
3	[1] 6.130	10	5.508
4	6.544	11	12.271
5	1.392	12	[1] 3.152
6	8.661	13	11.720
7	[1] 2.962	14	3.942
		15	[1] 5.260
		16	[1] 6.818

Block	Basal area	
	Range	Mean
All blocks	1.392 to 12.501	6.530
Nose and slide slope (1 to 7)	1.392 to 8.661	5.048
Hollow (8 to 16)	3.152 to 12.501	7.682
All blocks less blocks 5 and 12	3.162 to 12.501	7.138
Convex and straight slopes (1 to 4, 6, 7, and 14).	3.162 to 8.661	5.413
Concave slopes (8 to 11, 13, 15, and 16).	5.260 to 12.501	8.863

[1] These basal areas are in blocks only 50 feet long; the basal area values measured in the field have been doubled so that they are comparable with the other blocks which are 100 feet long.

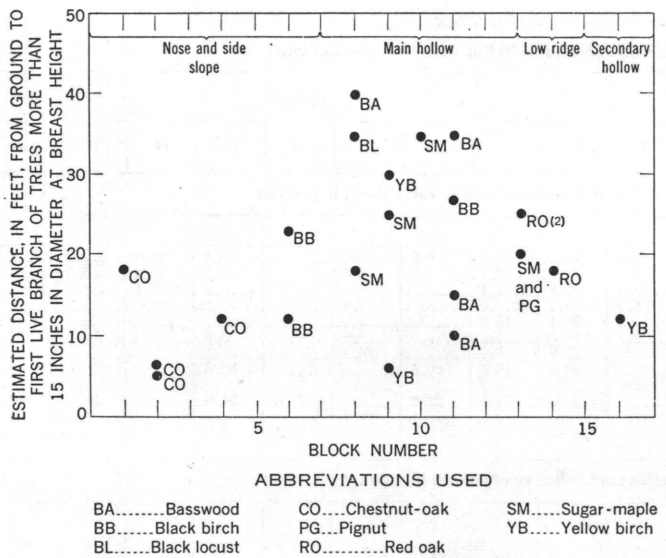


FIGURE 16.—Graph showing the form of trees along the traverse across valley 3.

The basal area data are not suitable for a detailed analysis, but do lend themselves to some simple calculations. Table 3 shows the range and the mean of all blocks—blocks in the hollow, and blocks on the nose and side slope. Note that the mean basal area for all blocks in the hollow has a considerably higher value than the mean basal area for all blocks on the nose and side slope. However, the mean basal area for all blocks in the hollow falls within the range of basal area of blocks in other parts of the valley.

The forest in blocks 5 and 12 has a much lower stand density than the adjacent blocks. Not only are there fewer stems, but almost all the stems are less than 6 inches in diameter. Both block 12, in the main axis of the hollow, and block 5 show signs of flood damage to the stands, presumably the result of the cloudburst of June 1949 (p. 42). Block 14, a low ridge, supports forest similar to that of the side slope. If the damaged stands of blocks 5 and 12 are eliminated from the calculations and block 14 is added to the nose and side slope category, the contrast between the two categories is increased (table 3). Note that in the adjusted classification the mean basal area of blocks on concavities within the hollow falls outside the range of basal area of blocks on straight and convex slopes.

The tallest trees are found in the hollow in valley 3. This fact is readily apparent to the ground observer. The relief of the tree canopy across the valley is less than that of the ground surface.

Total tree volume, or the amount of wood contained in all tree stems, is an important quantitative characteristic of a forest. Basically, volume is a function of stem diameter and height of stem. It has been demonstrated that the diameters of individual trees tend to be greater in the hollow of valley 3 than in other parts of the valley, and that total basal area also tends to be higher in the hollow. Greater height of trees growing in the hollow, therefore, indicates that the volume of wood in terms of cubic measure is also greater in the hollow.

Although no total height measurements of the trees were made, the distance from the ground surface to the first live branch of all trees more than 15 inches in diameter was estimated along the traverse. Figure 16 shows that this distance ranged from 5 to 23 feet on the nose and side slopes, and from 6 to 40 feet in the hollow. Height to the first live branch of five trees growing in blocks located in the hollow was 30 feet or more.

The forest growing in the upper part of valley 3 consists of all three forest types mapped in the Little River area. Yellow pine forest grows on the noses and on a part of the side slopes, oak forest grows on the side slopes, and northern hardwood forest grows in the hollow. Botanical data from the traverse across valley 3 show that the local distribution of the tree species used to define the yellow pine and northern hardwood forest types is closely related to topographic form. Although the most striking differences in the forest along the traverse are caused by abrupt changes in species composition, and thus forest type, differences in the diameter and height of stems and stand density are also great. Thus the northern hardwood forest growing in the hollow contains trees of generally greater height and diameter than the oak forest growing on the adjacent side slope and nose. Stand density as measured by basal area is also greater in the hollow. Furthermore, the tree species selected to define the forest types generally constitute the bulk of the stands in terms of numbers, size, basal area, and volume of wood.

VALLEY 1

Valley 1 on Crawford Mountain constitutes a different physical environment from the valley just described. It faces southwest, rather than north, and the slopes facing in this direction are probably the driest. The cobbles and boulders of the valley exhibit a marked increase in abundance and size in the hollow as compared with the side slope (see fig. 12), but the area of boulders does not extend nearly as far as in valley 3, and the boulders average only about half the size. Distribution of the vegetation units in the valley is shown in figure 17.

The vegetation of the valley differs from that of valley 3 mainly in that the northern hardwood type is absent. The forest of the hollow and side slopes consists primarily of chestnut-oak, red oak, and white oak (oak forest type). The trees growing in the hollow, however, show a greater height and diameter growth than those growing on the side slopes. A forest fire in 1952 killed many of the trees and cleared the ground of brush and saplings. Viewed 3 years later, the postfire growth of young sprout hardwoods appears taller and denser in the hollow than on the side slopes and noses. The hollow contains a dense growth of herbaceous plants, particularly black cohosh, which is almost lacking from the side slopes. Along the axis of the hollow, young black locust trees are more numerous and taller than those growing outside the hollow. Black locust is found in all three forest types, and is abundant in stands that have been opened up by fire, flood damage, or the activity of man. The noses and ridge crests support yellow pine forest consisting primarily of pitch-pine, table-mountain pine, and scarlet oak. Scrub-oak is abundant on the forest floor.

Valley 1 supports only two of the three forest types recognized in this study and lacks the northern hardwood forest, which is characteristic of the hollow in valley 3. However, as in valley 3, yellow pine forest grows on the noses and oak forest grows on the side slopes. The drainage area of the hollow of valley 1 is much smaller than that of the hollow in valley 3, and the orientation of the valley is different. The two valleys illustrate the range of variation of forests growing in first-order valleys, which is also readily apparent on plate 1. Thus all valleys do not contain all three forest types, but almost all valleys contain at least two of the forest types, and their distribution within the valley is closely related to topographic form.

OTHER FIRST-ORDER VALLEYS

The writers made detailed studies of the vegetation in the axes of five additional first-order valleys. The location of four of these valleys is shown on plate 1; the fifth, valley 2, is on the west slope of Crawford Mountain (fig. 1). In each of these valleys the data on vegetation were obtained from a series of 0.1 acre samples in a single traverse down the axis of the valley from the ridge crest or valley head through the hollow to the head of the stream. The tree species constituting the forests expressed in terms of the percentage of total basal area in the sample are shown in figure 18 and table 4. In figure 18 the percentages of the most abundant species are compared with the horizontal distance of each sample from the beginning of the traverse. In each traverse the drainage area of the slope above the sample increases as the distance increases. Approximate drainage areas at each station are shown in the figure above the sample.

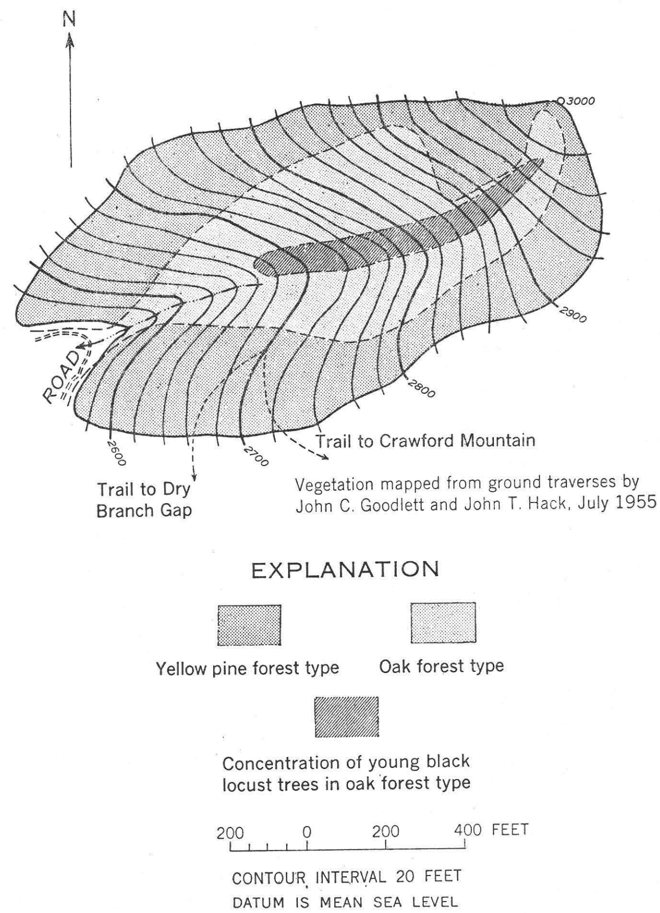


FIGURE 17.—Contour map of the upper part of valley 1, on the west side of Crawford Mountain, showing the distribution of forest types.

TABLE 4.—*Trees that constitute 5 percent or less of the basal area in first-order valleys*

[Trees that constitute over 5 percent of the basal area are shown in figure 18]

Valley	Drainage area, in square feet	Species
2	0	Black birch, basswood.
	28, 000	Black birch.
	200, 000	Witch-hazel.
	500, 000	Red oak, black locust, pin-cherry, mountain-maple.
6	0	Black locust, sassafras, witch-hazel, black cherry, pin-cherry, chestnut.
	15, 000	Black locust.
	40, 000	Hickory, flowering dogwood, witch-hazel, hop hornbeam.
	60, 000	Witch-hazel, hop hornbeam, butternut.
	150, 000	Striped maple, flowering dogwood, witch-hazel, hop hornbeam.
7	100	Witch-hazel, striped maple, black locust.
	300	Black locust.
	12, 000	Witch-hazel.
	35, 000	Do.
8	1, 000	Black locust, black cherry, butternut, mountain maple, striped maple, and shadbush.
	38, 000	Mountain-maple, shadbush, hemlock.
	60, 000	Mountain-maple and striped maple.
	300, 000	Mountain-maple, striped maple, black birch
9	100	Red maple, scarlet oak.
	360, 000	Sassafras, witch-hazel.

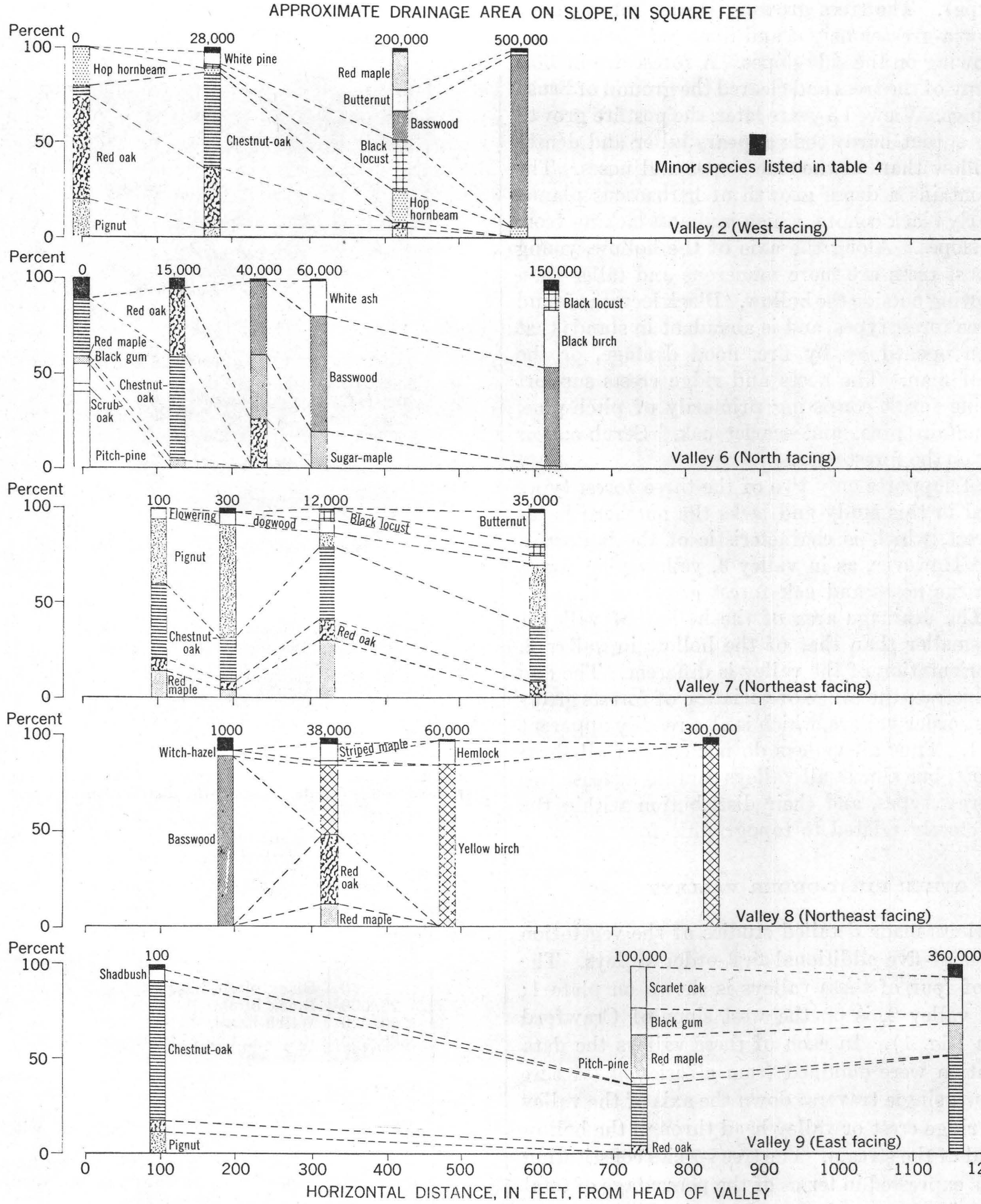


FIGURE 18.—Graph showing forest composition, expressed as percentage of basal area by species per unit area, in five first-order valleys. Trees that occur in numbers too small to be shown are listed in table 4.

Species composition of the forest varies from valley to valley and from hollow to hollow. Red maple and red oak are found in all five valleys. Chestnut-oak and black locust are almost as common. The hollows of valleys 2, 6, and 8 support forest of the northern hardwood type similar to the forest growing in the hollow of valley 3. The hollows of valleys 7 and 9 support forest more nearly resembling that of valley 1.

Valley 2 (fig. 1) lies on the northeast side of Crawford Mountain, and heads at a narrow ridge underlain by sandstone of the Chemung formation at an altitude of 3,200 feet. The lower part of the valley is cut into shaly beds. The valley is larger and deeper than valley 1 and faces northwestward. A traverse was made down the headslope into the hollow to an altitude of 2,750 feet. Vegetation was examined at four stations; drainage areas for these stations are shown in figure 18. The steepest slope, 30°, is in the upper part of the hollow at the inflection point, 580 feet from the crest. Northern hardwood forest occupies only the lower part of the hollow. At the lowest station the forest is almost entirely basswood.

Valley 6 lies near the east end of Buck Mountain (pl. 1). It is tributary to the North Fork of the Little River and is cut entirely in the Hampshire formation. It heads in a narrow ridge composed of flaggy red sandstone at an altitude of 3,300 feet. The valley opens to the northeast and, as does valley 3, has considerable variation in the composition of the forest. The traverse along which the samples were taken (see fig. 18) began on the ridge, went down the headslope into the hollow, and ended at an altitude of 2,900 feet at a horizontal distance of 630 feet from the ridge crest. This location is in the hollow still a considerable distance above the head of the stream channel. The steepest slope found is 37° at sample 2. Vegetation on the ridge and a few tens of feet downslope is yellow pine forest. The hollow supports northern hardwood forest with basswood and sugar maple predominating.

Valley 8 is a northeast-facing valley on the side of Reddish Knob, accessible from the forest road leading to the fire tower on the knob. Reddish Knob, over 4,300 feet in altitude, forms the valley head. The traverse (see fig. 18) extended down into the axis of the hollow and ended at station 4, at an altitude of 3,650 feet. Most of the traverse was in the outcrop belt of the Pocono formation. The hollow is floored by coarse boulders, and at station 4 the mean size was 290 mm. The large boulders in the hollow appear to be arranged in festoons that loop around the floor of the hollow in arcs concave toward the mountain. As one traverses down the hollow, one passes over a series of steps or benches that are several hundred feet wide and a dozen or so feet high.

The composition of the forest in this hollow is much like valley 3, and as shown in figure 18, the northern hardwood forest is composed mostly of yellow birch. The yellow birch appears to be most characteristic of hollows similar to this one that face a northerly direction and are at rather high altitudes.

Valley 7 is a small valley cut into the east end of Buck Mountain. Although the valley is exposed toward the east, a direction that ordinarily is associated with a relatively moist environment, the valley is not cut deeply into the mountain, but is shallow and as a consequence attains a drainage area of only 35,000 square feet at the head of the channelway. Perhaps for this reason the vegetation in the hollow is oak forest (fig. 18), and the northern hardwood forest does not occur. One of the characteristic features of this hollow is the presence of unusually large numbers of the herbaceous perennial, black cohosh. The traverse down the valley began on the east nose of Buck Mountain at an altitude of 2,600 feet and went down a horizontal distance of 600 feet where it ended at an altitude of 2,400 feet. Bedrock is shale and interbedded sandstone of the Hampshire formation.

Valley 9 lies in the eastern area of plate 1 to the south of Grooms Ridge. It differs markedly from the other valleys described, in that it contains heath plants in the hollow and even some pitch-pine. The traverse (fig. 18) extended a distance of 1,160 feet down the valley axis from an altitude of 2,800 feet to about 2,500 feet. The boulders on the floor of the hollow have a wide variation in size and at station 3, where they are the coarsest, their mean size is only 15 mm. Some boulders over 500 mm, however, were seen. The geologic environment is markedly different from the others. The valley is cut into the dip slope of a massive sandstone bed of the Pocono formation and probably does not penetrate into the shale beneath. Except in rare and excessively heavy rains it is probable, therefore, that surface water rapidly sinks into the ground and is carried off as ground water.

NONTREE VEGETATION IN FIRST-ORDER VALLEYS

The nontree species in the five valleys just described show a geographic segregation related to topographic form similar to that of the tree species. The common nontree species [4] that grow in the sample areas of the five valleys are shown in table 5.

Of the 16 species listed, 7 are members of the heath family of plants (Ericaceae), and generally possess the

[4] Those nontree species that have an overall frequency of at least 10 percent in 53 sample plots studied (9 are on noses and crests, 15 on side slopes, 18 in hollows, and 11 on flood plains).

shrubby form characteristic of the family. Of these heath plants, mountain-laurel (*Kalmia latifolia*) and fetter-bush (*Pieris floribunda*) perhaps are the most noticeable species. Dense tangles of these tall, evergreen shrubs mantle the noses and side slopes of the region, making travel extremely difficult. Their absence from many of the hollows, on the other hand, provides an easy way to descend from the ridges, even though many hollows are filled with large, loose boulders. Blueberries (*Vaccinium* sp.) and huckleberries (*Gaylussacia* sp.) add their woody stems to the general tangle of ground cover on noses, side slopes, and ridge crests.

TABLE 5.—*Distribution of common nontree species in five first-order valleys in relation to topographic position and forest type*

[E. denotes heath family (Ericaceae)]

Species	Topographic position			Forest type		
	Crest	Head slope	Hollow	Yellow pine	Oak	Northern hardwood
Pieris floribunda (E)	×	×	--------	×	×	--------
Vaccinum vacillans (E)	×	×	--------	--------	×	--------
Vaccinium stamineum (E)	×	--------	--------	--------	×	--------
Viburnum acerifolium	×	×	--------	--------	×	--------
Gaultheria procumbens (E)	--------	--------	×	×	--------	--------
Vaccinium angustifolium (E)	×	--------	×	×	×	--------
Kalmia latifolia (E)	×	--------	×	×	×	--------
Menziesia pilosa (E)	×	--------	×	×	×	×
Aralia nudicaulis	×	×	×	×	×	×
Smilax spp	×	--------	×	×	×	×
Polystichum acrostichoides	--------	--------	×	--------	×	×
Cimicifuga racemosa	×	×	×	--------	×	×
Parthenocissus quinquefolia	×	--------	×	--------	×	×
Dryopteris marginalis	×	×	×	--------	×	×
Aristolochia durior	--------	×	×	--------	--------	×
Laportea canadensis	--------	×	×	--------	--------	×

Table 5 shows that heath plants may grow in all parts of the valleys. Some valleys, however, lack heath plants entirely. None appear in the tallies for valley 2, and only Minnie-bush (*Menziesia pilosa*) appears in valley 8. Heath plants also are lacking in the hollow of valley 6. Of the five valleys, only these three support northern hardwood forest. Heaths are a particularly prominent part of the ground cover in the yellow pine and oak forest stands that mantle the slopes and noses adjacent to these hollows and the whole of valley 9. In general, the shrubby heaths are characteristic components of the ground cover in yellow pine and oak forest stands.

The ground cover in the northern hardwood stands of valleys, such as 2, 6, and 8, is distinctive not only because of an absence of shrubby heath, but also because of the presence of delicate herbaceous plants, ferns, and climbing vines. Two of the species, wood-nettle (*Laportea canadensis*), an unpleasant perennial plant possessing stinging hairs, and Dutchman's-pipe (*Aristolochia durior*), a woody climbing vine possessing large heart-shaped leaves, are restricted to the northern-hardwood forest type. Black cohosh (*Cimicifuga racemosa*), a tall, coarse, perennial herb, is abundant in hollows that support northern-hardwood stands and occurs less frequently in oak forest. For example, it occurs in the oak forest growing in the hollow of valley 7, but is absent from the hollow of valley 9.

VEGETATION ON RIDGES AND NOSES

In order to obtain further quantitative data concerning forests that grow on noses other than those at the heads of the five first-order valleys just described, the writers studied the divide between two valleys on Buck Mountain (locality 734, pl. 1). The radius of curvature of this nose is small (35–75 feet) and the environment is dry in terms of the drainage area available for a supply of runoff water. The bedrock is shale with interbedded sandstone layers. Table 6 shows the composition of the forest at three stations on this ridge. Chestnut-oak, black oak, and pignut occur in all three stations. Both chestnut-oak and pignut constitute more than 50 percent of the basal area in one sample. The third sample consists predominantly of pitch-pine (44.5 percent) and chestnut-oak (27.9 percent). Red maple, red oak, black gum, and black locust are other common species on the ridge, but they seldom constitute as much as 25 percent of the basal area. The forest at station 1 is an oak and hickory stand. At station 2, oak and pitch-pine trees constitute about 82 percent of the forest. At station 3, oak trees in the predominantly chestnut-oak stand constitute only 56 percent of the sample, and red maple makes up another 25 percent of the basal area.

TABLE 6.—*Vegetation data from traverse of nose locality 734, on Buck Mountain, showing species composition in terms of percentage of basal area in sample*

Species	Station 1 Oak forest	Station 2 Yellow-pine forest	Station 3 Oak forest
Pignut	79. 5	0. 8	1. 1
Flowering dogwood	2. 4	1. 0	11. 5
Chestnut-oak	3. 5	27. 9	53. 6
Black oak	14. 0	4. 8	2. 2
Red maple	--------	13. 6	24. 3
Pitch-pine	--------	44. 5	--------
Scarlet oak	--------	4. 0	--------
Red oak	--------	. 4	. 6
Black locust	--------	3. 2	5. 6
Radius of curvature of nose..feet..	75	35	45

The ground cover consists predominantly of shrubby heath plants. Blueberries are abundant in all three stands, and the yellow pine forest at locality 2 contains mountain-laurel and fetter-bush. Black cohosh grows in the oak forest stands.

Valleys 6 and 7 also head on Buck Mountain, and the first sample in each of these valleys can be compared with the traverse described above. All five stands contain chestnut-oak, and four stands contain red oak, pignut, and red maple. Two of the stands are of the yellow pine type and three are of the oak forest type. Within the yellow pine type, pitch-pine, red maple, chestnut-oak, and red oak constitute more than 75 percent of the basal area in both stands. Within the oak forest type, chestnut-oak and pignut are present in all the stands, and red maple, red oak, and black oak are present in two.

In places, the ridge crest along the Virginia-West Virginia boundary line north of Reddish Knob supports northern hardwood forest (pl. 1), which is absent from crests in other parts of the Little River area. The presence of this kind of forest on topographically "dry" sites is interpreted as an indirect effect of the altitude, which is more than 4,000 feet. Nevertheless, note that the two areas of northern hardwood forest are extensions of similar forest that occupies the heads of adjacent hollows. Examination of the bedrock suggests that the nature of the rock strongly affects the local distribution of forest types on the ridge.

Beds of massive sandstone alternate with shale beds along the ridge. In places, the shale is mantled with block rubble derived from the sandstone. One of the northern hardwood areas grows on block rubble over shale, and the other is underlain by shale. Areas underlain by massive sandstone support yellow pine forest or oak forest. Oak forest also grows on the shale, but yellow pine forest grows only on the massive sandstone on this ridge.

SUMMARY

Forests of first-order valleys vary much in form and composition. These variations may be categorized into three forest types which reflect differences both in overall appearance of the stands and in relative numbers and kinds of plants that are present. The evidence for recognition of three forest types within the valleys that were studied in detail is presented in figure 18 and tables 2, 5, and 6. The trees that constitute the bulk of the forest stands in these samples are shown in table 7, which also gives a measure of their importance in the stands. Note that the species used to characterize the forest types usually predominate. For example, sugar-maple, basswood, or yellow birch generally constitute most of the basal area in stands designated as northern hardwood forest.

The distribution of the three forest types within first-order valleys is most closely related to topography, as is well shown in plate 1, figures 15, 17, and 18, and table 7. The northern hardwood forest type almost invariably grows in hollows, but all hollows do not support forests of this type. The oak forest type usually grows on side slopes but may be found in hollows and on noses. Similarly, yellow pine forest characteristically grows on noses but is commonly found on side slopes and, in rare instances, in hollows.

FORESTS OF HIGHER ORDER VALLEYS

Second-order valleys are mantled with forest similar to that growing in first-order valleys below the hollow. The narrow flood plains and terraces usually support northern hardwood forest, which may extend onto the occasional foot slopes and other concavities in side slopes. Side slopes usually support oak forest or yellow pine stands.

The flood plains characteristic of third-, fourth-, and fifth-order valleys support forests that differ in some ways from forests of first- and second-order valleys. The forest of the flood plain of the Little River, a fifth-order valley, and its tributary, the South Fork, a fourth-order valley, were studied in some detail, in places.

The flood of June 1949 caused extensive damage to the flood plain of the Little River system and destroyed much of the forest growing on the flood plain. At this point only the relatively undamaged stands will be discussed, and the vegetation of the flood-damaged areas will be discussed on page 49. Additional studies of relatively undamaged flood-plain vegetation were made in the valley of the North River and its tributary, Skidmore Fork, and in the valleys of Hone Quarry Run and Wolf Run, tributaries of Briery Branch. Briery Branch, like the Little River, is a headwater stream of the North River and drains the area immediately northeast of the Little River basin.

The single valley flats that comprise the flood plains of these streams almost invariably support northern hardwood forest. The species composition of the northern hardwood stands growing on the valley bottoms at eight localities along these streams can be summarized in terms of frequency. Sugar-maple and hemlock were found in all stands sampled. Red maple and white pine each occurred in all but one stand. Most of the stands contain sycamore, black locust, basswood, red oak, and butternut. Black birch, tulip-tree, and witch-hazel appear in half of the samples. Other tree species that occur in less than half of the samples are yellow birch, shagbark-hickory, flowering dogwood, white ash, black cherry, cucumber-tree, striped maple, and elm.

An outstanding characteristic of these northern hardwood stands is the large number of hemlock and white pine trees that they contain, in contrast with the relative scarcity of these trees in the hollows of first-order valleys. First-order valleys tributary to the Moorefield River that head on the northwest slopes of Shenandoah Mountain, however, contain many hemlocks and white pines.

TABLE 7.—*Tree species that constitute more than 25 percent of the basal area in sampled areas in hollows, on side slopes, and on noses and ridge crests*

[NH, northern hardwood forest type; OF, oak forest type; YP, yellow pine forest type]

	Hollows																				
Valley	3								8			5			2			7		9	
Locality																					
Station	8	9	10	11	12	13	15	16	2	3	4	3	4	5	2	3	4	3	4	2	3
Species																					
Sugar-maple	29		67			36						33									
Basswood	27			57								39	61	52			93				
Black locust	30															28					
Yellow birch		58			78		97	100	36	85	96										
Black birch				38										31							
Red oak						29			37			26			31						
Chestnut-oak															50			39	29	32	53
Red maple																		31			
Pignut																			32		
Striped maple																					
Scarlet oak																					
Table-mountain pine																					
Pitch-pine																					
Forest type	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH	OF	NH	NH	OF	OF	YP	OF

	Side slopes								Noses and ridge crests								
Valley	3						10		10		5	7	9		3		2
Locality										734				734		734	
Station	2	3	4	5	6	7	4	5	1	2	1	1	1	1	1	3	1
Species																	
Sugar-maple																	
Basswood																	
Black locust																	
Yellow birch																	
Black birch				50	83												
Red oak		83				47											54
Chestnut-oak	90		71				79	68		28	30	40	75		89	54	
Red maple																	
Pignut												34		80			
Striped maple						41											
Scarlet oak									36								
Table-mountain pine									27								
Pitch-pine										45	41						
Forest type	OF	OF	OF	OF	OF	OF	YP	YP	YP	YP	YP	OF	OF	OF	OF	OF	OF

The flood-plain forests contain species of trees that are extremely rare or absent in the northern- hardwood forests of the hollows, including shagbark-hickory, tulip-tree, cucumber-tree, sycamore, elm, and beech. Of these species, sycamore and tulip-tree are common and important constituents on flood plains. In a few places sycamore or tulip-tree, or both, are found in the forest growing in first- and second-order valleys a few tens of feet upslope from the flood-plain forest.

The ground cover is similar to that in the northern hardwood forests of hollows. Heath plants are almost entirely absent. A few mountain-laurel bushes grow in three of the stands sampled. Ferns (*Dryopteris marginalis*, *D. spinulosa*, *D. noveboracensis*, *Adiantum pedatum*, *Polystichum acrostichoides*), vines (*Parthenocissus quinquefolia*, *Vitis* spp., *Smilax* spp.), and herbaceous plants (*Cimicifuga racemosa*, *Podophyllum peltatum*, *Rubus odoratus*, *Laportea canadensis*) constitute the bulk of the nontree species. The number of nontree species is generally larger than in the northern hardwood stands of first-order valleys.

In a few places the higher parts of the flood plains support oak forest or yellow pine forest. The large alluvial fan at the mouth of Wolf Run (pl. 1) supports a stand made up of pitch-pine, chestnut-oak, scarlet oak, black oak, white oak, red maple, and black gum. White pines grow at the stream margin. The shrubby ground cover consists of scrub oak, mountain-laurel, blueberries, and other heath plants.

Near the southeast end of Hearthstone Ridge, the valley bottom of the Little River widens to about 300 yards. At the foot of Hearthstone Ridge the higher, gently sloping flood plain supports both oak forest and yellow pine forest. (See pl. 1.) The forest consists mostly of black oak and red maple, although white pine, shagbark-hickory, and pignut are abundant. Red oak, white oak, chestnut-oak, sassafras, and flowering dogwood are present, as well as sycamore and tulip-tree.

A. VIEW OF BLOCK FIELD ON RIDGE CREST NORTH OF REDDISH KNOB

Geometric mean size of boulders on open slope in background is 240 millimeters. Note angularity of boulders and the yellow birch trees in foreground.

B. VIEW OF FLOOR OF HOLLOW IN VALLEY 3 NORTH OF REDDISH KNOB

Geometric mean size of boulders and cobbles is 220 millimeters. Note roundness of boulders and the open, nonshrubby forest floor characteristic of the northern hardwood forest type. Woody climbers in right foreground are Dutchman's-pipe.

A. VIEW OF AN ASYMMETRIC VALLEY

Valley is north of the Little River and the view is up the axis of the valley. Gentle, dry slope on right supports a stand of pitch-pine and table-mountain pine. Steeper, moister slope on left supports a forest consisting largely of oak tress.

B. VIEW OF A TYPICAL CHUTE

Chute is on a side slope in the valley of the Little River opposite the mouth of Hog Run and was formed by a debris avalanche in June 1949. Note the accumulation of slide debris in the foreground, washed and partially removed by floodwater in the main valley. Bedrock is sandstone and shale of the Hampshire formation.

A few black locust and sugar-maple saplings grow in the understory. A few pitch-pines and scrub-pines grow near the outer edge of the valley bottom. The ground cover contains a few shrubby heath plants—mountain-laurel and low sweet blueberry as well as black cohosh, greenbrier, and Virginia creeper.

Here and there in the flood-plain forest of the Little River stumps of recently cut trees furnished information about the age of the stands. Growth ring counts obtained from the larger stumps are shown in table 8. The stumps ranged in diameter from 22 to 30 inches, and in age from 90 to 174 years. Unfortunately, the largest living tree observed on the flood plain, a 38-inch tulip-tree growing at locality 770 (fig. 30, area 6) was hollow, and its age could not be determined. Only the outer 6 inches was sound and showed 125 to 150 growth rings. The tree was probably at least 175 to 200 years old. The areas supporting the old stumps escaped severe damage in the flood of June 1949, and the ages of the stumps indicate that these places have not been severely damaged by floods within at least 100 to 175 years.

TABLE 8.—*Ring-count data from tree stumps and a live tree in the valley of the Little River*

Location	Species	Approximate year cut	Diameter, in inches	Number of rings
		After		
Locality:				
778	Hemlock	1952	28	107.
778	do	1949	29	109.
778	do	1949	30	106.
730	White oak	1952	30	140.
730	Oak	1952	27	174.
730	Hemlock	1952	26	101.
778	do	Unknown—not recently	24	50 in outer 6 inches.
Near junction of North and South Forks.	Red oak	1949	22	146.
At foot of Hearthstone Ridge.	White pine	Unknown	30	90.
Locality 770	Tulip-tree (Live tree)		38	125–150 in outer 6 inches.

Many of the side slopes of higher order valleys are noses between first- and second-order valleys. Other side slopes are unbroken by tributary valleys, and may terminate in cliffs. Side slopes of both categories generally support stands of oak forest or yellow pine forest types. Occasionally the otherwise uniform side slopes are interrupted by minor cavities that might be called incipient tributary valleys. These concavities often support northern hardwood forest.

GENERAL HYPOTHESIS TO EXPLAIN THE DISTRIBUTION OF SPECIES AND FOREST TYPES

The vegetation of the upper Shenandoah Valley region is characterized by a pronounced geographic segregation of the species composing the flora. This segregation is generally coincident with topographic units that can be rigidly defined. Species assemblages often change abruptly with changes in the form of slopes. These changes in species composition are most noticeable in the tree species which comprise the forest canopy, but changes in the shrubby and herbaceous ground cover are similarly abrupt. Species and groups of species characteristic of the northern part of the eastern deciduous forest alternate with species characteristic of the southern and central Appalachians. The strong coincidences between the local distribution of species and groups of species and topography are modified by (a) the size of the valleys, (b) the orientation of the valleys and side slopes, and (c) the nature and attitude of the bedrock.

The fundamental coincidence between species composition and topography can be expressed as follows: (a) Forests consisting primarily of pitch-pine, table-mountain pine, and species of oak (yellow pine forest type) are generally restricted to noses, ridges, and other slopes that are convex away from the mountain; (b) forests containing one or more of the three species, yellow birch, sugar maple, and basswood, (northern hardwood forest type) are generally restricted to hollows and other slope surfaces that are concave outward; (c) forests consisting primarily of oak generally grow on straight slopes. However, all hollows do not support forests of the northern hardwood type, and all ridges do not support forests of the yellow pine type.

A further coincidence, not readily observable and perhaps largely theoretical, exists between these same topographic divisions of valley slopes and the distribution of runoff water. The ridges and hollows that characterize the slopes largely determine the distribution of runoff. The hollows and other minor concavities are areas where runoff is concentrated. Theoretically, noses and other convex areas disperse runoff, whereas the amount of runoff passing any point on a straight slope is proportional to the length of slope.

Thus many areas in which runoff is concentrated in large amounts support northern-hardwood forest, many areas in which runoff is dispersed support yellow pine forest, and many areas in which the amount of runoff is intermediate support oak forest. These relations between topography and forest type and topography and runoff suggest that different moisture regimes strongly affect the local distribution of species and forest types. But what is the connection between surface runoff, which is of no use to plants, and moisture regimes?

Runoff probably does not begin in all parts of a first-order valley simultaneously. In general, the soil mantle is thicker in hollows than on adjacent slopes and noses. Runoff may begin on noses, accelerate the saturation of the materials on the side slopes, and runoff from both areas may accelerate the saturation of soil materials in the hollow. Rainfall sufficient to saturate the mantle on slopes and noses and cause runoff may be insufficient to saturate the mantle in the hollow. Runoff from noses and side slopes thus may raise the moisture level of the mantle in the hollow to field capacity. Because of the greater volume of soil in the hollow, the total amount of water at any level of moisture content is greater in hollows than on side slopes and noses.

Furthermore, soil moisture undergoes gravity movement between rains. Gravity movements are affected by such things as the thickness and nature of the surficial deposits and the lithology and structure of the bedrock. In a general way, however, gravity movements of subsurface water probably follow the course of surface runoff, which theoretically at least can be predicted on the basis of topographic form. Thus a part of the subsurface water on noses and side slopes tends to move into hollows and onto foot slopes. This acts to keep the soil materials in concave areas nearer to field capacity than otherwise would be the case. In effect, intervals of relative dryness are shorter for concave areas than in adjacent convex or uniformity sloping areas.

It should be kept in mind that moisture present during the growing season is the primary consideration. Precipitation occurring during the dormant season is critical only when it falls in such small amounts that the growing season begins with a moisture deficit or it is released to the plants during the growing season in the form of melt water from snow or ice. Furthermore, the different moisture regimes are not static, but are subject to pronounced variation between rains. In other words, it is perhaps the duration of certain soil moisture levels during the growing season that affects the distribution of plants.

The possibility exists also that differences in the intensity of frost heaving related to differences in soil moisture affect the difference in species. For example, seedlings of such taprooted species as oak may be heaved out of the ground in moist areas, whereas fibrous-rooted seedlings of such species as sugar-maple may survive.

If gravity movement of water between rains affects the duration of a certain moisture level, then one would expect the size of the drainage basin to be of considerable importance. Small drainage basins should possess different moisture regimes than large drainage basins. Hollows with small drainage basins might not support the same forest type found in hollows having large drainage basins.

Three of the seven hollows in which the forest was studied in detail lack northern hardwood forest. The drainage basins in two of the three hollows (valleys 1 and 7) are small. This suggests that a definite but undefined and probably variable minimum area of drainage basin is essential for the establishment of forest of the northern hardwood type in a hollow. The vegetation map shows that the hollows of many small valleys lack northern hardwood forest.

But can the absence of northern hardwood forest from large hollows be explained, using the assumption that the distribution of forest types is strongly affected by different moisture regimes? For example, the hollow of valley 9 has one of the largest drainage areas, and the vegetation map shows many other large hollows that lack northern hardwood forest. This leads to a consideration of the retention and loss of soil moisture. Even though an area receives a large amount of moisture, either as precipitation or as subsurface gravity flow, if it is not retained by the soil mantle or is rapidly lost either through downward percolation or evaporation and transpiration, soil moisture levels will not remain high.

Differences in moisture retention owing to geologic factors should be considered first. Slopes in the upper Shenandoah Valley region are covered by a thin mantle of soil materials that reflects the geology of the underlying bedrock. In the Little River area localities underlain by the massive sandstone of the Pocono formation are mantled by sand and sandy loam. Localities underlain by shale of either the Hampshire or Pocono formations are mantled largely by silt loam and silty clay loam. In many places, especially in hollows, coarse-textured materials have been transported down over fine-textured materials.

In fine-grained deposits or soils the flow of moisture in the ground is retarded, and a loamy material will remain moist for a longer period than a sand. Maximum moisture retention occurs where such fine-grained material is overlain by porous rubble that protects the moisture-holding loam from evaporation. Favorable sites for such conditions are slopes below contacts between sandstone and shale, particularly in hollows.

On the other hand, sandy soils resting on thick permeable sandstone beds, such as those on the lower part of the Pocono formation as on Grooms Ridge, or Sand Spring Mountain, tend to be the driest sites, for most of the moisture that falls is lost through downward percolation to levels in the ground below the depth of penetration of plant roots. Such geologic conditions are most likely to be found on sandstone plateaus or ridge crests, but probably also occur in some hollows, such as valley 9, where erosion of the hollow has not penetrated the massive sandstone bed forming the slope. In this case the coarseness of the rubble in the hollow serves to accentuate the dryness of the environment.

Where the rock strata are dipping gently in one direction, shale beds that alternate with permeable sandstone beds or layers of igneous rock intruded into sandstone beds provide a large source of moisture. Water runs through the strata in the permeable layers along the contacts with the shale below, forming seeps on downdip slopes. Downdip slopes consequently have a different forest composition from updip slopes. This phenomenon will be discussed more fully in connection with the asymmetry of slope forms (p. 37).

Differences in the forest on opposite slopes as well as differences between hollows are also related to differences in exposure. For example, the northeast-facing side slopes of Sand Spring Mountain, Wolf Ridge, Chestnut Ridge, and Timber Ridge, all of which are underlain by the Hampshire formation, support large areas of northern hardwood forest. Presumably this is due primarily to reduced rates of evaporation and transpiration. Loss of soil moisture by these processes is most pronounced on south- and west-facing slopes and probably least on north-facing slopes. The prevailing westerly winds increase evaporation and transpiration rates on south- and west-facing slopes. Air and surface temperatures are higher here because the slopes receive the direct rays of the sun during the hottest parts of the day. Northern hardwood forest generally is absent from south- and west-facing side slopes, and from hollows of first-order valleys that trend southward and westward. This can be seen on the forest-type map in the valleys of Coal Run, Big Run, and the lower reaches of Briery Branch.

Differences in climate related to altitude also affect the distribution of trees. Altitudes within the Little River area range from about 1,600 feet to almost 4,400 feet, but the species that constitute the tree flora grow at all altitudes. The species that are found in the vicinity of Reddish Knob are also found on slopes at low altitudes and on the flood plain of the Little River. However, at the higher altitudes the local distribution and the abundance of tree species differ. The differences are probably caused by an orographic effect on the distribution of precipitation, particularly local thunderstorms. Lower temperature regimes of the higher altitudes are accompanied by reduced evaporation and transpiration rates, a higher proportion of precipitation in the form of snow, shorter growing seasons, and a greater instability in the soil mantle produced by frost. These effects, on theoretical grounds, would favor the growth of species characteristic of the northern hardwood type, and may help to explain the presence of northern hardwood forest on the ridge north of Reddish Knob (p. 27).

The distribution of yellow birch appears uniquely different from that of other tree species, and it suggests another cause of differential moisture retention in the ground: the retention of snow and ice for longer periods in fields of block rubble. Yellow birch grows in large hollows at high altitudes on coarse block fields, on flood plains at low altitudes, also generally on accumulations of boulders, and on residual block fields on ridge crests, noses, and side slopes below the outcrops of coarse sandstone beds. In this latter environment the yellow birch is commonly associated with mountain-ash. In some of these block fields a roughly circular area of blocks is completely bare of vegetation except for lichens. The bare area is bordered downslope and on the sides by an aureole of yellow birch and mountain-ash, which in turn are bordered by oak forest. The topographic position of these block fields is such that runoff water is not available in large quantities, for some of them straddle the crests of ridges. Yet they support a forest that elsewhere suggests a dependence on considerable moisture, since it is associated with large north-facing hollows and flood plains.

It is suggested that such large block fields that are either bare of trees or sparsely clothed in a forest of deciduous trees are favorable places for the accumulation of snow and ice. The snow and ice, because of poor thermal conductivity in the block fields during the warm months, may persist on into the spring and early summer providing a moisture supply of long duration and giving rise to seeps or even springs.[5]

A block field when dry is a poor conductor of heat because it is porous and contains stagnant air. During the winter months, snow falling on such a block field presumably packs down between the boulders. As rocks at the surface are heated during the day, the snow around the blocks melts and moves below to freeze in the lower layers of the field. When the blocks become firmly imbedded in ice to a point near the surface, the block field becomes a good conductor of heat rather than a poor one. The cold of the winter climate may therefore penetrate the ground to a greater depth in a block field than in a nearby area covered by forest litter. In spring when the upper layers of ice and hard-packed snow have melted, the ice below is protected from melting by the thermal blanket of stagnant

[5] The explanation that follows was suggested to the writers by some unpublished notes, concerning the subject of ground temperatures, loaned to them by C. V. Theis, of the U.S. Geological Survey. Theis, however, shares no responsibility for the present application of this principle of differential thermal conductivity.

air in the upper part of the block field. The warmth of summer will penetrate the ground to lesser depth under the block field than in surrounding areas where there are no blocks. The slow melting of the ice and snow will provide moisture for a period of time lasting into the summer.

This hypothesis may explain the occurrence of what appear to be moisture-loving species of trees on and around the margins of block fields, even on what appear to be dry sites. Block fields in hollows, of course, are moist places; they commonly contain springs. In valley 3 the writers pulled off a tier of boulders in the center of the hollow during the month of April 1956, and discovered that the lower boulders were embedded in ice. This was at a time when the average monthly temperature is normally well above freezing, and when the streams are flowing.[6]

The present distribution of many of the tree species as well as the forest types is closely related to topography, orientation of slopes, and the nature and attitude of the bedrock. These field relations have high prediction value, but the ultimate cause and effect relations are unknown. For this reason the field relations are stated in terms of coincidences. In theory, these coincidences rest upon differences in physiological processes of the species populations, and ultimately upon evolutionary processes. The obvious unifying principle underlying the relations is water. However, the manner in which the different moisture regimes affect plant distribution is not known in detail sufficient to explain the coincidences. Furthermore, moisture regimes in turn are affected by the basic factors that are of utmost importance in plant physiology, such as intensity and duration of light, evaporation rates, and temperature regimes.

CHANGES IN THE VEGETATION WITHIN THE RECENT PAST

The land now making up the George Washington National Forest, within which lie the areas studied, was acquired following passage of the Weeks Law in 1911. This act was designed primarily to protect the headwaters of navigable streams, and authorized purchase of lands in the Eastern United States that had been deforested by lumbering operations. According to information available to Mr. Richard Elliott, U.S. Forest Service District Ranger (oral communication, 1955), the period of most active logging in the Little River area took place between 1890 and 1910. This was borne out by examinations of growth rings in trees and stumps throughout the area. In 1955 many trees ranged in age from 45 to 60 years. Older trees often showed a sharp increase in ring width at about the fiftieth ring from the bark. This reflects a sudden increase in diameter growth—a "release" in forestry terminology—that often results when surrounding trees are removed or killed. At locality 770, on the North Fork of Little River (pl. 1), a double-stemmed hickory tree of sprout origin showed a piece of narrow-gage railroad rail completely embedded at the base of the closed crotch. Ring counts showed that the sprouts were about 50 years old. The rail presumably is a relic of the era of logging by means of narrow-gage railroads, and was left on the stump of a recently felled tree about 1905.

Charred stumps throughout the area indicate that fires have been common in the forest. Yet a map of forested and cleared areas in the Potomac River basin prepared in 1906 by W. W. Ashe (Parker and others, 1907, pl. X) shows most of the Little River area as "forest land in which the humus has been undisturbed by fire." About one-fourth of the area is shown as "forest land in which the humus has been partly destroyed by occasional fires" and, according to Ashe, less than one-twentieth of the area had been subjected to frequent fires that largely destroyed the humus and ground cover. This suggests that the incidence of fire increased after the period of rapid exploitation of the forest. Fire presumably decreased after inclusion of the area in the National Forest.

After the area was cut over, the chestnut trees were destroyed by a disease affecting the stem. By 1926, 80 to 100 percent of the chestnut trees in the area were infected by chestnut blight (Gravatt and Marshall, 1926). At the present time chestnut is completely absent from the forest canopy. Its former abundance is indicated by the old snags and the many small sprouts that arise from the still-living roots of chestnut trees whose stems have long since disappeared. The sprouts live a few years, sometimes attaining heights of 25 or 30 feet and diameters of 2 or 3 inches, then they in turn are infected by the blight and die.

To what extent did cutting, fire, and disease change the forest? In other words, how much do the present stands differ from the forest that grew prior to the period of rapid exploitation?

Ecological thought is summarized by Braun (1950, p. 192) in a general discussion of changes in the forests of the "Oak-Chestnut Forest region," within which the study area lies:

> The name, oak-chestnut, is used for this region although the Oak-Chestnut association, which characterized it, no longer exists in unmodified form. It is now so changed by the death

[6] Though there are no climatic stations nearby, the mean temperature may be compared with that at Big Meadows, Va., a station in the Blue Ridge at approximately the same latitude and with an altitude of 3,560 feet. During the period 1935–50 the mean monthly temperature for March was 37.5° and for April, 46.3°. These data are from the U.S. Weather Bureau (1952).

of the chestnut that its original composition can be determined only in the areas most recently invaded by blight, and there only because dead chestnut is still standing. The name is retained because it is impossible as yet to predict the final outcome of the partial secondary successions everywhere in progress * * *. Only after several generations of forest could an equilibrium be reached, and the dominants of the new climax be determined.

According to this idea the loss of chestnut has upset the forest organism to an extent that cannot even be evaluated for several generations and death of the chestnut has created a forest completely unlike any that had previously existed. This application of the theories of vegetational development will be discussed on page 6.

Forestry thought generally emphasizes the present scarcity of sawtimber, although concern about degeneration of the resource often is apparent. For example, a U.S. Forest Service report on the forests in the mountain region of Virginia (Lotti and Evans, 1943, p. 5) discusses the changes in the forest:

The original forest of the mountain region in Virginia contained a wealth of timber including oak, chestnut, yellow poplar, hickory, basswood, walnut, white pine, and many other species of relatively large size and high quality. At least 45 billion board feet of merchantable timber were available to the logger. Since settlement, however, the former permanent timber types have been changed to more or less unstable types dominated by inferior species. Forest fires, lumbering, land clearing, and disease have been the principal factors affecting this change.

The present forest is largely second growth, of seedling or multiple sprout origin, containing a scattering of holdovers from the original stand. Small sizes and low quality characterize the saw timber. The present board-foot volume is about one-tenth that of the original stand. For the most part, the forest is confined to the hills and ridges whose poor soils have been rendered still less productive by repeated fires.

"Permanent timber types" is the forestry equivalent of "climax," and "unstable types dominated by inferior species" can be equated with "partial secondary successions." The inferior species, meaning trees of inferior value, include red maple, black birch, black gum, sassafras, hop hornbeam, chestnut-oak, black oak, scarlet oak, scrub-oak, and pin-cherry (Lotti and Evans, 1943, p. 33). However in this assessment of change in forestry terms, the greatest contrasts between the forest of 60 years ago and the forest of today are stated in terms of quantity and quality of wood.

Forests that consist largely of trees less than 60 years old, of course, do not contain as much board-foot volume as old growth forests. Fire damage to stems and a higher proportion of stems of sprout origin to stems of seedling origin in the cutover stands would perhaps tend to reduce the quality of the trees in the second growth forest. Perhaps even more important, the cull trees of the old forest almost surely were left standing. In a sense, the quality of the present forest suffers from the presence of two generations of stems that a logger would consider defective.

The intensity of the logging operations in the Little River area is not known in detail. The use of railroad spur lines suggests a heavy cut. It seems safe to assume that most of the high-quality trees were removed. Trees of small diameter and defective trees of large diameter probably were not cut. In other words, the forest undoubtedly was subjected to a thorough harvest, but was not clear cut in the sense of being denuded of trees.

At present large trees are common in the hollows of first-order valleys and on parts of the flood plains of the larger streams. However, trees of large diameter are not necessarily old. Small trees ignored by loggers in 1890 might be large trees in 1955. Large and old trees of sufficient quality to be cut and sold at the present time do occur in the flood-plain forest of the Little River (table 8). Some of these large trees predate settlement of the region. They occur in stands with small, presumably younger trees of the same species.

Many of the present hardwood stems are of sprout origin, and presumably arose from stumps resulting from the logging operations. For example, almost all basswood trees growing in hollows consist of multiple-stemmed sprouts. A sprout is not a new generation but is only a new stem on an old root system. Thus a small sprout stem may be a part of a large tree that grew in the presettlement forest, whose root system was not killed by cutting its mature stem. This regeneration of stems through sprouting acts to maintain the species composition of a forest through several cycles of growth and harvest, unless cutting is followed by tillage or use as an open pasture. The relative numbers of stems of the different species often change, however, because of inherent differences in vigor of sprouting. Some species produce more and faster growing sprouts than other species.

The field evidence thus indicates that the local distribution of species in the present forests, and hence the distribution of forest types as used in this paper, is very nearly the same as in the old forest that was rapidly cut after 1890. According to the U.S. Forest Service, board-foot volume and quality of the trees that constitute the present forest are much lower than in the old forest. These differences may largely be a function of the age of the trees and not poor management.

The old forest was not uniformly excellent, but like the forest of today showed marked differences in quality between hollows and slopes. Maj. Jed. Hotchkiss, famous as Stonewall Jackson's topographic engineer during the Valley Campaign, is responsible for a description of the forests of western Virginia published in 1876, prior to the time of active logging (quoted by Hough, 1878, p. 467):

> Appalachia is both rich and poor in forestal wealth. On the Sandstone Mountain ranges, and in the slate and shale valleys, the trees are small, but the growth is dense, of oaks and other hard woods, pines, etc., good for charcoal, with larger trees in the hollows and more fertile spots. On the limestone ridges and adjacent valleys, as also in the calcareous and some shale valleys, oaks, walnuts, white and yellow tulip-poplars, birches, beeches, locusts, cherries, sycamores, and other timber trees are found to grow to a large size, often several feet in diameter, and to a great height. Only portions of this region have been reached by railroads, and extensive forests of excellent timber remain without means for reaching markets. There are some forests of white pines and other conifers, but these timbers are not abundant as forests in this region.

Much of this passage could have been written to describe the present forests. Most of the forest growing on side slopes and crests is classed as cordwood, whereas most of the forest growing in hollows is classed as sawtimber. This is true of the present forest, and is shown by the 1940 survey of the forests in the mountain areas of Virginia (Lotti and Evans, 1943). The quotation shows clearly that much of the old forest was of poor form, small size, and low quality.

This similarity is to be expected, perhaps, because differences in the environment within small distances or differences in site quality could hardly have been less effective in determining form and composition of the forests of the past than at present. Although the white man was not a factor in these forests until recently, such things as wind, fire, floodwaters, and Indians acted to keep the presettlement forest in a state of flux. There is no reason to believe that the forest that was cut beginning in 1890 had been stable for any long period of time.

ASYMMETRIC FORMS

Many of the features observed in the mountain valleys of the Little River area, as well as the valleys themselves, are asymmetric. That is, one side of the valley is steeper or has different geomorphic characteristics than the other. A striking example is offered by Hog Run (pl. 1). The east-facing side of this valley is very steep and smooth with no first-order channelways, whereas the west-facing side is gentler and broken by many small first-order valleys. Many valleys in the region likewise have different vegetation on one slope than on the other and have different sizes of surface debris. Put in another way, topography, vegetation, and the mantle of the surficial deposits have variations that are related to directions of the compass, or azimuth.

The writers studied these variations and believe that variations in slope, vegetation, and the coarseness of the surface are related to the availability of moisture in the ground and to the relative importance of the processes that transport soil material. Ground moisture varies considerably for several reasons, including the form of the terrain as discussed on pages 5–7, but with respect to azimuth these variations are controlled primarily by two factors—exposure and geologic structure. Thus slopes tend to be steepest and wettest on the downdip side of ridges where water seeps downdip along the bedding planes to emerge on the slope. Northeast-facing slopes likewise are steeper and wetter than slopes facing in other directions because they are better protected from the drying effects of the sun and prevailing winds.

Variations with respect to azimuth warrant careful analysis because they reveal fundamental relations between factors controlling both the topography and the composition of the forest. The argument to be presented runs as follows: From a study of the vegetation growing on slopes it has been shown that the distribution of many kinds of plants is closely related to topographic form. Similarly, evidence has been presented which indicates that runoff is controlled by topographic form. Some plant species are characteristic of areas where runoff is concentrated; other species are characteristic of areas where runoff is dispersed. It has been argued (p. 29) that within limits the drainage area above a point can be used as an indirect relative measure of moisture regimes. If this argument is accepted, then a few species, including those used to define the units used in plate 1, can be used as rough indicators of wetness and dryness, and we are justified in supposing, for example, that slopes supporting yellow pine forest are drier than slopes supporting northern hardwood forest. It is found that the forest believed to represent relatively dry areas is associated with the gentle slopes, whereas the forest representing the wetter areas is associated with steep slopes. Similarly, in studying the size composition of the surface mantle it was found that the steeper and moister side slopes are generally mantled by finer grained soil than the drier side slopes.

The meaning of these relations will be discussed later after the differences have been described and established. Once the observer knows that it exists, the asymmetric character of terrain, including the surface debris and vegetation, can be seen on the ground. The asymmetry has two components, however, with different azimuths northeast and southeast and the relations are subtle. They were first appreciated by the writers in the field but were not understood until a statistical study of the map area of plate 1 was undertaken. It is appropriate, therefore, to begin the discussion of each asymmetric feature with a brief statistical analysis.

ASYMMETRY IN THE TOPOGRAPHY

In order to resolve the slopes of the Little River area into components of asymmetry, a part of the area of plate 1 was selected for statistical study. The procedure resembled the grid sampling method described by Strahler (1956, p. 589). A rectangular grid containing 100 points of intersection approximately 2,000 feet apart was laid off on the topographic map. The location of this grid is shown in figure 19. The intersection points serve as sample locations within the area included in the grid, and were used to study the asymmetry in the vegetation pattern as well as in the slopes.

The grid sampling method may be objected to on the grounds that it may introduce a bias in the data, because of a possible correlation between the spacing of the grid and the spacing of the topographic features. Because no such correlation was apparent in this case, the grid sample was treated as a random sample.

Each intersection point fell somewhere on a mountain slope. A line was drawn at right angles to the contour lines from the point to the top of the slope and to the bottom of the slope. The contours crossed by this line were then examined and the point located at which the 100-foot contour lines were the closest. This point represents the steepest slope on the line. The horizontal distance between the 100-foot contour lines was measured, and the slope in percent recorded. The direction in which the slope faced (or azimuth) was also measured within a few degrees and recorded. We now had 100 slope values representing an approximately random selection of the steepest slopes on the mountain side. A cumulative frequency curve of the slope values in percent was plotted, and the population was found to be approximately log normal.

The geometric mean slope is 54.4 percent. In order to test whether there were significant differences in slope in different quadrants, the population of 100 slopes was divided into four quadrants selected so as to bring out the greatest variability. The slope values were then converted to logarithms, and the results tabulated as shown in table 9. The mean values for the southeast and northeast quadrants are considerably larger than the values for the southwest and northwest quadrants. Inasmuch as the standard deviations (representing the variability or range in values of the slopes) are large, doubt might be raised concerning the significance of the differences. An analysis of variance, single variable of classification, (Dixon and

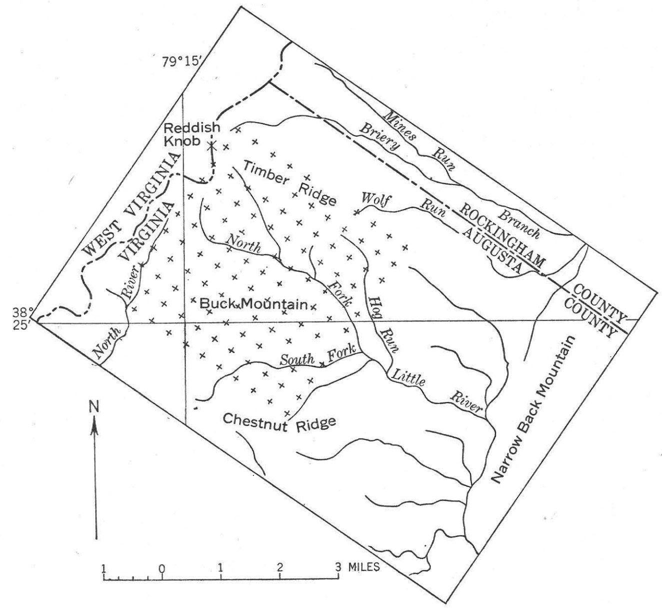


FIGURE 19.—Map of Little River area showing the grid used for sampling slopes.

Massey, 1951, p. 121) gives the results shown in the lower part of table 9, and indicates that significant differences exist between the means of the quadrants at the 95 percent probability level.

The 100 slope values were then analyzed graphically by plotting on a polar projection as shown in figure 20. This plot has been smoothed by averaging the values of all the slopes that are within 30° on either side of the azimuth of the points on the graph. For example, to obtain the value 68 percent at 30° east of north, all the slopes having an azimuth between 0° and 60° were averaged. Each point represents the average of 15 to 25 slopes. In view of the statistical analysis of the data and the large deviation of the slope values, it must be borne in mind that the plot is only an approximation. The plot, however, supports the conclusions drawn from table 9, but in addition suggests that the steepest values are between azimuths of 110° and 170° with a less prominent maximum between 30° and 50°. The averages of these azimuths are approximately northeast and southeast.

Thus a statistical analysis suggests that slopes on the average are steeper on the northeast and on the southeast than they are in the other directions, with the largest effect in the southeast quadrant. The southeast effect can be seen in the Little River area on the ground and on maps. Note, for example, on plate 1 that the small valleys draining Buck Mountain to the north are considerably steeper on the sides that face southeast. The valleys north of the North Fork and north of Hog Run, similarly, are steeper on the southeast-facing sides. In fact, in most of the area this effect is noticeable, and the correlation with the geologic structure is fairly obvious, for in this region the dip of the rocks is to the southeast, as shown in plate 1.

The relative steepness of the northeast-facing slopes is less apparent by casual inspection. Nevertheless it can be seen both in the Little River basin and in areas nearby where the effect of the geology can be eliminated. Narrow Back Mountain, at the extreme southeast end of the Little River area, is underlain by overturned beds of the Hampshire and Pocono formations. On the southeast side the mountain is drained by streams whose course is at right angles to the strike, so that differences in their slopes are presumably unaffected by the geology. Yet it is readily apparent that the valleys are asymmetric and steeper on the northeast-facing than on the southwest-facing sides.

TABLE 9.—*Analysis of variance of slopes*

Data

	Quadrant				All slopes
	NE(10°–100°)	SE(100°–190°)	SW(190°–280°)	NW(280°–10°)	
Number of slopes	27	28	22	23	100
Mean slope ... percent grade	57. 3	62. 5	51. 3	51. 3	56. 1
Coefficient of variation ... percent	18	28	19	19	24
Total value of slopes ... logarithm of percent	47. 0818	49. 8028	37. 4456	39. 1361	173. 4663
Mean slope ... do	1. 7438	1. 7787	1. 7021	1. 7061	1. 7346
Sum of squares of differences ... in logarithmic form	0. 3892	0. 4440	0. 1698	0. 1725	1. 1755
Standard deviation ... do	0. 131	0. 128	0. 090	0. 089	0. 11

Analysis

	Sum of squares	Degrees of freedom	Mean square	Variance (*F*) ratio
Between quadrants	0. 1103	3	0. 03678	3. 0073
Within quadrants	1. 175	96	. 01223	------
Total	1. 2853	99	------	------

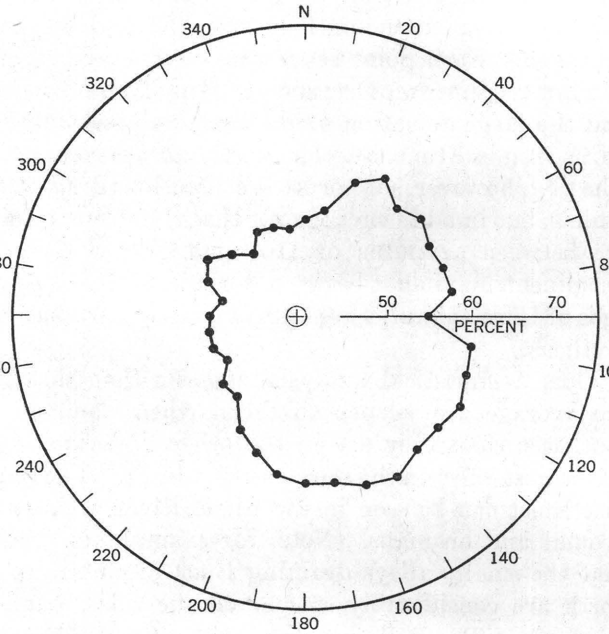


FIGURE 20.—Graph on polar coordinates showing the mean gradient in percent of 100 steep slopes oriented as shown in the diagram. See text for explanation of construction of the diagram.

The northeast effect is more clearly brought out in a mountain ridge known as Shaw Ridge in the Palo Alto area northwest of the Little River area, shown on the Geological Survey's McDowell quadrangle (location shown in fig. 1). This ridge trends northeastward and is underlain by thin-bedded sandstone and shale of Devonian age, that strike parallel to the trend of the ridge. A part of the ridge is shown in figure 21. The ridge is drained largely by small tributaries of the South Branch of the Potomac River that trend northwestward at right angles to the strike of the rocks. Asymmetric topography is evident, the northeast-facing slopes being much steeper than the southwest-facing slopes. This difference must be related to factors other than the geology.

In addition to steepness there is a difference in drainage density between the northeast- and southwest-facing slopes. Note, for example, the first and second valleys on Shaw Ridge south of Palo Alto. These contain streams of the second order. On the southwest-facing side, valley walls are broken by numerous small gullies or first-order valleys. The northeast-facing, steeper valley walls, on the other hand, are smoother and for the most part uninterrupted by tributaries. Probably the difference in drainage density is related to slope length. The southwest-facing gentle slopes perhaps developed so great a length that water flowing from the ridge crest to the bottom of the slope attained sufficient discharge to erode gullies.

The Shaw Ridge area will be discussed again in connection with the asymmetry of the vegetation pattern.

Over the largest part of the Little River basin the northeast-facing effect is not readily apparent in the topography. Buck Mountain, however, is a ridge that trends northwestward at right angles to the strike of the rocks so that differences in form between the valleys that drain off it to the northeast and those flowing to the southwest cannot be attributed to the geology. An analysis of the area including Buck Mountain, enclosed by the North and South Forks of the Little River and by the ridge south of Reddish Knob, does reveal slight differences showing that Buck Mountain is asymmetric. Some of the differences that can be measured are shown in table 10.

TABLE 10.—*Comparison of two sides of Buck Mountain*

	Northeast-facing side	Southwest-facing side
Number of valleys draining each side	11	5
Average drainage area of valleys at point along channel 3,000 ft from ridge crest sq mi	0. 122	0. 174
Drainage density miles per sq mi	7. 0	8. 1
Bifurcation ratio [1]	7. 0	4. 8
Average channel slope of streams at distance of 3,000 ft from ridge crest percent	18	15. 6

[1] Defined by Horton (1945, p. 286) as the ratio between the number of streams of one order to the number of streams of the next higher order.

The most obvious difference is that there are nearly twice as many valleys on the northeast, wet side as on the other. As a consequence, at the same distance from the drainage divide the drainage basins of the northeastward-trending valleys are smaller. The drainage density on the northeast side similarly is smaller. On the other hand, the bifurcation ratio on the northeast side is larger. That is, on the northeast side the major valleys have more tributaries of the next lower order than the major valleys on the south side. These statements are not paradoxical, for the valleys of the south side attain a higher order, most of them being third-order valleys, so that in the same distance from the source the south side of the mountain may have actually more channelways. The stream channels of the larger valleys are steeper on the north side. This difference is in harmony with the smaller drainage areas on that side. These differences can perhaps be summarized in the statement that the drainage network is more developed on the southwest than on the northeast side of the mountain.

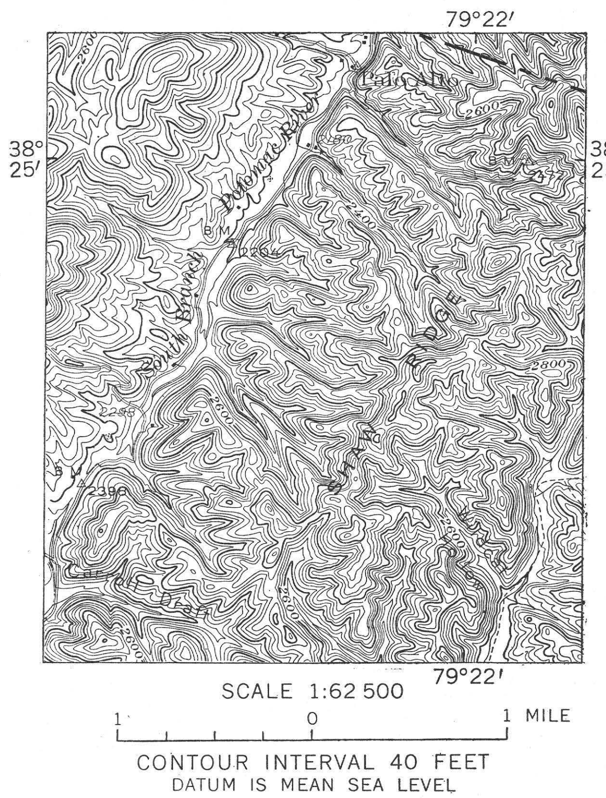


FIGURE 21.—Topographic map of Palo Alto area in West Virginia showing asymmetric valleys. See figure 1 for location.

ASYMMETRY IN THE VEGETATION PATTERN

The asymmetry of the forest vegetation in the Little River area is considerably more obvious than that of the topography, and both the northeast and the southeast components can be seen on the ground. In order to correlate the azimuths of asymmetry with the topography, a graphic treatment similar to the topographic analysis shown in figure 20 was made. Analysis of variance, however, such as was made for the slope values in different quadrants was considered unnecessary.

The analysis of the vegetation is based on the same 100 slopes that were used in the analysis of the topography. Each of the 100 slopes selected by the grid intersections shown in figure 19 may be represented by a line extending from a ridge crest to a valley bottom. Each of the lines crosses at least one, and many cross all, of the three vegetation types shown in plate 1. Therefore, by measuring the total length of each slope (or line) and the length of the part that crosses the yellow pine unit, a measure of the dryness of the slope is obtained. Conversely, the proportion of the line or slope that lies within the northern hardwood unit and

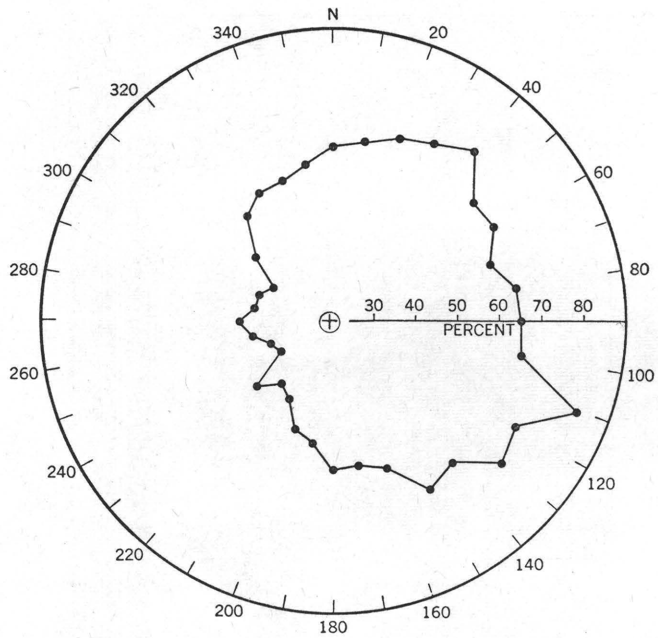


Figure 22.—Graph on polar coordinates showing the mean percentage of the transect covered by moist-type vegetation (oak forest and northern hardwood forest) on 100 slopes oriented as shown in the diagram.

the oak unit is a measure of the wetness of the slope. This measure of wetness is expressed in percent and represents the percentage of the slope distance from crest to foot of slope that is occupied by the two moister forest types. The 100 slopes were measured in this manner to obtain a population of 100 slopes, each having a certain percent wetness as well as an azimuth. This population was then treated graphically in the same manner as the slope steepness. The result is shown in figure 22, a graph drawn on polar coordinates. As in figure 20, each point represents the average of all the values within 30° on either side of the azimuth of the point.

It is immediately apparent on comparing figures 20 and 22 that there is a correlation between the kind of vegetation and the steepness of slopes having the same azimuth. The moist-type vegetation has two maximums, the larger one on southeast-facing slopes and the smaller on the northeast-facing slopes.

On the ground the differences in vegetation with respect to the azimuth of the slope or aspect are readily apparent. These differences are also strikingly shown by plate 1. Both effects are shown, for example, on Buck Mountain. Note that each valley that trends parallel to the strike of the rocks in a northeastward direction is covered on the northwest-facing or updip side mostly by the yellow pine unit. The opposite, downdip side is covered mostly by the wetter oak unit. This is the effect of the geology, the stronger of the two effects. An observer examining a distant view of these mountain valleys in a direction parallel to the regional strike gets the impression that the mountains are like a washboard, with each northwest-facing slope being solidly covered by a stand of yellow pines.

The lesser effect, that of exposure, may also be clearly seen in Buck Mountain. Note that all the valleys draining the mountain to the northeast have in them large areas of the northern hardwood unit, whereas the valleys draining to the southwest have much smaller areas of this unit. This effect occurs in spite of the fact that hollows are larger in area on the southwest side.

Large differences in the vegetation that are due to exposure were observed in the Shaw Ridge area already described on page 36. In this area the south-west facing slopes along the road east of Palo Alto support an open forest containing pitch, table-mountain and scrub-pines, chestnut-, black, red, and scarlet oaks (yellow pine forest). Ericaceous shrubs are abundant. The northeast-facing slopes support chestnut-oak, red oak, white oak, red maple, and white pine (oak forest). Hemlock is abundant. The southwest-facing slope measured 26° in steepness, whereas the northeast-facing slope measured 31°.

Less striking evidence of asymmetry is common in the Little River area. Valley 10 (pl. 1), a definitely asymmetric valley, is tributary to the North Fork of Little River, to the south of Hog Run. Downslope from the hollow, the writers made a traverse down the northwest-facing slope and up the southeast-facing slope. Table 11 shows the composition of the forest at the localities sampled on the nose (station 1), the side slope (stations 2, 4, and 5), and the foot slope (station 3). The nose and side slopes support yellow pine forest, but the amount of pitch-pine and table-mountain pine ranges from 2.4 to 31.6 percent of the basal area in the samples. Pitch-pine and table-mountain pine constitute more than 30 percent of the basal area of the forest on the nose, and the forest extends with little change down the northwest-facing slope as far as the lower side slope (station 2) where the amount of pine is much less. On the southeast facing side slope the amount of yellow pine never exceeds 3 percent of the basal area in the samples. Yellow pines are absent from the forest growing on the foot slope.

Asymmetric distribution of vegetation in the Little River area also is well shown by the northern hardwood forests of hollows and flood plains. Northern hardwood forest growing in hollows generally extends considerably farther from the central axis of the hollow in a direction leading toward a downdip slope or toward a slope with a northeast exposure. The flood-plain forests generally extend a short distance up the mountain slopes on the moister and northwest sides.

TABLE 11.—*Vegetation data from traverse across valley 10 showing species composition, in terms of percentage of basal area in sample*

[×, present in the stand, quantitative data lacking; U, present as shrubby ground cover; Tr., comprises less than 1 percent of the basal area]

Species	Nose (station 1)	Side slope, northwest facing (station 2)	Foot slope, northwest facing (station 3)	Side slope, south east facing (station 4)	Side slope, south facing (station 5)
Red maple	4.8	×	8.3	----------	----------
Table-mountain pine	27.1	×	----------	2.4	1.5
Pitch-pine	4.5	×	----------	----------	1.5
Scarlet oak	36.3	×	----------	2.5	4.5
Chestnut-oak	22.0	×	63.1	79.4	67.8
Scrub-oak	U	----------	----------	U	U
Pignut	Tr.	----------	----------	10.3	16.8
Black gum	1.5	×	4.7	Tr.	----------
White oak	3.0	----------	----------	4.9	----------
Shadbush	Tr.	----------	Tr.	----------	----------
Red oak	----------	×	----------	Tr.	----------
Black oak	----------	×	----------	----------	5.8
Scrub-pine	----------	----------	----------	----------	1.4
Black locust	----------	----------	18.6	----------	----------
Witch-hazel	----------	×	Tr.	----------	----------
Sassafras	----------	----------	Tr.	----------	----------

ASYMMETRY IN THE TEXTURE OF THE SOIL MANTLE

In the course of traverses across the Little River area, the writers were impressed that the ground surface was generally stonier in the yellow pine forest than in the oak forest. The great local variation in the size of the cobbles on the ground, and the powerful effect of the size of the drainage area above the slope, obscured the differences. These variations made it impossible to reach a conclusion as to whether real differences with respect to the asymmetry actually did exist. The question was resolved by studying four valleys that are tributary to the North Fork of the Little River and that enter the river from the northeast (localities 802, 803, 808, and 809). These valleys are all small valleys of the first order. They are cut in shale interbedded with highly permeable, thin-bedded flaggy sandstone that dips gently southeastward, so that the effect on the differences in moisture of the two valley sides is especially pronounced. As a consequence, the asymmetry is especially well developed. A view looking across the flood plan of North Fork toward and into the axis of one of these valleys is shown in plate 3*A*. Note that the gentle slope on the right supports yellow pine forest. The forest growing on the steeper slope on the left consists mostly of oak.

Differences in soil materials on gentle northwest-facing and on steeper southeast-facing slopes were studied by an analysis of variance of randomly selected particles near the base of each of the two sides of the four valleys. The field procedure was to enter each valley to a point above the mouth beyond the round of the intervalley spur where the side slopes are straight. A point was chosen above the base of each slope about 100 feet away from the stream. No special effort was made to "randomize" these locations, as they were of necessity selected where underbrush was thin enough for the work to be done. At each locality a tape 50 feet long was stretched diagonally up the slope, and the grains, pebbles, or cobbles that lay beneath each foot marker on the tape were measured. Two of these traverses were a little short because of obstructions at one end. Each particle selected in this manner was tallied and classified according to size. The size classes are based on the phi scale (Krumbein and Pettijohn, 1938, p. 84) and are bounded by limits half way between each whole phi unit, so that the average of each class interval is a whole phi unit. All particles smaller than −1.5 phi units were assumed to have an average size of −1 phi unit (2 mm). This assumption is, of course, not strictly true; but since the number of such particles was relatively small, the error introduced is not large. The complete data obtained on each of the sides of the four valleys are shown in table 12. The table shows that all the means on the four southeast-facing (steep) slopes are less than any one of the means on the four northwest-facing (gentle) slopes. Analysis of variance (Dixon and Massey, 1951, p. 134) of the data in table 12 shows that the differences in mean size of the particles between the steep and gentle slopes are significant at the 99.5 percent probability level. The difference in means between the valleys are not significant at the 95 percent probability level.

The differences between opposite slopes at these valleys can be observed and appreciated by careful inspection of the ground. The gentler northwest-facing slopes are covered by more flags and rock particles than the opposite more loamy slopes.

The differences in texture described here are of course related to the effect of geologic structure. Differences due to the effect of exposure were not observed in the Little River basin, but are clearly visible on the ground in the Shaw Ridge area (fig. 21). The valley southeast of Palo Alto has relatively fine grained surface material on the steep northeast-facing slope and on the basis of field inspection is described as a silty clay loam. The material on the opposite gentler slope is a stony silty clay loam, and numerous rock particles of pebble size are scattered on the surface. The writers believe, therefore, that the texture of the mantle in these mountain areas differs in a manner related to the asymmetry of the vegetation and the topography. It is less apparent than the other phenomena because overshadowed by the much greater textural differences related to geology and to drainage area and surface form described on page 5.

TABLE 12.—*Data for analysis of variance of the texture of soil material on opposite sides of four valleys*

Particle size, in phi units, and number of particles in samples from indicated localities								
Valley at locality 802		Valley at locality 803		Valley at locality 808		Valley at locality 809		Total or average
Average size	Number	Average size	Number	Average size	Number	Average size	Number	
Northwest-facing or gentle slopes								
−1	6	−1	4	−1	4	−1	5	------
−2	1	−2	0	−2	0	−2	0	------
−3	2	−3	1	−3	2	−3	2	------
−4	5	−4	7	−4	3	−4	6	------
−5	11	−5	8	−5	14	−5	10	------
−6	9	−6	15	−6	15	−6	17	------
−7	9	−7	13	−7	12	−7	10	------
−8	3	−8	3	------	------	------	------	------
−9	2	------	------	------	------	------	------	------
Total[1]	−248	−280		−266		−257		1,051
Mean[2]	−5.16	−5.49		−5.32		−5.14		−5.28
Southeast-facing or steep slopes								
−1	14	−1	4	−1	8	−1	7	------
−2	1	−2	2	−2	1	−2	1	------
−3	2	−3	4	−3	9	−3	4	------
−4	3	−4	7	−4	12	−4	10	------
−5	8	−5	13	−5	8	−5	17	------
−6	12	−6	9	−6	6	−6	8	------
−7	4	−7	4	−7	6	−7	3	------
−8	2	−8	2	−8	1	------	------	------
Total[1]	−190	−211		−211		−215		−827
Mean[2]	−4.13	−4.16		−4.13		−4.30		−4.30

[1] Total of average sizes per number of particles.
[2] Size in phi units.

RELATION OF ASYMMETRY TO MOISTURE CONDITIONS AND THE PROCESSES OF EROSION

Asymmetric valleys have been noted by many geologists. Thornbury (1954, p. 112) notes the general occurrence of valley cross profiles in which the north-facing sides are steeper than are the south-facing sides, and he attributes this asymmetric character to exposure and climatic conditions. Judson and Andrews (1955, p. 333) have recently described such valleys in Wisconsin. There has, however, been little attempt at analysis of the processes that cause the asymmetric forms. The valleys of the Little River area perhaps offer an unusual opportunity for analysis as there are two components in the pattern of the asymmetry by reason of which some of the possible causes of the asymmetry may be isolated.

Availability of soil moisture appears to be the most important variable to which the other factors are directly or indirectly related. This is suggested primarily by the distribution of vegetation. The moistness of an area is determined at any place by the rate at which water enters the ground and the rate at which water is lost. Where exposure, geology, and climatic factors are the same, hollows are moister than side slopes because larger quantities of water are available during rains and during the melting of snow, and the water accumulates due to slow percolation under the influence of gravity; also the coarser texture of the soil in such places favors infiltration. On the other hand, where the amount of runoff is constant, the moister areas are those where evaporation is inhibited by lower soil temperatures and there is protection from the wind. Extreme conditions occur where the two effects work together as in deep northeast-facing hollows or on sharp southwest-facing ridges. The effect of seepage through porous rocks is equal to or is more important than exposure, for such rocks form reservoirs for water that may outlast the driest seasons. The diabase sill shown in figure 24, for example, defines a break in moisture on the slope, indicating that seepage along the surface of the sill and below the level of the sill supplies the greater moisture required for trees that constitute the oak forest unit.

The texture of the soil, on the other hand, appears to be more closely correlated with topographic form than with exposure. The coarsest debris occurs in the hollows regardless of the exposure or the geology. The differences in soil on opposite sides of asymmetric valleys are not nearly so great as the differences in vegetation. The differences in texture, therefore, may be primarily related to the amount of runoff rather than to the duration of soil moisture. The coarse debris in the hollows is attributed to the sorting effect of the large discharge through and over the debris during heavy precipitation. This effect may also be partly or wholly responsible for differences on opposite slopes, owing to the greater slope length of the drier and gentler slopes that permit somewhat greater concentration of runoff near the base. The slope is more stable because disruption of the vegetation and movement of the mantle occurs only during heavy rains at infrequent intervals. Furthermore, considerable washing of the fine-grained material may go on without disturbing the vegetation cover. This difference in effectiveness of creep versus surface runoff or rill wash may well account for the differences in soil texture, for creep favors the transport of coarse material as well as fine. Sheet wash and rill wash, on the other hand, leave the coarsest material behind, performing a sorting action. Presumably further lengthening and flattening of the drier slope would result in the dissection of the slope by gullies that eventually would grow into valleys of a lower order.

If processes of mass movement are considered as equally important in erosion of these valleys as the work of running water, the several phenomena are perhaps more easily understood. Mass movement of rock waste must go on wherever there is a slope, and in these mountains we can suppose, although we have little data, that is important and that the convex-upward profiles of the slopes are related to this process, as suggested by Gilbert (1909, p. 345). Consider the difference in vegetation on opposite slopes of asymmetric valleys. The gentler dry slope is covered by dense thickets of pitch- and table-mountain pine and heath. The ground is held by closely spaced gnarled roots and branching stems of laurel and other ericaceous plants that form, in places, dense thickets, which suggests that the drier slope is more stable or is stable for longer periods. The opposite wetter slope is open with few obstructions on the ground, so that one may see through the forest for hundreds of feet or even yards, and the heath is less dense or is lacking. Probably the steeper wet slope is less stable, whether as a consequence of the sparse heath vegetation or as a direct consequence of greater moisture. Material is removed largely by creep; at least creep is relatively more important. On the drier slope which, on the average, is twice as long, creep is less effective either because of the direct effect of lesser frost or the indirect effect of denser vegetation. Surface runoff falling at a rate heavy enough to exceed the infiltration capacity of the soil is able to remove finer particles from the ground surface.

Probably, however, the asymmetric valleys may be regarded as a graded terrain in which the slopes are adjusted to carry rock waste from the ridge crests and all parts of the valley through the channelway to the master stream. The ridge crests are being lowered by chemical and mechanical weathering, creep, and sheet erosion during heavy rains. The channelway is eroded by the action of running water, a process that is most effective during infrequent but violent rains. The difference in altitude between the ridge and the channelway is determined by the relative rates of lowering of the two places. Similarly, the form of the slopes across which the rock waste must be transported is determined by the relative rates of activity of different processes; on those slopes that are moist a large part of the year and protected from the sun, mass movement is more important. The effectiveness of this process is proportional to the steepness of the slope. On the opposite side of the valley, sheet erosion and rill erosion are more important; the effectiveness of these processes increases in proportion to discharge, a function of drainage area or slope length. Therefore, on the dry side of the valley the rock waste is transported on a gentle but longer slope, whereas on the moist side it is transported on a steeper but shorter slope.

Table 13 summarizes the most important differences between the opposite slopes of the asymmetric valleys.

TABLE 13.—*Summary of characteristics of opposite sides of asymmetric valleys in the Little River basin*

Characteristics	Northwest- or southwest-facing slopes [1]	Northeast- or southeast-facing slopes [1]
Declivity	Gentle	Steep.
Moistness	Dry	Wet.
Surface mantle of stones.	Coarse	Fine.
Predominant vegetation.	Yellow pine forest unit.	Oak forest unit.
Density of cover	Dense, many shrubs.	Open, few shrubs.
Drainage density	High	Low.
Drainage network	Well developed	Less well developed.
Postulated most important process.	Slope wash and channel erosion.	Creep.

[1] Differences between northwest and southeast characteristics are related to the prevailing southeasterly dip of the rock strata. Differences between northeast and southwest characteristics are related to exposure.

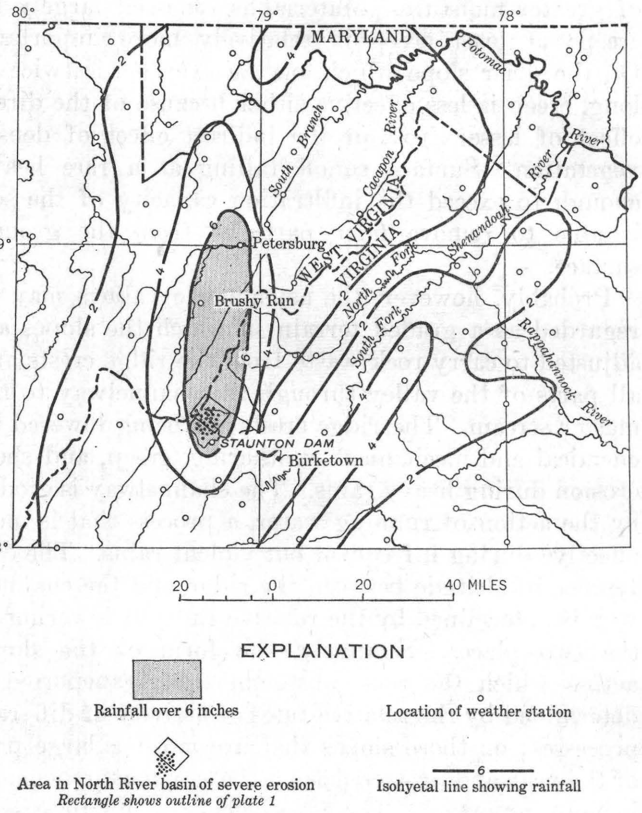


FIGURE 23.—Map of parts of Maryland, Virginia, and West Virginia, showing total rainfall during June 17 and 18, 1949. Data from U.S. Weather Bureau, (1949).

EROSION AND DEPOSITION IN THE FLOOD OF JUNE 1949

During the night of June 17–18, 1949, the Little River basin was the center of a violent rainstorm of rare frequency. Although records of rainfall during this storm are scant, the highest rates of runoff ever recorded in Virginia occurred at this time in the headwaters of the North River. Brief descriptions of the storm have been published by the Weather Bureau (U.S. Weather Bureau, 1949, p. 82) and by the Virginia Division of Water Resources (Mussey, 1950). The effects of the same storm on an area in West Virginia have been described by Stringfield and Smith (1956).

Although the storm covered a wide area, the highest intensity was within the basin of the North River, mostly in the Little River basin within the area shown on plate 1. The storm caused something over 100 landslides, tore up the bottoms of many valleys, and destroyed hundreds of acres of forest land. The flood area was first visited by the writers in 1954 when the damage was still quite fresh. It was apparent that many erosional features as well as depositional landforms, such as debris fans and bottomland ridges and terraces, resulted from the 1949 flood. These are familiar features of the Appalachian Mountains landscape whose origin was not understood by the writers until they were seen in the wake of a flood competent to produce them. The Little River basin was selected for this study because of the opportunity to study the effects of such a flood, and the possible importance of similar great floods in the erosional history of the Appalachian Mountains.

DESCRIPTION OF THE FLOOD

The June 1949 flood resulted from a storm that affected a large area in western Maryland, West Virginia, and Virginia. Isohyets for the 48-hour period July 17 and 18 are shown in figure 23. Severe damage to slopes and valley bottoms occurred in the North River basin and also in the Petersburg area of West Virginia, though the damage in the latter place was less spectacular. Stream-gaging stations and rain gages unfortunately were not within the areas of heaviest damage. The nearest gage, at Staunton Dam, recorded a total of 7.24 inches in the 24-hour period ending at 8:00 a.m. on June 18. This includes the time of greatest intensity of rainfall. A point rainfall of this rate is in itself not a fall of remarkable intensity, and judging by the damage done, the rainfall in the center of the storm was much larger. Rainfalls as high as 50 inches in this period of time have been recorded, and rain exceeding 30 inches fell in 4½ hours at Smethport, Pa., in July 1942 (Jennings, 1950, p. 5). Estimates of discharge were made at localities nearer to the center of the Little River area after the flood (Mussey, 1950, p. 12) and are more pertinent. A discharge of 1,840 cubic feet per second per square mile occurred on Coal Run (pl. 1) at a drainage area of 2.4 square miles. This, however, was not in the region of heaviest damage. The Little River itself at a drainage area of 25 square miles reached a maximum of 1,320 cubic feet per second per square mile. These discharge rates are comparable with the maximum discharges during the Smethport flood of 1942 at similar drainage areas, (Eisenlohr, 1952) and exceeded peak rates of the New England flood of August 1955 (U.S. Geol. Survey, 1956, table 2, p. 10–29).

The estimated discharge of the Little River near its mouth reached 32,900 cubic feet per second. This discharge occurred in a valley 800 feet wide where the normal channel width is about 50 feet. The extraordinary size of the flow may perhaps be appreciated by considering that it is over three times the average annual discharge of the Potomac River at Point of Rocks, Md., where the Potomac has a drainage basin of 9,650 square miles.

As is generally the case in floods in small drainage areas, the distribution of runoff was spotty. Mines

Run (pl. 1), 3 miles from the center of the heaviest damage, rose only 2 feet above low water (Mussey, 1950, p. 10). The North River in its lower course had a record-breaking flood that damaged property in excess of $2 million and killed 3 persons. In this part of the storm area, however, the 48-hour rainfall was only about 2 inches. The confinement of excessively heavy precipitation and resultant flash floods of this type to areas of small size is not unusual, but is the rule. Recent studies of thunderstorms (Byers and Braham, 1949) have shown that precipitation in thunderstorms is associated with individual storm cells of small diameter, and this fact probably accounts for the large variation within small areas.

The recurrence interval of great floods like the 1949 flood is a climatic factor of greatest importance, because of the effect of such floods on the composition of the forest and on the form of slopes, as well as their importance as geologic agents. Existing climatic records in the region are clearly inadequate for an accurate estimate of the recurrence interval. Nevertheless an idea of the order of magnitude of the recurrence interval can perhaps be obtained.

Studies of rainfall intensity and frequency covering the entire United States (Yarnell, 1935, fig. 59) indicate that in northern Virginia a 24-hour rainfall of 6 inches may be expected to recur on the average every 100 years. The intensity of the 24-hour rainfall increases southward and is about 9 inches in the Great Smoky Mountains of Tennessee-North Carolina. As the 24-hour rainfall in the area of severest damage in the Little River basin must have been much greater than the 7 inches recorded by the nearest rain gage, the recurrence interval of the Little River flood probably is longer than 100 years.

This conclusion agrees with an estimate of Mussey (1950, p. 20), based on an analysis of the streamflow records near Burketown. This gaging station is in a downstream reach (fig. 23) where the drainage area is 416 square miles, and it is a long way from the severely damaged area. Mussey's estimate of the recurrence interval at Burketown is 80 years. The much more intense flood of the Little River at a drainage area of 25 square miles may have a much longer recurrence interval. Accurate flood records have not been kept for a long enough period of time to give us comparative data that might be used to judge the recurrence interval of the Little River flood. The problem of estimating these frequencies is discussed by Hoyt and Langbein (1955, p. 59–66), and, as indicated by their figure 20, the 1949 Little River flood is of the same order of magnitude as the largest discharge ever recorded in a drainage basin of the same size. Study of the forests in the Little River basin suggests that no storm producing comparable damage occurred prior to 1949 within the life span of the trees now standing. Many stands of old hemlock on the flood plains of nearby undamaged areas suggest that extraordinary floods have not occurred within the last 150 years.

These considerations suggest a long recurrence interval for the 1949 flood. This interval is longer than 100 years and might be much longer. On the other hand, certain landforms and the deposits on them that may be seen within the Little River valley and similar mountain valleys suggest that extraordinary floods of comparable size and recurring phenomena and, in fact, have occurred in the same place rather recently. Fresh debris fans, unweathered and lacking any noticeable soil profile but now covered by old trees, are perhaps the most convincing evidence. They are described on page 58.

FLOOD LANDFORMS ON SLOPES

CHUTES

The most spectacular remains of the 1949 flood are the many scars or chutes on the mountain slopes resulting from the avalanching of debris. In 1955, 6 years after the flood, they were still prominent features for they were thickly covered with tree seedlings less than 7 years old. More than 100 of them were formed during the flood. The chutes are areas on the mountainside in which the trees and the surficial mantle of soil, rubble, and boulders have been partially or completely removed by slides. Generally a chute extends from a short distance below the ridge crest all the way down to the channelway.

Most chutes are trough shaped, only a few feet deep, and are typified by the chute shown in plate 3*B*. They may range in width from 20 feet to over 1,000 feet, though they are judged to average about 50 feet. They are commonly bordered by ridges of stones like levees 1 to 3 feet high which were pushed aside onto the bordering stable ground as the slide advanced. Such border ridges are characteristic features that aid in the recognition of older slides now overgrown by trees.

As shown in plate 1, chutes are most numerous in the hollows, where they may join together and merge with the channelway. Some chutes begin lower down the mountain at an impervious layer, or at some place where sliding of debris was encouraged by geologic conditions, such as the base of a resistant sandstone bed. Many of the chutes are associated with small or incipient hollows on side slopes, and their location is favored by indentations or irregularities on the slopes that cause the concentration of runoff. Some chutes occur adjacent to long grooves that appear to be the remains of an older chute now overgrown with trees and unaffected by the 1949 flood. The typical pattern of the chutes and their relation to drainage channels and other flood features are shown in plate 4.

Another striking correlation that may be seen by comparing the geologic map and the map of the flood damage on plate 1, is the relation of the chutes to the Hampshire formation. To the writers' knowledge no chutes of any magnitude occur in the Pocono formation. They are generally confined to the Hampshire formation, though the slides that formed the chutes in many places included sandstone boulders derived from the overlying Pocono. This may be partly because the area of maximum precipitation coincided with the area in which the outcrop of the Hampshire formation is most extensive. Probably the alternating shale and sandstone of the Hampshire formation favor sliding and the formation of chutes, whereas the more massive sandstone of the Pocono does not, or does so to a lesser degree. Inasmuch as the Pocono commonly forms coarser blocks on weathering, it may be more stable during times of heavy runoff and thus was not affected as much by the 1949 storm.

The chutes were produced by a kind of landslide called a debris avalanche by Sharpe (1938, p. 61). This type of slide characteristically occurs in humid climates and is accompanied or preceded by heavy rains. Such slides have been of common occurrence in the Appalachians, especially in the Great Smoky Mountains, and in New England, and they invariably are associated with intense rainfalls and flash floods (see, for example, Cleland, 1902; Moneymaker, 1939; and U.S. Geological Survey, 1949, p. 14). In the writers' opinion many examples of debris avalanching have gone unnoticed by scientists and are not recorded in the geologic or hydrologic literature. Chutes similar to those in the Little River area have been observed in many places in southwestern Virginia and eastern Tennessee. Four debris avalanches occurred in the Pocono Mountains of Pennsylvania during the great storm associated with hurricane Diane, August 18–19, 1955, and they are described on page 55.

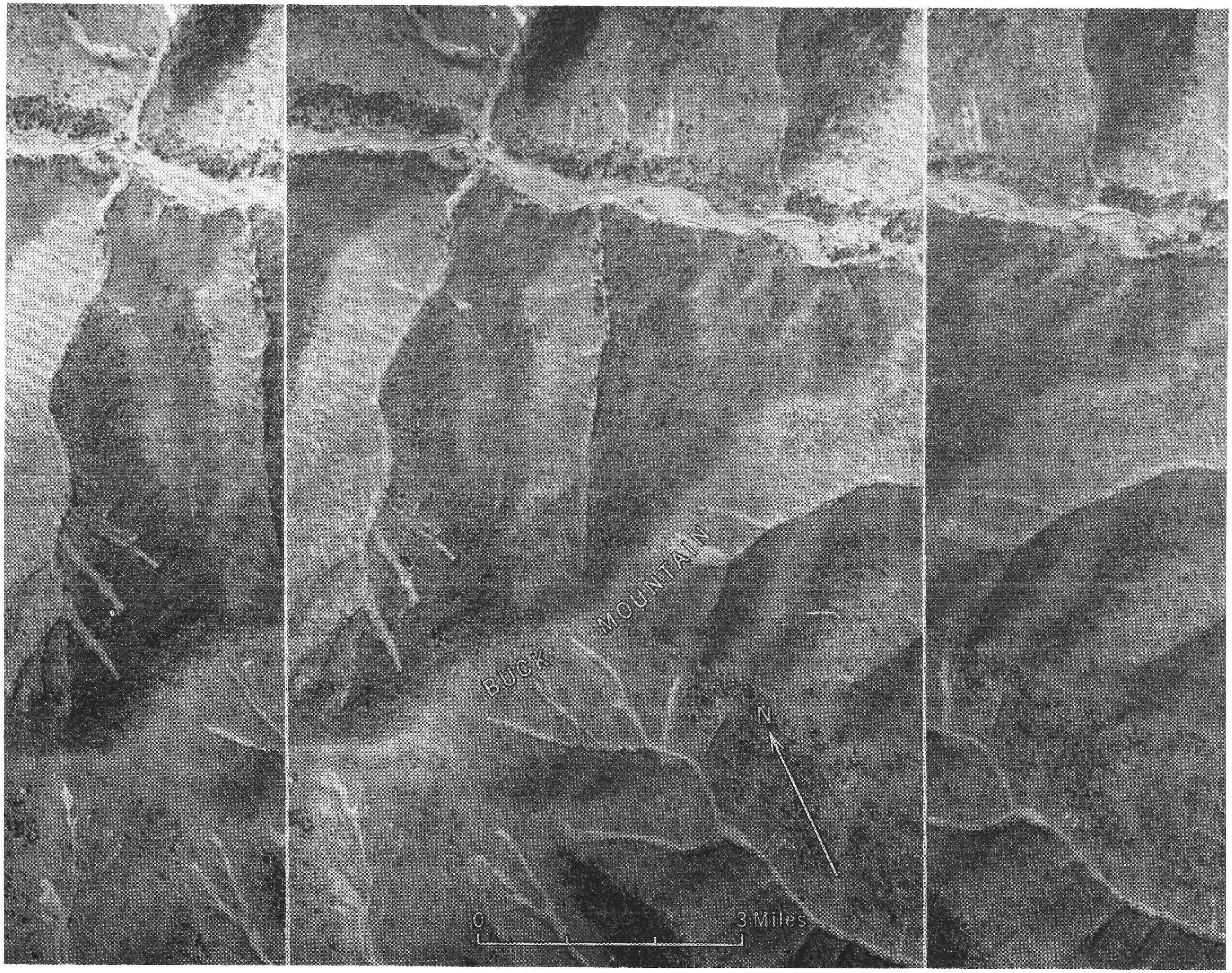
The forces involved in the debris avalanches of the Little River area are certainly not well understood. It is known, however, that they are associated with extraordinary runoff, as are all slides of this type that have been described in the Appalachians. They were in some places a result of oversteepening at the base of the slope, caused by bombardment and erosion by a flooded stream. In other places they were caused by the removal of debris where the runoff was concentrated, as in the upper part of a channelway, or in a hollow. The frictional resistance of the vegetation and its ponding effect during large flows of water may have been an important foctor. In hollows where coarse boulders occur with little fine-grained interstitial material, the protecting mat of humus and leaf litter may locally have caused hydrostatic pressures to build up.

Though the chutes are for the most part free of flood debris, the material transported by avalanching was not everywhere completely removed. Where the chute lies above a flat or gently sloping valley bottom, a large pile of stones and broken trees is generally present. Old slides formed by floods before 1949 have been located by such forested piles of debris. Where sliding occurred directly above an open stream channel, the flow was generally competent to carry away all the debris.

Where avalanching occurred in hollows, the chutes form a branching pattern, as though an extension of the stream network. They coalesce in a downslope direction or merge with channels. In these situations, as the avalanche moved downslope the accompanying discharge increased, so that generally the stream draining the hollow was competent to carry away all the debris. Debris is not always removed, however, and in many valleys there are coarse accumulations of boulders and plant debris that were spread across the stream channel or the lower part of a hollow. Such an accumulation in valley 4 is shown in plate 5*A*. The main avalanche was halted in the upper left hand corner of the area of this photograph, and formed a tangled mass of trees and boulders. The boulders in the forground spewed out below the main accumulation, filled in the existing small channelway, destroyed the shrubs and small trees, but left the larger trees standing. Partial sliding of debris in this manner was common, and it is probable that this process may account for some of the transferral of coarse debris from the upper slopes of a hollow to the lower slopes.

In 1955, 6 years after the formation of the chutes, the damage still appeared remarkably fresh. Young trees, many of them 4 to 5 years old, grow in the chutes. Gullies have formed, and the exposed ledges of rock are breaking up by weathering. Presumably, forest trees eventually will re-cover the surface of the chute, and blocks of rubble will gradually accumulate to form a continuous debris mantle.

The chutes now constitute natural drainageways on the slopes. Most of the chutes occupy former depressions or groovelike areas, and the impression is inescapable that the chutes are indeed incipient hollows or channelways, that were partly obliterated during the passage of time by falling blocks and mass movements. They are, at rare intervals of time, flushed out and deepened by heavy runoff and the avalanching of debris.



AERIAL PHOTOGRAPH (STEREOTRIPLET) SHOWING PART OF BUCK MOUNTAIN AND THE NORTH FORK OF THE LITTLE RIVER

The top of the photograph faces northeast. The view shows the pattern of chutes, damaged stream channels, and debris fans typical of the most severely damaged area. Viewed stereoscopically the photograph shows the asymmetry of the first-order valleys.

A. VIEW UPSLOPE OF ANGULAR DEBRIS

Debris is in valley 4 on north side of Buck Mountain; it was transported during the flood of June 1949 by debris avalanches and deposited in the channelway below a debris dam of trees and shrubs. Note the absence of small trees and shrubs.

B. VIEW OF CHANNELWAY

Channelway is in lower part of valley 5 about three-fourths of a mile from ridge crest at head of valley. Bedrock exposed and valley walls steepened by the 1949 flood.

WATER BLOWOUTS

Another common feature of the slopes produced by the 1949 flood are holes in the debris mantle averaging about 50 feet in diameter. Similar features occur in the Smethport, Pa., region and are described by Eisenlohr (1952, p. 77–78), who termed them "blowouts." Since this term may be confused with blowouts formed by wind action, the term "water blowout" is used here. These features characteristically are semicircular in plan. The upslope side is a crescent-shaped scarp generally exposing the bedrock at its base. The downslop side is a pile of debris that has slumped or been thrown out of the cut or break. Water blowouts show no evidence of erosion or break in the ground cover either above or below. Eisenlohr believes that they form as a result of hydrostatic pressure at geologically favorable horizons where water in the ground is concentrated at one point by intersecting fractures. He noted in Pennsylvania that they occurred in rows along the bedding planes, and that observers had seen the blowouts burst forth.

The water blowouts in the Little River area may have this same origin, though they occur on forested slopes rather than in sod-covered fields. Possibly they are merely small chutes that end at the base against a ledge of resistant rock. On the other hand, the prominent bedding planes and the well-developed fracture pattern that are characteristic of the Hampshire formation in this area lend credence to a hypothesis involving hydrostatic pressure such as suggested by Eisenlohr.

A row of water blowouts on a side slope near the junction of the North and South Forks of the Little River (locality 752) was studied in detail and is shown on a planetable sketch map (fig. 24). At locality 752, three water blowouts are present on a 40° slope on the Hampshire formation, about 80 feet above the flood plain of the Little River. The water blowouts are localized along a sill of diabase (described on p. 4). The map also shows the location and kind of every tree larger than 6 inches in diameter, and whether there is landslide debris caught behind the tree. Though not shown, the mountainside continues on up beyond the top of the map.

The distribution of tree species, shown in figure 24, suggests that there is a sharp break in moisture conditions directly above the diabase sill. The forest growing on the side slope, both above and below the sill, consists predominantly of oaks. However, note that pitch-pine, table-mountain pine, and black oak grow only above the sill. These species grow in dry environments such as noses and crests. Hemlock and tulip-tree grow only below the sill; also all but one of the white pine trees grow below the sill. In the Little River area, tulip-tree is absent from noses and crests, and almost completely restricted to flood plains. Hemlock and white pine are most abundant on flood plains, and rare on noses and crests. Thus the oak forest type growing below the sill contains several species characteristic of the flood-plain forest that are rare or absent from the yellow pine forest type growing above the sill. This may be the result of groundwater seepage out of the Hampshire formation above the impervious diabase that supplies moisture to the soil on the entire slope below.

Consider now the condition of the upslope side of the tree trunks. Figure 24 shows, in addition to the tree species, those trees that are scarred on the upslope side and those that have rocks leaning against the upslope side. First note that most trees on the flood plain have debris piled against them on the upstream side, and are scarred. The scars reflect destruction of the bark in a zone extending from about one-half or one-third the circumference of the tree as much as 2 or 3 feet above the ground. The debris piles generally consist of 2 or 3 boulders or a small pile of gravel leaning against the trunk. On the slope, with a few exceptions, fresh scars and piles of stones occur only below the blowouts. They do not occur above the blowouts or on the lower slopes away from the blowouts. These scars and piles are evidence that considerable debris moved down the slope from the blowouts without causing any damage to the ground. This argument is further supported by the distribution of small trees. Trees 0.5 to 2 inches in diameter occur above and to the side of the blowouts, but not below them where they have been removed by the falling debris. Table 14 shows the composition of the forest at two places on the sketch map area below the line of blowouts. One sample was taken immediately downslope from the westernmost blowout and the other from the undisturbed side slope. Note that only 1 tree in the diameter classes 0.5 to 2.0 inches appears in the sample below the blowout, whereas 34 stems in these size clases are present in the sample located downslope and to the side of the blowout. Below the blowout are many small stems, all broken off or bent over and buried under debris. Most of these are dead, but a few support vertical live sprout stems less than 0.5 inch in diameter. This indicates that the movement of debris downslope from the blowout destroyed most of the smaller stems in the forest stand. Trees larger than about 2 inches in diameter withstood the destructive force of the moving debris and were at most damaged on the upslope side. Note further that stems 0.25 to 0.5 inch in diameter are more numerous below the blowout (57 stems) than to one side (32). Ring

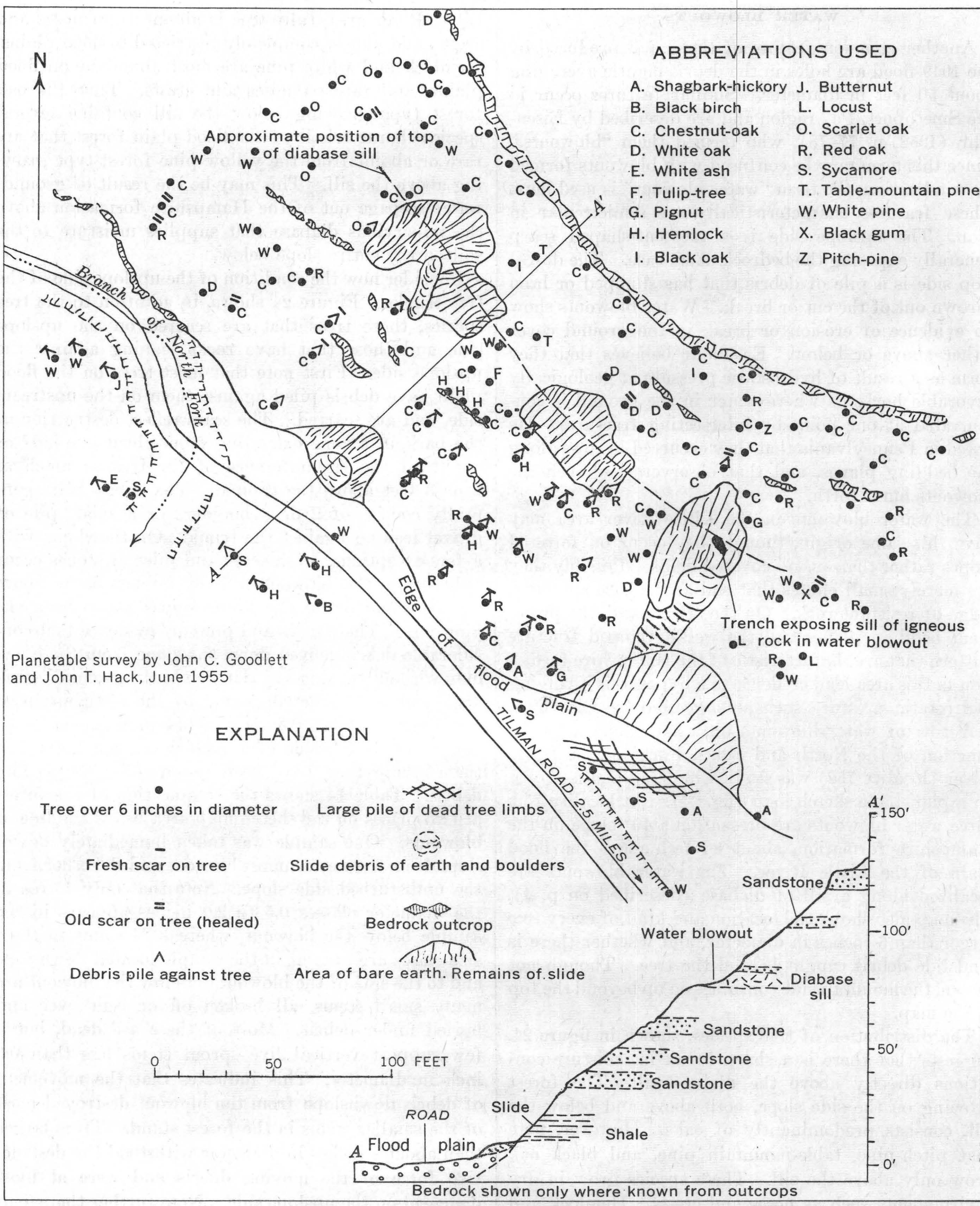


Figure 24.—Map and geologic section of lower part of slope near junction of North and South Forks of the Little River at locality 752, showing blowouts resulting from heavy rains of June 17 and 18, 1949. See plate 1 for location.

counts showed that they probably originated after the flood, and are now filling the bare spaces created in the stand by the moving debris.

The field evidence indicates that, like the debris avalanches, the water blowouts were accompanied by the flow of a large volume of water. The transfer of debris downslope was either explosive or sufficiently fluid so that the soil mantle was not destroyed.

Note in figure 24 that two slides occur at the edge of the flood plain. They have no relation to the water blowouts, and probably are gravity slides activated by undercutting of floodwater of the Little River.

TABLE 14.—*Composition of the forest growing downslope from the diabase sill*

[Data derived from 0.05 acre samples]

Species	Sample below blowout—number of trees by diameter, in inches						Sample to west of blowout—number of trees by diameter, in inches					
	0.25–0.5	0.5–1.0	1–2	2–6	6–10	10–20	0.25–0.5	0.5–1.0	1–2	2–6	6–10	10–20
Red maple							5	4	4			
Shadbush	4						4	2	3			
Pignut	1			5			1	1	4			
Flowering dogwood							4	1		1		
Witch-hazel	32						17	6	3			
Black gum	8											
White pine												1
Scrub pine								1				
White oak	2			1					1			
Scarlet oak	1			1				1	1			
Scrub-oak	7											
Chestnut-oak						1		1		10	2	1
Red Oak	2	1		2	1							1
Black locust									1			
Sassafras							1					
Hemlock										1		
Total	57	1	0	9	1	1	32	17	17	12	2	3

SUPERFICIAL DAMAGE TO SLOPES

Considerable superficial damage to slopes other than the activation of landslides resulted from the heavy runoff. Many minor slippages of the debris mantle occurred, and are evidenced today by narrow crescentic scars running parallel to the contour. Presumably leaves, twigs, and other light-weight debris were moved downslope by the runoff and piled behind obstructions. Evidence of this type of damage is seen in these mountains after every heavy rain.

Large areas of the valley side slopes and noses show no evidence today of any damage at all. Undamaged thickets of mountain-laurel with closely spaced stems suggest a long period of stability. The floors of nearly all the hollows in the flood-damaged area, on the other hand, show considerable evidence of heavy runoff even where chutes do not occur. As an observer proceeds downward into a hollow from a ridge into the area of concave slopes, evidence of the violent storm becomes more and more apparent. As the moisture-loving trees, like the red oak, sugar-maple, and basswood, become more abundant, the underbrush lessens; small trees are absent; and it is possible to see long distances in the open woods. Piles of small dead tree trunks and limbs are scattered behind obstructions, and except for the herbaceous plants, such as the wood nettle, the ground becomes barren. Whereas in the upper part of the hollows and in hollows unaffected by the 1949 storm, the block rubble on the ground is covered with humus and moss; in the areas where runoff was presumably heavy, this cover of moss is absent. To the observer, the complete absence of tree seedlings and the tough blanket of moss and humus and clinging rootlets is evidence of concentrated runoff just as spectacular as the chutes, especially since the block rubble is so coarse and the slopes so steep (generally 30°). In order to accomplish this removal, the water not only saturated the porous rubble but must have run down over the surface with a great velocity.

Though the evidence of high discharges is abundant and unequivocal, it is hard to imagine runoff rates that would accomplish the damage. In a small hollow such as that of valley 1 with a drainage area of 160,000 square feet, calculation shows that with an assumed rainfall rate of 6 inches per hour, sustained until the infiltration capacity of the ground was exceeded, the resulting stream at the head of the channelway would discharge at a rate of 22 cubic feet per second. Judging by accounts of other severe floods, the rainfall intensity may have risen for short periods to values many times that of 6 inches per hour.

FLOOD DAMAGE TO VALLEY BOTTOMS

CHANNELWAYS OF SMALL VALLEYS

At the points where the unusual discharges of the 1949 flood were concentrated in the channelways, damage took the form of an enlargement of the stream channel. Small valleys in surrounding regions unaffected by the flood have very narrow stream channels floored by coarse boulders. Fine-grained material and organic matter borders the bouldery channel on both sides. During the 1949 flood, large amounts of the poorly sorted material of the adjacent side slope and the coarse boulders under the channel bottom were washed away. A much enlarged ditchlike channel was cut; it has steep sides and in most places a bedrock floor. Proceeding downstream from the hollow, the flood channel first deepens to a troughlike cross section and then widens as it lengthens, until at a distance of about a mile from the valley head the flood channel is several times as wide as it is deep.

Typical dimensions of first- and second-order valleys on the north side of Buck Mountain are shown in table 15.

TABLE 15.—*Depth and width of channels in valleys 4 and 5*

Valley	Distance from ridge crest, in miles	Stream order	Channel width, in feet	Maximum depth, in feet	Ratio of maximum depth to width
5	0.12	1	19	2.0	0.10
5	.19	1	16	4.5	.28
4	.23	1	14	6.5	.46
4	.32	1	17	9.0	.53
5	.38	1	32	10	.31
4	.56	1	20	4.0	.20
5	.69	1	50	12	.24
4	.8	2	23	5.5	.24

In figure 25, the widths of channels enlarged or created by the 1949 flood are compared with the channel widths of streams in undamaged areas peripheral to the Little River basin. The graph shows that enlargement was fairly consistent regardless of the size of the stream involved. On the average, the flood created channels 5.5 times as wide as normal channels.

The banks eroded by the 1949 flood are generally fill that consists of loam and boulders such as are found on the side slopes. Plate 5*B* is a typical view of a channel in valley 5, showing the bedrock floor and steep eroded banks of valley fill. Before the flood, the stream must have flowed on top of a thickness of fill ranging from 5 to 15 feet that was flushed out of the valley by the flood. In some valleys only partly damaged remnants of the pre-1949 fill may still be seen. Presumably as time goes on and the flood damage heals, the channel will be gradually refilled or partly refilled. This healing process has clearly already begun. A cloudburst

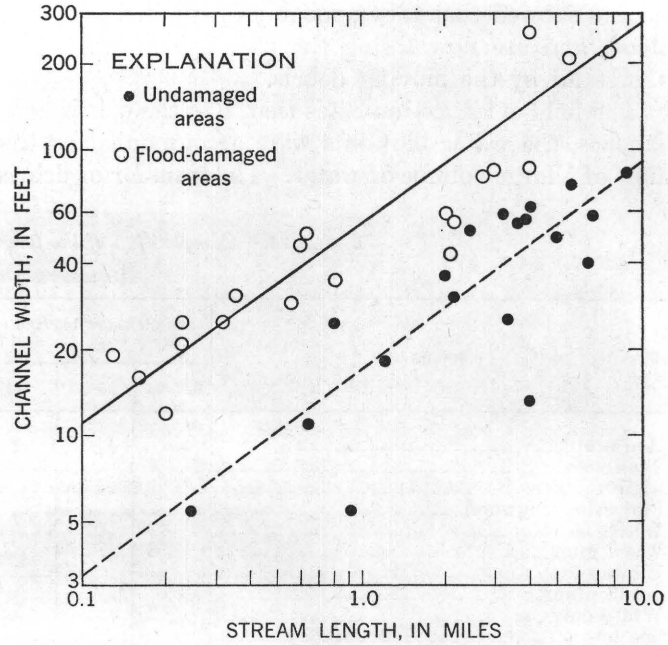


FIGURE 25.—Graph on logarithmic coordinates showing the width of 1949 flood channel at localities in the flood-damaged area, and the width of ordinary channels outside of the flood-damaged area.

observed by the writers on July 8, 1955, centered on Buck Mountain and had its greatest effect in valley 5.

A few days after this rain, the upper part of the channelway was found to be floored by fresh debris as shown in plate 6*A*. Note that the fresh debris uniformly covers the channel floor. Freshness is attested by the many thin blocks that are standing on edge and otherwise balanced in unstable positions. Since interstices between blocks are in many places filled with loam, and since the fresh debris ends abruptly at a point downstream, presumably the debris was deposited as a rather viscous mass such as a mud flow. The debris was probably derived both from the exposed surface of chutes in the upper part of the watershed as well as from the exposed banks on the side of the channelway.

CHANNELWAYS OF LARGE VALLEYS

It is in the large valleys like the main stem of the Little River and the North and South Forks that the role of extraordinary floods in the erosion process can be fully appreciated. The 1949 flood produced spectacular effects in these valleys, and it was here that the landscape was most altered. A fourth- or fifth-order mountain valley in the Devonian sandstone area undamaged by the 1949 flood is from 400 to 1,000 feet in width. The stream channel is more than 50 and less than 100 feet wide. The flood plain is an uneven surface of old abandoned channelways and gravel bars. It is mostly floored by sandy soil, with here and there a boulder projecting above the forest litter. Stream channels generally flow between banks a few feet high, but occasionally 10- or 15-foot-high banks resembling terraces border the steams. Alluvial fans frequently occur on the valley bottoms at the mouths of valleys of lower order.

The Little River valley shows many of these features in the making. The extent to which the valley floor was damaged is shown in plate 1. In some places the entire flood plain was torn up and its cover of trees washed away. More generally a part of the pre-1949 valley bottom remains. On these undamaged areas the flood left a layer of sand 4 inches to 1 foot thick that buried the bases of the trees.

Prior to the 1949 cloudburst, the U.S. Forest Service practiced intensive management in the forest growing on the valley floor of the Little River, which contained a considerable quantity of white pine. Most of these intensively managed stands were destroyed by the cloudburst (Mr. Richard Elliott, U.S. Forest Service District Ranger, Dry River District, George Washington National Forest, oral communication, 1955). Aerial photographs taken in 1942 show that most of the Little River valley supported forest of mature trees, many of which were conifers, presumably white pines and hemlocks. These stands were dense enough to produce a closed canopy. Comparison of preflood and postflood photographs shows no obvious relation between damage and condition of the forest cover.

The details of the flood damage and subsequent changes that have taken place were studied at localities 730 and 778 and are shown in figure 26. At both these localities large areas of the pre-1949 valley bottom remain (area B, fig. 26). They are covered by northern hardwood forest containing an abundance of hemlock and white pine (see table 16, station 2). The forest is open and has a sandy floor with boulders or piles of boulders here and there. Probably the sand was deposited by floodwater and has thickened over a long period of years. The sandy deposit laid down by the 1949 flood averages about 3 or 4 inches in thickness; in 1955 the base was clearly marked by a dark organic layer 1 inch thick that could be exposed almost anywhere in the undamaged area (B) by making a cut in the ground with a spade.

The pre-1949 stream channel can be identified at one of the localities studied (fig. 26, area C). This area is floored with coarse gravel and boulders and contains a sparse growth of small trees 6 years old or younger (table 16, station 1), berry bushes, and herbaceous plants. The trace of this area at locality 730 corresponds to the trace of the stream channel as shown on the U.S. Geological Survey's topographic map of the Parnassus quadrangle published in 1947, and to its trace as shown on aerial photographs taken before 1949.

The area torn up by the 1949 flood is distinct and is at present the most conspicuous feature of the valley bottom (fig. 26, area D). This area is covered by rather open forest of young trees, mostly sycamores and locusts but with many other species present (table 16, station 3). They are 6 years old or younger as determined by counting the rings. Some of the trees have already grown to heights of more than 15 feet. The ground between the trees is covered by a distinctive deposit of sand and gravel, markedly different from that in the undamaged area or the present stream channel. Grid samples of rock particles were made of this material at three localities. It is poorly sorted and its frequency distribution (fig. 27) shows at least two peak sizes—one in the granule size range at about 3 mm and one in the cobble size range between 50 and 200 mm.

TABLE 16.—*Species composition of flood-plain vegetation at locality 778*

	Old, relatively undamaged flood plain—	Flood plain, severely damaged by 1949 flood	
	Station 2	Station 3	Station 1
Hemlock	×	×	×
Yellow birch	×	×	×
Red oak	×	×	×
Red maple	×	×	×
Sycamore	×	×	×
White pine	×	×	×
Sugar-maple	×	×	×
Tulip-tree	×	×	×
Cucumber-tree	×	×	----------
Shagbark-hickory	×	----------	----------
Witch-hazel	×	----------	----------
Elm	×	----------	----------
Flowering dogwood	×	----------	----------
Butternut	×	----------	----------
White oak	×	----------	----------
Black birch	×	----------	----------
Hop hornbeam	×	----------	----------
Basswood	×	----------	----------
Black locust	----------	×	×
Pitch-pine	----------	×	×
Willow	----------	×	----------
Cottonwood	----------	×	----------
Chestnut-oak	----------	×	----------
Sassafras	----------	×	----------

The forest of mature trees growing on the pre-1949 valley bottom, of course, appears different from the young stands that occupy areas of flood plain torn up by the 1949 flood and the recently abandoned channels. The casual observer sees only sycamore and black locust on the younger surfaces and is impressed by the white pine and hemlock in the old forest. However, the forests of the two kinds of surface are similar with respect to species composition, as is shown by the data in table 16. The eight kinds of trees, characteristic of

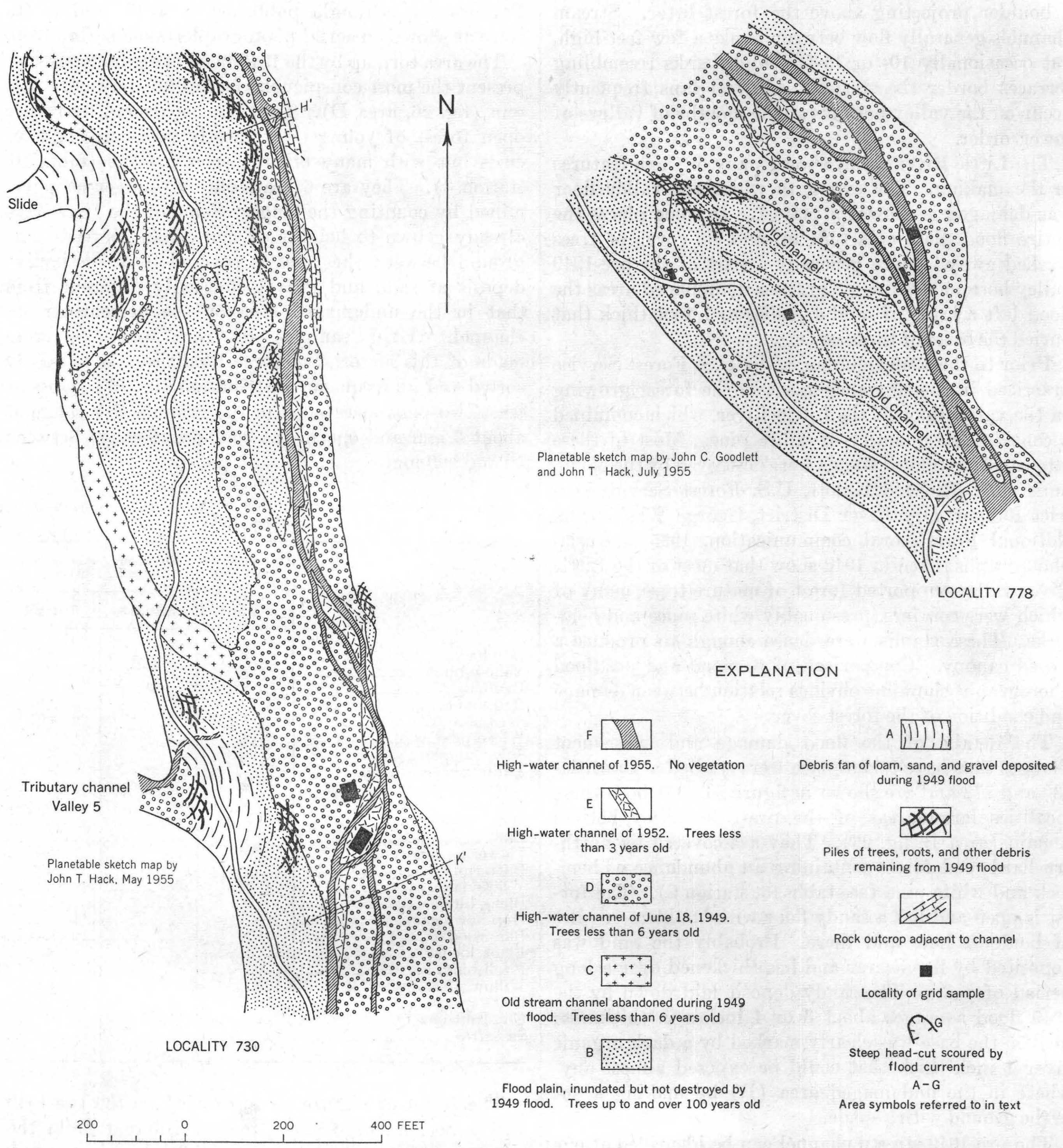


Figure 26.—Sketch map of two areas on the floor of the Little River valley. Prepared with open sight alidade; distance measured by pacing and with pocket rangefinder. See figure 28 for sections *H–H'* and *K–K'*.

northern hardwood forests of the flood plains, are common to both types of surface. Within a period of 6 years the bare areas created by the flood have been re-seeded by the tree species that generally constitute the bulk of the forests of the flood plain. The old forest contains a few more tree species than the young stand of the severely damaged flood plain at station 3, and almost twice as many as the young growth in the channel at station 1. Apparently the large bare area at station 3 is more readily reoccupied by trees than the narrow area at station 1, with its marginal closed-canopy forest. In large part, the greater number of species in the damaged flood plain may be the result of periodic inundation by seed-carrying floodwater. Note that pitch-pine, a species rarely seen in mature forests of the flood plains, occurs in both of the young stands.

The width of the flood channel created by the high water varies greatly from place to place. Changes in width of the flood channel are, as might be expected, associated with changes in channel depth and slope. Narrow places generally are related to piles of trees. An interesting example is presented at locality 730. Here the original stream channel ran along the west wall of the valley. It was apparently blocked by an accumulation of rubble deposited by a debris avalanche. The main flow, therefore, was diverted to the east side of the valley where it was confined on the east bank by a rock outcrop. The flood failed to tear out the trees in the center of the valley, owing to the protection afforded by piles of tree trunks. During this time, of course, the main forested part of the valley bottom was completely inundated by several feet of water. Downstream from the constricted place the flow in the forest attained sufficient force to gouge out the valley floor, and at area G (fig. 26) it cut large holes 8 feet deep that resemble plunge pools. Downstream, the flood

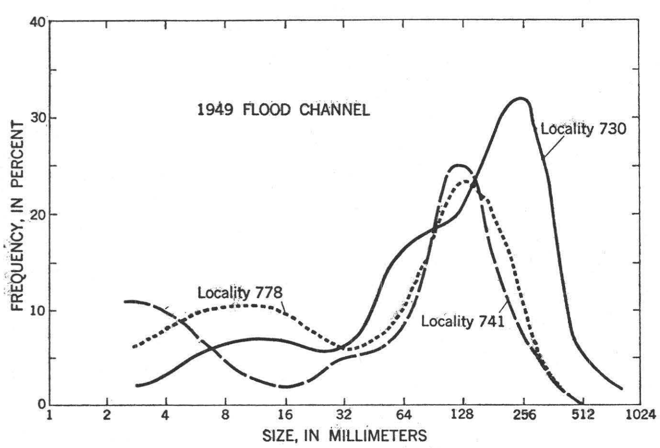


Figure 27.—Frequency curves showing size composition of samples of the deposit of the 1949 flood of the Little River.

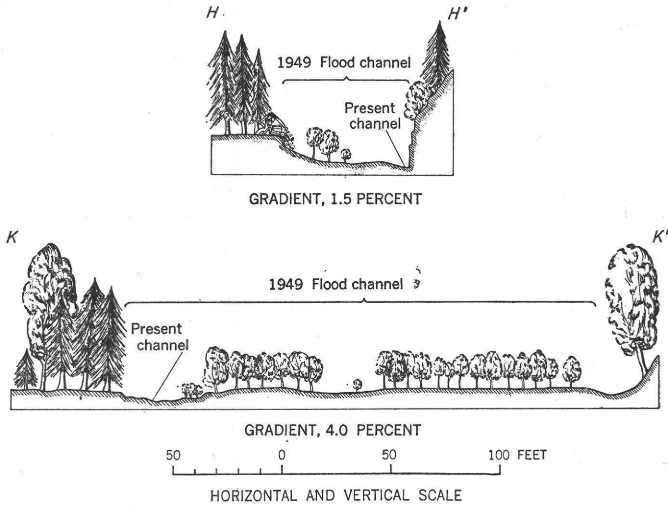


Figure 28.—Sections of the channel that was created by the 1949 flood in the North Fork of the Little River. See figure 26 for location of *H–H'* and *K–K'*.

channel was widened until it occupied two-thirds of the valley floor.

Sections of the channel at *H–H'* and *K–K'* (fig. 26) are shown in figure 28. The shape of the channel at both of these sections was created by the 1949 flood. Note that at the constricted location (*H–H'*) the average channel depth is 10 feet, whereas at the wide location (*K–K'*) the channel bottom is actually higher than the undamaged valley floor that forms its west margin. This presumably means that the valley floor was aggrading at the wide reach, whereas it was most certainly degrading at the narrow reach. As might be expected from a consideration of Rubey's concept of adjusted cross sections of stream channels (Rubey, 1952, p. 129), the average channel slope at the narrow and deep reach (*H–H'*) is low and was measured at 1.5 percent; whereas the average gradient at the wide reach where the flood caused aggradation is relatively steep and amounts to about 4 percent.

Several constrictions in the 1949 flood channel similar to the one just described are present in the North and South Forks. They are associated with a deepening of the channel, so great that the river at low water flows at a level 15 feet below the first bottom, whereas at other reaches the first bottom may be only a foot or two above the channel. When these differences in height of bank are observed in the years following the great flood, their origin is clear. If, however, they were observed years afterward when the forest vegetation had reclaimed the 1949 flood channel, such differences in height of bank might very likely be mistaken for the difference between a flood plain and a terrace.

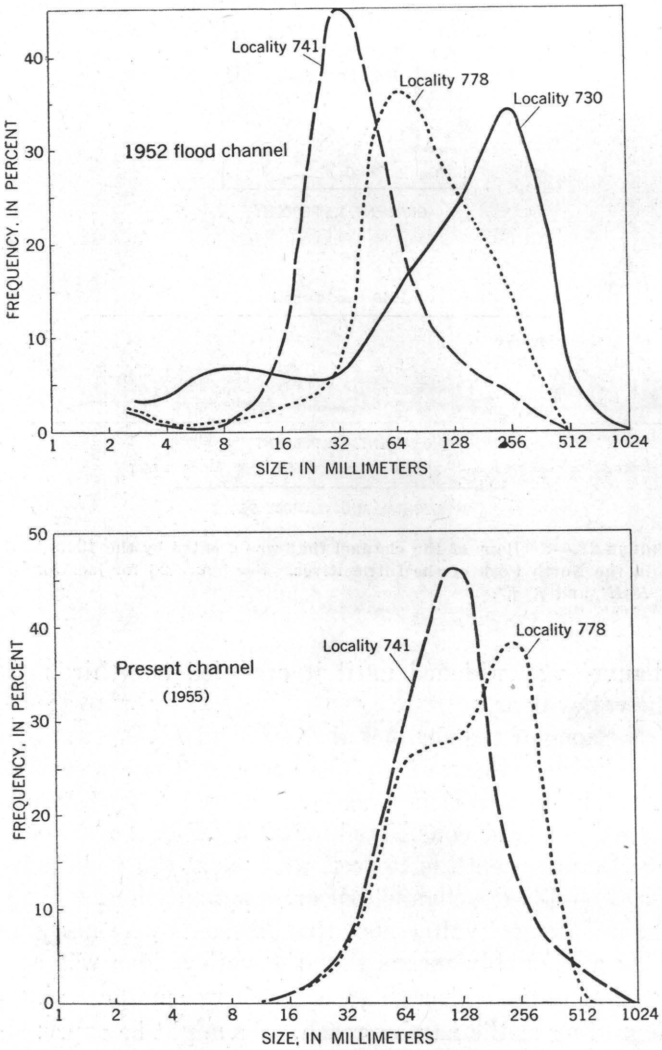


FIGURE 29.—Frequency curves showing the size composition of deposits on the floor of the Little River valley.

CHANGES ON THE VALLEY BOTTOM SUBSEQUENT TO THE FLOOD

In addition to the 1949 flood, less severe but nevertheless damaging floods affected the Little River valley in the spring of 1952 and in the summer of 1955. These floods also left their mark on the vegetation, on the shape of the valley, and on the surface debris. The history of the valley floor subsequent to 1949 suggests that the features commonly observed on the bottomlands of similar mountain valleys have been produced by the cumulative effect of many floods. These include floods of great rarity that affect the entire valley floor, and floods of annual frequency that serve only to keep open the stream channel.

A belt of ground, 10 to 50 feet wide, damaged in 1952 borders the present channel along the length of most of the valley (fig. 26, area E). This belt is marked by stands of small trees, mostly sycamores, less than 4 feet high whose growth rings as examined in 1955 were always three or less. These trees apparently mark an area of the valley floor that was torn up by a minor flood in 1952. The occurrence of such a flood in the spring of 1952 is confirmed by Mr. Richard Elliott, U.S. Forest Service District Ranger, (oral communication 1956). Like the 1949 flood, the 1952 flood left behind a deposit in its flood channel distinctive from the debris on the adjacent valley floor. Whereas the 1949 flood deposit is distinctly bimodal (see fig. 27), the 1952 deposit has only one large mode or peak, and the debris has a mean diameter markedly less than the adjacent debris in the channel of 1955 and 1956. Frequency curves showing the character of this deposit are shown in figure 29. The good sorting and relatively finer mean size are distinctive features apparent even on casual inspection.

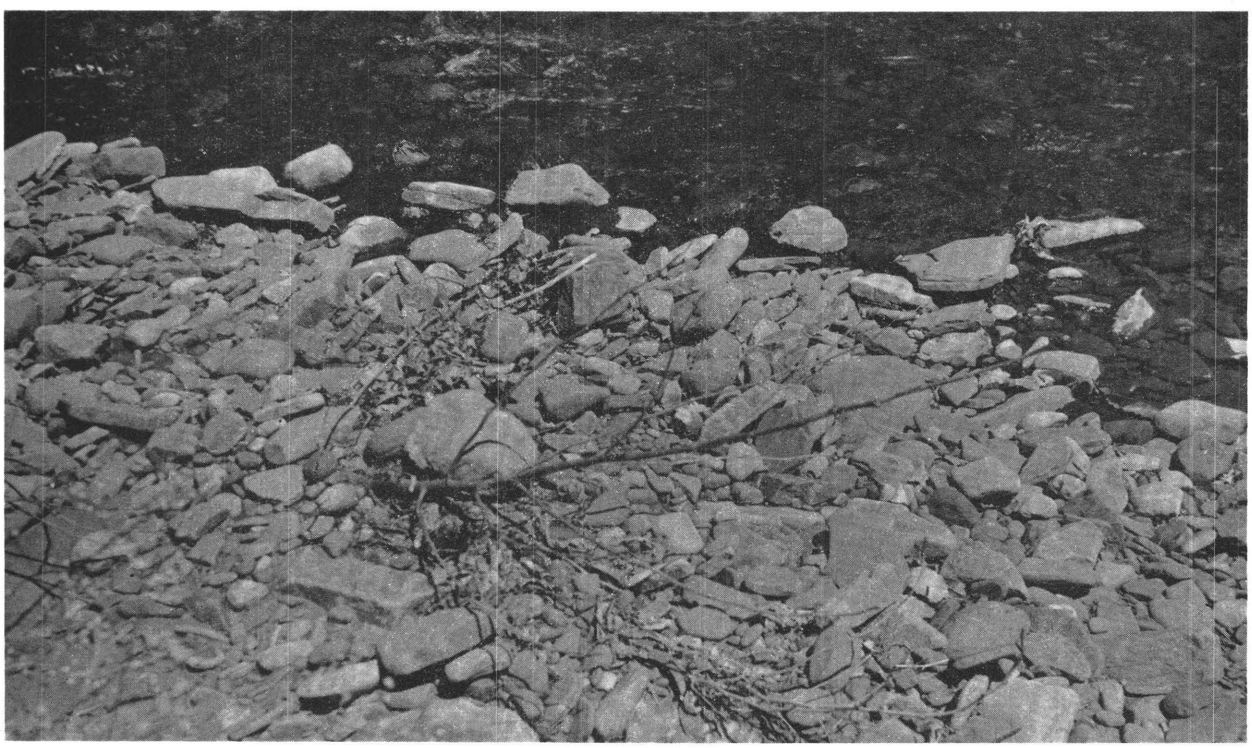
Apparently the 1952 flood had sufficient force within a rather narrow channel to uproot the small trees that had taken root since June 1949. It moved considerable debris, but most of it was less than 100 mm in diameter.

In 1955 the Little River again flooded with sufficient force to move debris on the bed and banks and to uproot trees. This flood was observed by the writers. The moving water by no means inundated the whole valley floor and was, in fact, confined largely to the area of the 1952 flood channel. In places, high water spread over parts of the 1949 channel. Very little of the 1952 vegetation was uprooted. As shown in plate 6*B*, however, some few trees that had sprouted since 1952 were knocked over by the moving bed material. Disturbance of the bed material was confirmed also by conditions at the fords along the road up the valley, where minor changes in the configuration of the bed were observed. Nevertheless this flood was relatively insignificant, for, after it receded, the changes made could be detected only by careful observation. The channel occupied the same position as formerly. The present channel, 2 to 3 feet below the 1952 channel, is dry part of the year, especially during late summer and fall. Flow during winter and spring and wet months prevents growth of trees in the channel. The 1955 flood was effective in preventing encroachment of vegetation onto the low banks.

The present channel contains material that has a larger mean diameter than either the 1949 flood channel or the 1952 flood channel, but it is unimodal (fig. 29). Probably this channel has contained the highest velocities of flow during all the periods of high water since 1949. The finer fragments are therefore swept out during floods to be deposited in areas of less velocity at the channel margins or on higher surfaces.

The sequence of events that have occurred in the Little River valley since 1949 suggests a mechanism by which

A. VIEW OF DEBRIS DEPOSITED DURING THE FLOOD OF JULY 8, 1955, IN VALLEY 5



B. VIEW OF COBBLES ON BANK OF THE LITTLE RIVER

Cobbles were moved by the flood in 1955. Note the sycamore tree in the foreground knocked over by boulders; tree became established after the 1952 flood.

A. VIEW OF CHANNEL OF THE LITTLE RIVER AT TILMAN ROAD IN 1955

View is from a rock ledge 75 feet above the valley floor. The 1949 flood channel is marked by low deciduous trees, mostly sycamores and black locusts. Undamaged flood plain on the left is covered by a tall stand that contains hemlocks and white pines. Trees at right on the steep side slope are mostly oaks.

B. VIEW OF DEBRIS FAN

Fan is on the flood plain of the North Fork of the Little River. It formed at the mouth of a second-order stream.

many familiar features of the bottomlands in mountainous regions of the Appalachians are formed. The transportation of coarse debris (the major work) and erosion of the valley floor and sides are accomplished during major floods that have a very low frequency of occurrence. During these floods, channels are abandoned, parts of older flood deposits are scoured and, in places, are left as terracelike remnants high above the new channels. As the resulting wide area of debris is healed and overgrown with trees, it is inundated occasionally by lesser floods that carry sand and silt and deposit them in the quiet backwater in the forest, slowly burying the bases of the trees. Gradually a sandy flood plain or bottomland is accumulated, with here and there coarse boulders projecting through to the surface. The area near the stream channel is generally less sandy, for it is reworked at more frequent intervals, and the chances are good at any one place that it has been worked over in the last 20 or 30 years; this area is therefore characterized by a forest of sycamores and other deciduous trees growing on gravelly or cobbly soil. The innermost area of the valley is of course the channel; this area is flooded every year or two and generally is well marked by prominent banks that support no trees. As the healing process following a large flood goes on, and larger and larger trees take over the adjoining banks, the channel becomes more and more stable, until eventually an extraordinarily large flood starts a repetition of the cycle. Plate *7A* shows the main valley of the Little River 6 years after the flood during the healing process of the flood channel and the stabilization of the present channel by vegetation.

DEBRIS FANS

Fan- or cone-shaped accumulations of sorted debris consisting mostly of stones and gravel, but also containing broken tree trunks and branches, are common and spectacular features resulting from the 1949 flood. They are localized by two factors, as follows: First, they must occur where a chute or stream channel enters the channelway of a valley of higher order so that there is an abrupt decrease in slope and an abrupt increase in discharge; and second, the channel of the valley of higher order must not impinge directly on the debris entering from the smaller stream, but must be away from it so that the debris enters the larger valley at a relatively quiet place. At such places there is an obvious decrease in velocity of flow, and a decrease in capacity of the water flowing out of the smaller tributary. Small steeply conical debris fans, for example, have formed below many chutes, especially below the the side slopes of a very large valley on an undamaged portion of the bottomland. Examples are shown in figure 26 (area A) just west of section *H–H′*, and at the southeast end of the area of figure 30 (area 4).

Larger fans, containing similar but perhaps coarser material and having gentler slopes, occur at the mouths of first-, second-, and third-order streams as they enter the North and South Forks and the Little River. A large fan with very low slopes is found at the mouth of Hog Run. Where two streams of similar size such as the North and South Forks join, no fan occurs. Most of the larger fans are compound; that is, they contain not only debris deposited during 1949, but also debris that was carried down at earlier times and now is overgrown with trees. Many of these fans have been partly destroyed by washing during the 1949 flood, and large cuts in the fanglomerate are exposed. A typical accumulation of 1949 debris is shown in plate *7B*.

A well-developed compound fan at the mouth of a primary valley tributary to the North Fork of the Little River (locality 770, pl. 1) was mapped by the writers and is shown in figure 30. In the 1949 flood, the entire load of coarse debris derived from the smaller valley, including boulders and cobbles as well as uprooted trees, was arrested by the flood-plain forest just below the juncture. The major part of the debris formed a high pile of cobbles and dead tree stems, but a limited quantity spewed out farther with sufficient force to destroy smaller trees in an area 300 feet long. An older fan (area 3) still overgrown with old trees occurs at the west edge of the mapped area. This fan was partially destroyed by the 1949 flood, and it ends abruptly at a high-cut bank 20 feet above the river channel.

Over a dozen compound debris fans were observed, including a compound fan beneath a chute. These older features are unequivocal evidence of damaging floods in the area that occurred at some time in the past. As most of these fans are overgrown by mature trees, including many over 100 years old, they must have been formed by an extraordinarily large flood prior to 1840.

FORMATION OF TERRACES

The importance of the cloudburst flood in the formation of terraces should be emphasized. Terraces 10 to 20 feet high formed during the Little River flood in two ways. First, at several places in the valley, debris dams consisting of broken trees and boulders blocked the valley, protecting the forest down current and forcing the major part of the flood flow into a rather narrow channel. At such places a deep channel was cut, 15 to 20 feet below the former flood plain, whose gradient at the narrowest place is less than the average stream gradient. When these areas are recovered by forest they may easily be mistaken for terraces cor-

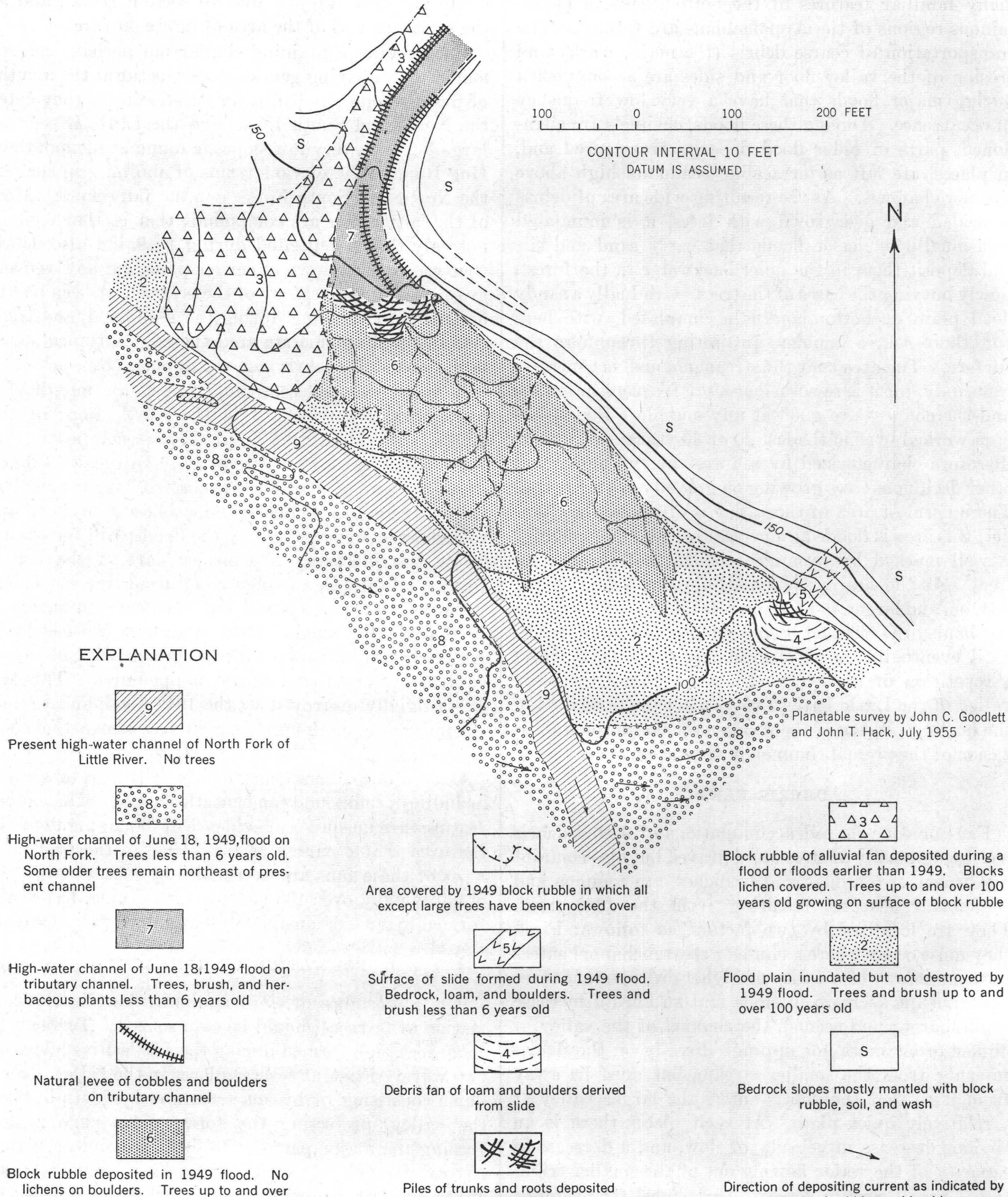


Figure 30.—Sketch map of debris fan at the mouth of a tributary of the North Fork of the Little River (locality 770, pl. 1).

relative with other such remnants at roughly comparable height above the channel. It is conceivable that during the erosion of a valley, terraces formed originally in this manner might be preserved for a long time, eventually to form remnants at considerable distance above the stream.

A second method of terrace formation is the erosion by the main stream of alluvial cones or fans at a juncture with a minor tributary. Such fans have been constructed over a long period of time by the accumulation of debris on the floor of the principal valley. They grow at intervals of many years whenever a "cloudburst" flood flushes out the debris in the tributary. The fan persists as long as it is in a position shielded from the direct force of the flood flows in the main valley. Eventually such fans are cut through by the main river and during the process form steep banks and terraces. One such terrace along the South Fork of the Little River is over 30 feet high.

Vegetation in the valley floor is a factor impeding flow and causing entrapment of debris. Probably erosion can take place and the valley can be cleared of debris only in rare floods of such magnitude that a part of the forest is entirely destroyed. During intervals of smaller flows when the current is confined to a narrow channel, the net result of stream activity is filling of the flood channel and aggradation of the flood plain.

CLOUDBURST FLOODS IN OTHER PARTS OF THE APPALACHIANS

Fresh evidence of flood damage such as is still visible from the flood of 1949 in the Little River area and near Petersburg, Va. (Stringfield and Smith, 1956), is apparently rare in neighboring areas. Similar damage, however, may be seen at many places in other parts of the Appalachians. In the fall of 1955, during a trip to northeast Tennessee, C. S. Denny, R. B. Neuman, and J. T. Hack observed chutes like those in the Little River area near Radford, Va., near Wautauga Lake, Tenn., and near Gatlinburg, Tenn. The flood damage around Wautauga Lake was caused by the heavy rains of August 1940 (U.S. Geol. Survey, 1949). The damage near Gatlinburg occurred during a sudden thunderstorm in the summer of 1951 on the southeast slopes of Mount LeConte (J. B. Hadley, U.S. Geological Survey, oral communication, 1955). Several chutes were formed in areas of phyllite, and the damage to the master stream of the area was mainly a great enlargement of its channel; this is similar to the damage in the Little River valley. The storm that caused the damage near Radford, Va. has not been identified but it may have occurred during the heavy rains of 1940.

In September 1955 Hack visited the Pocono Mountains of Pennsylvania to examine the effects of the intense rains associated with hurricanes Diane and Connie. The valley of Brodhead Creek in northeast Pennsylvania above Stroudsburg was severely damaged during the floods of August 17–20, 1955 (U.S. Geol. Survey, 1956, p. 8). In places the entire valley floor was reworked by the floodwater which carried away all the vegetation and exposed the valley fill of gravel and cobbles. In the headwaters of Brodhead Creek, four chutes were observed on the face of the Pocono Escarpment.[7] One of these was examined, and it was found to be similar in form to the chutes in the Little River valley. The chute has a debris cone at the bottom, is 1,000 feet long, and 50 feet wide, and has an average slope of 21°. The floor of the chute is composed of clayey till that rests on interbedded sandstone and shale. On the day observed, only 2 weeks after the chute was formed, its floor was deeply furrowed by gullies, indicating that the slide was followed by erosion due to intense runoff.

Debris fans similar to those observed in the Little River valley were formed by the August 1955 flood at many places where small tributaries joined a larger valley.

Similar types of erosive damage caused by the floods of August 1955 have been reported from the Catskill Mountains of New York and from western Massachusetts and western Connecticut.

Data bearing on the occurrence of debris avalanches and associated damage caused by torrential rains are too few for reliable conclusions to be reached as to their relative frequency in different areas. Yarnell's data (1935) on the frequency of intense rainfalls suggests that a higher recurrence interval might be expected for damaging storms in the southern Appalachians than for those in the northern Appalachians. On the other hand, the debris avalanches of New England are well known (Sharpe, 1938; Flaccus, 1958), and they have occurred fairly frequently in the White Mountains during the last 100 years or so. It may be that in the White Mountains the high frequency of occurrence of this phenomenon is related in some way to a lack of equilibrium in the landforms and soils that is a result of glaciation. In the southern Appalachians, debris avalanches and flash floods probably are normal phenomena associated with the erosion of areas of high relief.

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[7] The four chutes are in the vicinity of Skytop. Three are in Pike County, 0.4 mile northeast of Salus Lake, and one is in Monroe County on slopes of Mount Wismer above Coleman Pond.

RELATION OF FORESTS TO FLOOD DAMAGE

The presence of compound debris fans in valley mouths (page 53) provides some evidence of the efficacy of forests in controlling flood damage to slopes. A flood-control survey was conducted by the U.S. Forest Service (Northeastern Forest Experiment Station, 1950) in the Potomac River headwaters area following the severe flood of June 1949, and particular attention was given to the landslides. Presumably this study included the Little River area. According to the report (p. 31–32), "there was evidence that these lands had not recovered to a point where they could resist the severe stresses developed by this unusual storm." It was assumed that 20 to 30 years of intensive protection had not made up for an unknown period of logging, grazing, and burning that occurred prior to Federal acquisition of the lands. A relation between forest quality and incidence of landslides was apparent:

> Most of the landslides started on steep slopes near the tops of hogbacks or divides. In these areas natural regeneration had been slow; it consisted of inferior young stands of rather open and brushy type. In general, slides did not occur where thrifty normal stands had developed. In fact, when some slides reached better stands, the slide was restricted in width and a few slides stopped altogether.
>
> This storm showed how long it takes land to recover fully from past abuse. It showed the urgency for early initiation of good land-use and management practices * * *.

Compound debris fans are unequivocal evidence of flood damage to slopes in the past, prior to the period of logging and probably prior to the time of settlement by the white man. Either the forests mantling the slopes in the past were not all "thrifty normal stands"—a possibility—or the slope forests, regardless of quality, cannot control huge volumes of runoff. There is a limit to the amount of runoff that a forest can withstand. This limit determines the density of drainage channels, and were there no limit to the protective powers of the forest there would be no stream channels at all.

FORM, PROCESS, AND VEGETATION

Geomorphic processes strongly affect, and in turn are strongly affected by the vegetation mantling the slopes in the central Appalachians. The mountainous terrain produced by geomorphic processes creates a pronounced geographic segregation of species and groups of species. On the other hand, geomorphic processes take place in or through the forest vegetation and are modified by it. In large part, the present landscape is the product of a long period of interaction between botanical and geomorphic processes.

Data have been presented describing the topographic form, the mantle of superficial debris, and the vegetation of a mountain area. Relations between these elements of the environment have been pointed out, and various inferences made concerning the forces that control the relations. Some of these ideas can now be brought together so as to consider the meaning of the data in relation to existing theories of erosion, the development of land forms, and the development of vegetation.

Various theories in the past have been used to explain the origin of mountain landforms. Gilbert's ideas have probably formed the basis for most thinking on this subject in America. His ideas are succinctly summarized in his paper on the convexity of hilltops (Gilbert, 1909, especially p. 344 and 345). Concave-upward slopes are produced by the concentrated flow of water. The transporting power per unit of volume of water increases with the volume; also, for a given volume of water, the transporting power increases with the slope. A stream automatically adjusts slope to volume in such a way as to equalize its work of transportation in different parts. Convex-upward slopes, on the other hand, are a result of transportation by processes known collectively as creep, in which the impelling force is gravity and which depends for its effectiveness on slope. On a hill or mountainside the mature or adjusted profile of the slope is everywhere just sufficient to produce the velocity required to transport the material across the surface to the channel below. The slope steepens downward because the volume of material transported increases as slope length increases. Two domains of erosion are visualized: (a) the domain of stream sculpture, associated with concave profiles; and (b) the domain of creep and convexity. Gilbert also recognized that changes in the equilibrium of the environment would result in the enlargement of one of these domains at the expense of the other. He stated, for example (1909, p. 348), that the removal of vegetation gives waterflow greater velocity, causes gullying that changes the texture of the topography, and enlarges the domain of stream sculpture.

The framework suggested by Gilbert for the analysis of slopes applies very well to the Little River area. Its forms may be defined in terms of the two overlapping domains. The domain of stream sculpture is largely confined to the channelways. During heavy rains, however, differential movement of debris occurs in the hollows. In cloudburst floods, runoff is sufficient to move material on side slopes and even on noses. In effect, the floods act so as to increase the drainage density and momentarily enlarge the domain of stream sculpture. Thus in 1949, as shown in figure 31, the channelways on Buck Mountain were extended almost to the ridge crests. The streams of the entire area were momentarily increased in order, for a new set of bifurcations was added at the heads of the former channelways.

The domain of creep includes the noses, side slopes, and hollows. Its work is less important in the channelway, affecting only the steepness of stream banks and other minor features. The volume of material that is transported by creep is larger on the side slope than on the nose and larger in the hollow than on the side slope.

Theories advanced to explain the development of vegetation fall into two general categories. Most ecologists have thought of plants as members of highly organized "associations" whose present relations are best explained in terms of past changes in the complex organism itself (p. 61). A few ecologists and most other botanists have held that the plant association is an accidental conglomeration of individual plants that arrived in an area and were able to survive there. The latter view emphasizes the necessity of a plant to adjust to its environment at a point in space and time. It is thus primarily oriented toward a consideration of relations that exist at the present time between a plant and its environment. These ideas of the individual plant as the fundamental unit of vegetation were forcefully stated by H. A. Gleason (1926, 1927) in papers describing what he termed the "individualistic concept of the plant association."

Gleason (1926) pointed out that no two areas of vegetation have precisely the same structure—that is no plant association is repeated exactly in space—and that there is no general agreement among ecologists as to how much variation may be permitted within a single association. Thus, no two ecologists are likely to interpret a piece of vegetation the same way or map it alike. He came to the general conclusion that vegetation is the result of plant migration and environmental selection and that each species has its individual peculiarities of migration and environmental requirements which determine its distribution. Its seeds migrate and grow where the environment suits their physiological requirements, in company with seeds of other species of similar environmental requirements that happen to arrive in that spot. Thus, according to Gleason (1926, p. 25) the plant associations of an area depend strictly upon the coincidence of two sets of variables:

> These primary causes, migration and environmental selection, operate independently on each area, no matter how small, and have no relation to the process on any other area. Nor are they related to the vegetation of any other area, except as the latter may serve as a source of migrants or control the environment of the former. The effect of these primary causes is therefore not to produce large areas of similar vegetation, but to determine the plant life on every minimum area. The recurrence of a similar juxtaposition over tracts of measurable extent, producing an association in the ordinary use of the term, is due to a similarity in the contributing causes over the whole area involved.

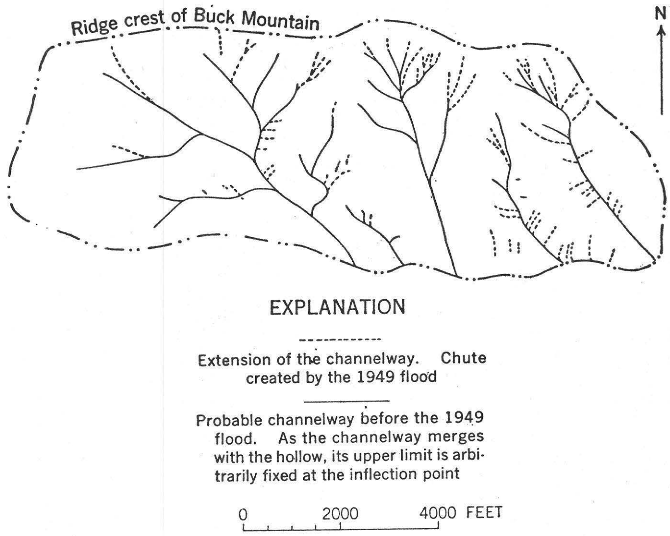

FIGURE 31.—Drainage map of the valleys that drain the south side of Buck Mountain and are tributary to the South Fork of the Little River (pl. 1). Shows the increased density of drainage that carried the 1949 flood runoff.

Gleason's ideas are applicable to the analysis of the vegetation of the Little River area and its relation to geomorphic processes. It has been shown that the local distribution of species and forest types is roughly coincident with well-defined differences in topographic form, which create differences in the environment. The topographic forms in turn are controlled by geomorphic processes. The process of stream sculpture thus produces slopes that are concave upward. These slopes generally support northern hardwood forest. Similarly, the process of creep produces convex-upward slopes that generally support yellow pine forest. The topographic forms are subject to severe modification by geomorphic processes acting at the present time, and the plant cover rapidly adjusts to the changed environments. For example, cloudburst floods may produce concavities on the side slopes of valleys and thus change the composition of the forest in small areas.

GRADED SLOPES AND THE DEVELOPMENT OF FORMS

The most important lesson to be learned from the landforms of the Little River area relates to the extraordinary regularity of the landforms, and the nicety of adjustment of the soils and vegetation to them. The close relation between these three terrain elements has been demonstrated over and over again in the preceding pages. The correlation extends even to the asymmetry in their distribution pattern. The explanation for the relation is that the mountains are shaped or graded in such a way that the products of decay of the bedrock can be moved across the ground surface and carried off in the channelways out of the area. Various processes that differ in relative effectiveness in different parts of the valley act to transport the debris, so that the graded slope must also be different from one part of the valley to another. The resulting regular forms are the product of this adjustment in a region where the underlying bedrock is rather uniform. As time goes on, the entire landscape is lowered. Though the slopes may flatten through time, the entire mountain mass retains a form graded for the transportation of waste materials.

The vegetation reflects the local differences in process, slope, and environment. Differences in forest type within one valley are often as great as the regional differences between the forests of the northern Appalachians and those of the southern Appalachians. The magnitude of these differences is a reflection of the extreme diversity in the physical environment between different parts of the valley.

Consider as a dynamic system the graded profile of a first-order valley, and compare the processes that blunt and lower the crest with those that erode and lower the channelway. The ridge crest is in an exposed position at the head or side of the valley. Motion of material on the very crest is possible only laterally. The impelling force must be one or more of the processes of creep, such as the action of growing roots, burrowing animals, falling raindrops, frost, tree blowdowns, and the like. These processes are weak and act only slowly. Their effectiveness, however, is relative to the strength of the material on which they act. Thus, it takes longer to comminute and transport a quartzite than it does a shale or an unconsolidated deposit. Their effectiveness is also relative to the curvature of the crest, for the degree of curvature determines the confining pressure or frictional resistance that checks the erosive and transporting forces that are dependent on gravity. On a knife-edged ridge, for example, the strength of the material is reduced to so low a figure that one can readily conceive of even a quartzite rapidly downwasting by the action of these weak forces.

In the channelway the action of creep is relatively unimportant. Transportation of debris is accomplished by the kinetic energy of large flows of runoff water. The energy of the maximum flows is proportional to discharge, a function of drainage area, or size of the valley above. The increase in kinetic energy downstream is limited by the rate of flattening of the channel slope, and is adjusted so that the coarsest blocks derived from the downwasting of the mountain are ultimately carried out of the drainage system. At any one time the channelway is floored by a lag concentrate of the blocks too coarse to be moved by the latest floods. The channelway is, of course, a zone of great instability, in contrast to the crest or to the nose where, because there is less material involved in transport, the ground is much more stable. The differences are strikingly reflected in the vegetation.

The forms of the ridge crest and channelway, as well as the slopes between, are interdependent. The potential energy available for erosion and the grading of slopes is a function of the total relief. Assuming two areas having initially the same relief, the difference in altitude between the crest and the channelway is at any point of time determined by the strength of the rock. A strong rock will, by its resistance to comminution and creep, support sharp, narrow divides. The resistance of the comminuted blocks to breakage and wear during stream transportation will require steep slopes in the channelway for the streamflows to have the competence to carry them off. In two areas having the same bedrock exposed to erosion for different periods of time, the area exposed for a longer time will, of course, have more blunted divides and gentler slopes in the channelway. Local irregularities in form are a function of variations of strength of bedrock.

Concept of the study state.—The concept of graded slopes just described may be expressed in terms of Strahler's concept of a steady state in an open system (Strahler, 1952, p. 934). The slope forms and the debris that mantles them are in a steady state, or state of continuous adjustment, dependent on the interrelations between factors such as the kind of bedrock and its resistance to weathering, the relief, the climate, the exposure, and others. Inasmuch as the system is open, some of these factors may be changed through time. As a result, the form as well as other interrelated phenomena must change. For example, as the relief is reduced, the slope must flatten and the texture of material on the slope must change; or, if the frequency of flash floods changes, so other factors must change. The vegetation, its distribution and composition are, of course, a part of the open system.

GRADED SLOPES AND THE DEVELOPMENT OF THE VEGETATION

The vegetation of the Little River area shows an extraordinarily regular distribution of forest types that is related to the similarly regular landforms. The elegance of the adjustment of vegetation, landforms, and soils is a function of the geomorphic processes that maintain the graded slopes.

Although many species grow in a wide range of environments in the area, a part of the flora, both tree and nontree, grows only in specific environments that can be defined in terms of topography, and interpreted in terms of geomorphic process. The species that show local distribution possess sufficiently distinctive forms that their presence or absence largely determines the physiognomy or appearance of the plant cover. The local distribution of species is interpreted as a physiological response by individual plants of the present species populations to the different environments present in the area. Thus similar environments usually support similar groups of species and forest types, although the element of chance in the dispersal of plants requires that the types be defined broadly. Under this concept, the vegetation of the past is significant largely because it provided the area with a series of species populations whose evolutionary development determined the physiological responses of the present plants to their environment. However, the physiological aspects of this argument are theoretical, because plant physiology is unable to explain the field relations of trees at the present time.

The series of coincidences between plant cover and landform led the writers to believe that the local distribution of many species and of the forest types is largely determined by the duration of moisture in the ground during the growing season, although the physiological mechanisms that must be involved are not known. The ground moisture regimes also largely determine the nature of the geomorphic processes most active in a given area. Thus the vegetation and the geomorphic processes are primarily controlled by the same environmental factor. The moisture regimes are largely the result of landform, which in turn is the result of geomorphic process. Even more involved, differences in the form and structure of the forest types probably affect the nature of the erosion processes, although both are primarily a function of moisture regimes. These interrelations can perhaps be clarified by a few examples.

Concave areas on slopes, which characteristically support northern-hardwood forest, are the product of the geomorphic process of stream sculpture. However, once formed by stream sculpture, a concavity undergoes erosion and grading largely by creep, which is encouraged by the same moist conditions that seem to determine the distribution of the northern hardwood forest type. Convex areas on slopes characteristically support yellow pine forest; therefore, the distribution of yellow pine forest is related to the distribution of landforms created largely by the process of creep. Rates of creep probably are extremely slow on these noses and ridge crests because the environment is dry and because the volume of material originating on the slope above is less. Dryness presumably controls the presence of the yellow pine forest. Convex areas thus tend to be more stable habitats for plant growth than concave areas, and the yellow pine forest probably undergoes less disturbance than the northern hardwood forest. It can perhaps be said, then, that the yellow pine forest is characteristic of relatively stable areas, whereas the northern hardwood forest is characteristic of relatively unstable areas.

The yellow pine forest, characteristic of areas where the process of creep goes on at a slow rate, contains a dense shrubby ground cover consisting of heath plants and scrub oaks. The nothern hardwood forest, characteristic of areas where the process of creep is perhaps most active, is floored by ground cover that consists largely of herbaceous perennials. Shrubby heath plants are almost entirely absent. Although the possibility exists that the composition of the ground cover in these areas is determined by the relative rates of creep, it seems more likely that both the relative rates of creep and the species composition of the ground cover are most closely related to moisture regimes. Recall that the ground cover in northern hardwood stands in flood plains of the larger valleys also consist predominantly of herbaceous perennials. Nevertheless, the presence of shrubby ground cover in areas where creep is unimportant would tend to raise the threshold at which increased moisture would increase rates of creep. Although moisture regimes probably determine the composition of the vegetation and the predominant geomorphic process, the form of the vegetation tends to resist a shift in the balance of the erosion processes.

The nature of the yellow pine forest growing on noses and slopes undergoing slow erosion by creep may thus be an important factor in maintaining the stability of these slopes. Nevertheless, dense though the ground cover is on these noses and slopes, it cannot withstand large amounts of runoff and is destroyed. Concurrently, the slopes move into the domain of stream sculpture and undergo erosion by this geomorphic process. Vegetation cannot control runoff in large quantities, as damage to slopes by the 1949 cloudburst demonstrated.

The effects of floods on forests in the flood plains of larger streams illustrate another aspect of the adjustment of the plant cover to severe shifts in process in the open system. Whenever a stream leaves its channel the flood-plain vegetation is affected. Seedlings and ground-cover plants are washed away, and new seed is washed in. The bases of forest trees are buried by sand and silt deposited by the floodwater. Flash floods completely destroy the plant cover in some places and merely deposit sediment on the forest floor in other places. The result is the creation of a complex forest consisting of many species of trees of many different age classes, almost invariably referable to the northern hardwood forest type. Past floods of various intensities and recurrence intervals have undoubtedly churned the flood-plain forest, keeping it in a state of flux without appreciably altering the species composition. In places, however, flash floods result in the cutting of deep new channelways in the flood-plain deposits and the erosion of alluvial fans. In the present forest, the higher parts of flood plains, terraces, and alluvial fans often support oak forest or yellow pine forest. Therefore, floods in the past may have resulted in minor changes in the proportions of the different forest types in the predominantly northern hardwood forest of the flood plains.

The effects of cloudbursts, a part of the present complex of environmental factors acting upon the landscape, thus illustrate one way in which the equilibrium that exists between landform and vegetation is constantly being upset by change. The readjustment is rapid, and in the case of the vegetation presumably reflects the physiological responses of the available plants to the immediate environment. A small area on a slope, for example, may support in turn oak forest, northern hardwood forest, and oak forest again—not because of successional changes brought about by the vegetation itself, but primarily because of changes in geomorphic processes which in turn result from variations in local or regional weather patterns within the present climatic regime.

Landforms of the past probably were similar to those of the present, except for more relief and steeper slopes. If this be true, the distribution of forest types on slopes in the recent past would have resembled closely that seen on slopes now. However, the lowering of divides might have resulted in the severe restriction of areas occupied by some species. For example, yellow birch is common in the vicinity of Reddish Knob but is rare on lower mountain masses such as Buck Mountain. Spruce, nearly absent from the Little River area, but common a few miles away on Spruce Knob (Core, 1929), might have been common on Reddish Knob in the past.

In short, in the Little River area the vegetation affects and is affected by many of the differences in geomorphic processes and the resulting landforms. A valley thus illustrates adjustment of many components of landscape within an open system. At a point in time, noses and ridge crests, undergoing slow erosion by creep, usually support yellow pine forest whose structure encourages slow rates of creep. Hollows, where creep perhaps is most active because they contain material derived from a large source area, often support northern hardwood forest, whose delicate ground cover exerts little inhibiting effect upon creep. Channelways, the domain of stream sculpture, contain no trees. Side slopes are highly variable in form, plant cover, and erosion process. The delicate adjustment between topographic form, slope exposure, soil materials, plant cover, and geomorphic process is perhaps best demonstrated by the characteristics of opposite sides of asymmetric valleys, summarized in table 13.

EXPLANATION OF LANDFORMS INVOLVING MULTIPLE EROSION CYCLES

The forms of an area such as that of the Little River basin have been envisaged by some geologists as resulting from the dissection of one or more peneplains. According to G. W. Stose (*in* Stose and Miser, 1922, p. 19) the ridge of Shenandoah Mountain supports remnants of a peneplain, termed the "summit peneplain," between 3,500 feet and 4,000 feet in altitude. The floor of the Shenandoah Valley a short distance to the east, according to this interpretation, is a dissected peneplain known as the "valley-floor peneplain."

Other geologists, however, have pointed out the close relation between the altitude of the mountain ridges of this region and the structure and physical properties of the bedrock (Edmundson, 1940, and Thompson, 1940). In the Little River area itself there is no vestige of a former surface of low relief. The altitudes of the ridges are belived to result from the action of a regularly spaced drainage network on rocks of different resistance to erosion, a hypothesis to explain the accordance of summits advanced by Shaler over a generation ago (Shaler, 1899). The crest of Shenandoah Mountain corresponds to a syncline in which is exposed sandstone of the Pocono, the most resistant rock of the area. Remnants of basal beds of this formation form the highest parts of Buck Mountain. A dip slope on the Pocono determines the line of flatiron-shaped ridges that includes Grooms Ridge and Sand Spring Mountain. Narrow Back Mountain again is localized by the presence of overturned Pocono.

The regularity of the spacing of streams, the parallelism between ridge crests and stream profiles, and the repetitious uniformity of the graded slope forms are features that are adequate to explain the rough accordance of summits on rocks of similar resistance to erosion. This kind of argument has been used for many years by those opposed to an explanation of mountainous topography like that of the Appalachians by a theory involving multiple erosion cycles. (See for example

Tarr, 1898, Shaler, 1899, Daly, 1905, and Rich, 1938.) Some of the recent quantitative work in geomorphology, such as the work of R. E. Horton (1945), lends support to the logic of these early objections by emphasizing the regularity and orderliness of the drainage network.

Other explanations of the topography that differ from the concept of the steady state in an open system might be offered, such as that of Penck (1953) in which the mountain area because of its predominant convex-upward forms and the lack of foot slopes would be defined as an area in which erosional intensity is increasing (aufsteigende Entwicklung). The applicability of Penck's theory of slope development is better considered in relation to the forms of a larger area including a greater variety of rocks than is described in this report. Nevertheless Penck's ideas are subject to some of the same objections as is the concept of multiple erosion cycles. The close relation between geology, vegetation, and form do not support the Penckian concept, for in his concept the gentler slopes of the upland areas, such as the ridge crests, owe their form to the existence of an ancient topography that had a lower relief than the present topography. The contrasts in the vegetation are not so great between upper slopes and lower slopes as they are between opposite slopes, or between individual organic elements of the valley at the same altitude. Furthermore, the parallelism between the profiles of the channelways and the intervening ridge crests argues against the existence of relict forms.

DEVELOPMENT OF THE VEGETATION ACCORDING TO THE THEORIES OF BIOLOGICAL SUCCESSION

The vegetation of areas such as the Little River basin has been interpreted by most ecologists in terms of a general theory of vegetational development formulated primarily by F. E. Clements (1916; Weaver and Clements, 1929). Clements' theory based largely upon deduction, envisages the development of "climatic climax" vegetation by means of biological succession in almost stable environments. Biological succession is the process through which tightly organized groups of species called associations interact with their substratum to modify the habitat and pave the way for occupation by other associations, not previously able to occupy that habitat. According to this generalization, the outcome of successional developments is determined primarily by climate, because the characteristics of the substrata undergo extremely slow and orderly change related to the formation, uplift, and dissection of one or more peneplains.

A recent comprehensive treatment of the forest of Eastern United States by Braun (1950) illustrates a modified application of Clements' ideas to a specific area. According to Braun, the Little River area lies within the "Ridge and Valley Province" of the "Oak-Chestnut Forest Region." Braun believes that this forest was derived from a mixed Tertiary forest that mantled the Schooley peneplain. According to Braun (p. 225–242), the principal features of the present topography formed during the Harrisburg cycle of erosion, and she related the present distribution of plant communities to postulated events in the physiographic history of the region that created differences in habitats. Thus, according to Braun, the ridges that represent the Schooley peneplain and their side slopes that were formed during the Harrisburg cycle of erosion support oak-chestnut climax communities. "Valley floors" such as the Shenandoah Valley, represent the Harrisburg peneplain, and support white oak climax communities. "Ravine slopes," formed during the present erosion cycle, support mixed mesophytic climax communities. Braun's discussion (1950, p. 242) of this ravine climax shows a long view of geomorphic process and vegetational change that differs from that of the writers:

> On the ravine slopes formed in the latest erosion cycle, the vegetation is developing in response to present forces both topographic and climatic. Although very limited in extent, it seems logical to assume that mixed mesophytic forest is the potential climax of the area; that by its development the extent of the mixed forest, greatly restricted at one or more times during the Tertiary and early Pleistocene, may expand eastward into what we now know as the Oak-Chestnut region. The outliers are forerunners in a development which would take thousands of years to complete, for it must await the development of land surfaces and of soils no longer related to the Harrisburg cycle. That these mixed mesophytic communities are not relics of a former more extensive mixed mesophytic region (mixed forest of the Tertiary) seems certain because of their limitation to surfaces produced in the last (or present) erosion cycle.

The writers believe that the present distribution of vegetation can be accounted for largely in terms of present relations of the component species to environments, and that environments can be accounted for largely in terms of geomorphic processes acting at the present time. The physiological basis for coincidences observed between species and environments are unknown. The origin of the present relations of species to environments constitutes a knotty problem in the evolution of physiological responses, which can hardly be solved by the methods of physiological plant ecology. In the words of Raup (1942, p. 344)—

> Anyone who has tried to define a plant community and to solve the impenetrable maze of cause and effect relations that

exist in it at a point in time must have wondered how he could ever hope to project it backward into history without either losing it completely or merely compounding his unsolved problems. Yet we find that the developmental view of vegetation is confidently pushed back even into remote geologic time, and both complex communitites and successions are reconstructed on meager paleontological evidence.

Present relations provide a basis for extrapolation to some unknown but not too distant time in the past, perhaps not even to the Pleistocene. Not only is fossil material lacking, but also there exists the additional complication that plants are living matter, capable of evolutionary change. In other words, fossil evidence that the same species had existed in the area in the past would not at the same time constitute proof that their physiological requirements and therefore their ecologic relations were the same as modern species.

CHANGES IN THE RATE OF EROSION AS AN EFFECT OF CHANGING CLIMATE

The writers' interpretation of the landforms of the Little River is based largely on processes that are observed to be active today. On the other hand, it is probable that large climatic changes of worldwide extent have taken place recently enough to have had an effect on the processes that produced the forms that we see. If it is assumed that cloudburst floods like the 1949 flood have had a recurrence interval of 600 years, then in all the 10,000 years of postglacial time there have been 16 flash floods such as that of 1949 in the Little River area. On the other hand, at this time the ice sheet covered all of New York State, the climate of northern Virginia must have been quite different from today's, and the recurrence interval of flash floods was probably different. It is a reasonable speculation that some of the effects of the colder climate may still be preserved as features of the landscape. Since we cannot observe changes in the environment through geologic time, we can only argue the probable effects of climatic change on the basis of interrelations between various elements of the environment inferred from spatial relations that are observable today.

Consider first the probable effect of a change toward a colder climate. Probably there would be an increase in snowfall and an increase in ground moisture, favoring the processes referred to as mechanical weathering and creep. The change might be manifested by an increase in the frequency of unusually snowy and cold winters, or put in another way, by an increase in the severity of winters. It is also a reasonable conjecture that the frequency of severe thunderstorms and hurricanes that might produce floods of cloudburst proportions would be lower during a cold period.

The effect of such a change in climate to colder conditions might be to increase ground moisture, increase the area occupied by the northern hardwood forest, and decrease the area of yellow pine forest. Concomitantly floods in which the vegetation was damaged and the rubble on the ground removed would occur less frequently. It would therefore follow from the argument on the preceding pages that the thickness of the surface mantle of debris would be increased, the upper end of the channelway would move somewhat farther down the valley, and the fill in the valley would thicken. Because the realm of creep would be increased at the expense of the realm of stream sculpture, the summits would become more rounded and the slopes somewhat gentler. Because of fewer periods of heavy runoff, the debris on the slopes and in the hollows would contain more fine-grained material, and the areas of coarse block rubble would be confined to a smaller part of the valley above the channelway. On the other hand, block fields associated with resistant sandstone beds on ridges and noses, such as those around Reddish Knob, would be especially active because of greater cold and greater snowfall.

Consider now the effect of a change to a warmer climate. We may postulate that with such a change the frequency of cloudburst storms would increase, whereas the frequency of cold and snowy winters would decrease. These changes would result in drier soil conditions, so that areas of yellow pine forest would be expanded to cover a larger part of the valley. The sorting action of running water on the slope would result in a general increase in mean size of the slope debris. The area of coarse block rubble in the hollows would be enlarged. Along the channelways and in the larger valleys the erosive activity of running water would be accelerated, as would the downvalley movement of debris. In exposed places on ridges and noses, however, the block fields below resistant sandstone beds would be stable, and the forest would encroach on their margins.

The above hypothetical argument implies that the form of the terrain is graded in adjustment to a certain climatic regimen and that the debris mantle and vegetation are interrelated components of the terrain. The climatic regimen is defined in terms of the recurrence interval of events that happen sporadically at intervals of rather long duration. Some of the controlling climatic events occur simultaneously from valley to valley. Others, however, are limited to small areas, so that the history of one valley is by no means identical with that of the next, though they may be similar. Some of the most important work of erosion may take place at intervals so widely spaced that they bridge what we commonly think of as minor climatic changes.

The foregoing analysis demonstrates something of the difficulty in determining whether or not a certain landform or deposit is a relic feature of a climate that no longer exists. It may simply be a feature formed by a process active only at widely spaced intervals of time in the modern regimen of climate.

The writers believe that most of the landforms of the Little River area might have been formed in a climatic regimen such as exists today. One feature of the landscape is worth discussion as an example of a landform that probably did not form in today's climate. The first-order valleys cut into the Pocono formation in the eastern part of the area are a drier environment than most other hollows and differ in many ways. They are exemplified by valley 9 at Grooms Ridge (pl. 1; described on page 25). This hollow contains yellow pine forest in contrast to most other hollows. Ericaceous shrubs, such as mountain-laurel, are distributed throughout the area above the channelway, suggesting considerable stability and dryness. The texture of the surface debris, furthermore, is relatively fine. In the coarsest part the mean diameter of the rubble is only 15 mm, whereas the overall average for hollows is over 100 mm. This is because though many large boulders are present, there is sand and gravel between them. Furthermore, the ground slope in the hollow attains a steepness of only 20°, 10° lower than the average for the other studied.

It is suggested that this hollow may not have been affected by the processes of erosion for a long interval of time. The debris on its floor collected during a colder climate when creep was more active because of greater snowfall. It differs from other hollows in that it has formed only a shallow cut into the dip slope of a massive permeable sandstone on a rather gentle slope, and a much heavier rainfall would be required to move the fill than in typical hollows. Presumably the extreme cold periods required for the filling, and the heavy rains required for the subsequent sorting and removal of the fill, have not prevailed in this valley for a long time, at least during the present regimen of climate.

Response of vegetation to climatic changes.—The effects upon vegetation of changes in climate can be spelled out in somewhat more detail. For example, a change to a warmer climate might eliminate northern hardwood forest from the crest of Shenandoah Mountain (p. 27). Conversely, a change to a colder climate might result in expansion of northern hardwood forest on the crest of Shenandoah Mountain, or its appearance on the crest of lower mountains such as Buck Mountain. Spruce forest might occupy part of the crest in the vicinity of Reddish Knob.

Because of the scarcity of data concerning forests of the past, more detailed speculations concerning changes in the vegetation in response to changes in climate are futile. Carried to extremes, climatic changes would destroy or severely modify present forest types, the basis for extrapolation. A loss of species now present in the flora, or the addition of species characteristic of other areas, could create entirely different species groupings possessing entirely different ecologic relations.

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