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ACTING DIRECTOR

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The Physiography of the Upper James River Basin in Virginia

BY

FRANK J. WRIGHT

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CONTENTS

PAGE

Introduction 1
Review of previous literature 2
Acknowledgments 6

The initial surface 7
The earliest restored surface 9

The Upland Peneplane 11
- Levels represented in this region 11
- Dissection of the Upland Peneplane 11
- Monadnocks on the Upland Peneplane 12
- Local remnants of the Upland Peneplane 13
- General character of the warped Upland surface 14
- Domes in the Plateau 15
- Domes in the Alleghany Ridges 16
- Possible Blue Ridge Dome 17
- Relations between the domes 17
- Origin of the domes 18
- Drainage development on the Upland Peneplane surface 19
- Drainage of the domes 19
- Earlier versus later warping 21

Monadnocks on the Valley Peneplane 23
- Anticlinal ridges 23
- Synclinal ridges 24
- Monoclinal ridges 24

The Valley Peneplane 27
- Extent of development 27
- Degree of perfection 28
- Monadnocks in the Valley 29
- Warping 30
- Typical areas of the Valley Peneplane 31
- Degree of dissection 33

The Terraces 35
- Origin and characteristics of terraces in general 35
- Characteristics of terraces in the valleys of the Alleghany Ridges subprovince 38
- Conclusion 41

PAGE

Drainage 43
Drainage development 43
Importance of the subsequent drainage 43
Principal ridge and valley makers 45
Origin of the anticlinal valleys and synclinal ridges 46
Drainage of the anticlinal ridges 47
Drainage of the synclinal ridges 48
Drainage of the anticlinal valleys 48
Drainage of the synclinal valleys 49
Drainage of the monoclinal valleys 49
Asymmetrical topography 49
Drainage modifications 50
Minor drainage changes 51
Slash School marsh 52
Drainage relations northwest of Eagle Rock 53
Windgap in Sallings Mountain 53
Cases of imminent capture 54

Minor topographic features 57
Limestone sinks and caverns 57
Natural chimneys 57
Natural Bridge 58
Pyramid Hill 58

Bibliography 61

ILLUSTRATIONS

PLATE

I. A contour map of the restored Upland (Cretaceous?) Peneplane showing its strongly warped character ..... In pocket

Facing page

II. (A) Sounding Knob; (B) "The Alleghany Front" 12

III. (A) The Upland Peneplane on the Alleghany Mountain; (B) Alleghany Mountain 16

IV. (A) Walkers Mountain; (B) Rich Patch Mountain at Clifton Forge 24

V. (A) Monterey Mountain; (B) Valley Peneplane in the vicinity of Mt. Solon 28

VI. (A) Mole Hill near Harrisonburg; (B) Valley Peneplane near Staunton. 30

VII. (A) Valley Peneplane near Fincastle; (B) Valley Peneplane west of Covington 32

VIII. (A) Terrace near Covington; (B) Terrace near Millboro Springs 36

IX. (A) Terraces on Jackson River near Covington; (B) Monterey Mountain 40

X. (A) Bolar anticlinal valley; (B) Warm Springs anticlinal valley 46

XI. (A) Monterey synclinal valley; (B) Windgap in Sallings Mountain near Natural Bridge 50

XII. (A) Sinkholes near Eagle Rock; (B) Natural chimneys near Mt. Solon. 54

XIII. Natural Bridge 58

FIGURE PAGE

1. Index map showing location of area studied 3
2. Rock-defended floodplain terraces 36
3. Floodplain terraces 36
4. Rock terraces 37
5. Rock terraces due to successive uplifts 37
6. Rock-defended rock terraces 38
7. Sketch from photo showing sag in the Blue Ridge through which James River flows 44

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LETTER OF TRANSMITTAL

VIRGINIA GEOLOGICAL SURVEY,

UNIVERSITY OF VIRGINIA,

CHARLOTTESVILLE, JULY 15, 1925.

Governor E. Lee Trinkle, Chairman, and Members of the State Geological Commission:

Gentlemen:—I have the honor to transmit to you, herewith, and to recommend for publication as Bulletin No. XI of the Virginia Geological Survey Series of Reports, a manuscript and illustrations of a report entitled "The Physiography of the Upper James River Basin in Virginia," by Doctor Frank J. Wright.

This report embodies the results of a detailed study of the surface features of the central part of the Valley province of Virginia, and constitutes a distinct and valuable contribution to the geology of the western part of the State.

Respectfully submitted,

ALBERT WILLIAM GILES,
Acting Director.

THE PHYSIOGRAPHY OF THE UPPER JAMES RIVER BASIN IN VIRGINIA

By Frank J. Wright.

INTRODUCTION

In the region to be discussed in this paper a crystalline oldland on the southeast was overlapped by Paleozoic sediments on the northwest; the inner margin of these sediments was involved in folds which were closely compressed near the oldland, becoming more open and finally disappearing toward the northwest; the entire area was more or less perfectly peneplaned, and later uplifted with warping; the uplifted peneplane (usually called the "Cretaceous peneplane") was then maturely dissected in hard rock areas and reduced to a new peneplane (usually called the "Tertiary peneplane") in weak rock areas; the whole was finally uplifted again and further dissected.

The Paleozoic rocks in the Newer Appalachians region range in age from Cambrian to Carboniferous. The lowest member is the Shenandoah limestone which has a minimum thickness of 1,500 feet. Owing to its relatively low resistance it is a leading valley maker, although its cherty members form hills and low ridges. The Martinsburg shale is less resistant than the Shenandoah limestone which it overlies. The resistant Massanutten sandstone succeeds the Martinsburg shale and has a thickness of 500 to 600 feet. In the Monterey Folio it is subdivided into the Juniata, Tuscarora, and Cacapon. The Massanutten sandstone is an important ridge maker. Following the Massanutten sandstone the Rockwood formation, comprising 150 to 200 feet of quartzite and shale, frequently flanks ridges composed of the former. The next formation, the Lewistown limestone, is a valley maker with a thickness varying from 300 to 500 feet. The Monterey sandstone is a thin ridge former whose thickness is usually less than 300 feet. The weak Romney shale with an average thickness of about 1,000 feet underlies many valleys. The overlying Jennings formation is several times as thick as the Romney and is sometimes exposed in valleys, but its sandy members form

ridges. The Hampshire formation, with an increasing percentage of sandstone and an average thickness of 1,650 feet, is a mountain maker. The very thin Pocono sandstone frequently caps high mountain areas. The Greenbrier limestone (350-400 feet) and the Canaan formation (1,000-1,300 feet) form valleys, while the Blackwater (400 feet) is resistant and covers much of the higher portions of the Plateau. It is thus seen that the Massanutten sandstone, the Monterey sandstone, the Hampshire formation, the Pocono sandstone, and the Blackwater formation are the leading ridge formers in the district.

The oldland on the southeast is to-day represented by two physiographic provinces, the Blue Ridge and the Piedmont. The Blue Ridge comprises a belt of maturely dissected complex mountains whose steep eastern slopes descend to the gently rolling surface of the Piedmont.

The folded rocks form what is known as the Newer Appalachians or the Appalachian Valley province. In the belt of close folds limestone and shale are the leading rock types and consequently the valley element greatly predominates. In the area of open folds sandstone is abundant and ridges are prominent with subordinate valleys. These two sharply contrasted subprovinces are called the Appalachian Valley and the Alleghany Ridges respectively.

The area of maturely dissected horizontal rocks on the northwest is the Appalachian Plateau. It is separated from the Ridges on the southeast by the Alleghany escarpment, a southeastward facing scarp more than 1,500 feet high.

All the provinces trend northeast and southwest in conformity with the structure of the rock. The index map, Figure 1, shows the exact location of the area under consideration. It comprises the Staunton, Monterey, Natural Bridge, and Lexington quadrangles of the United States Geological Survey.

REVIEW OF PREVIOUS LITERATURE.

Compared with many other areas in the Appalachians the literature of the region under discussion is scanty[1]. Some very early references are made to the geography of the district which are of greater historical than scientific value. Quite naturally the first objects to attract attenion were the scenic features such as Natural Bridge and the limestone caverns.

The first thoroughly scientific work was accomplished by the distinguished geologist, William Barton Rogers, who, as Director of the Geological Survey of Virginia from 1835 to 1841, laid the foundations of Virginia

[1] Complete bibliography may be found at the end of the bulletin.

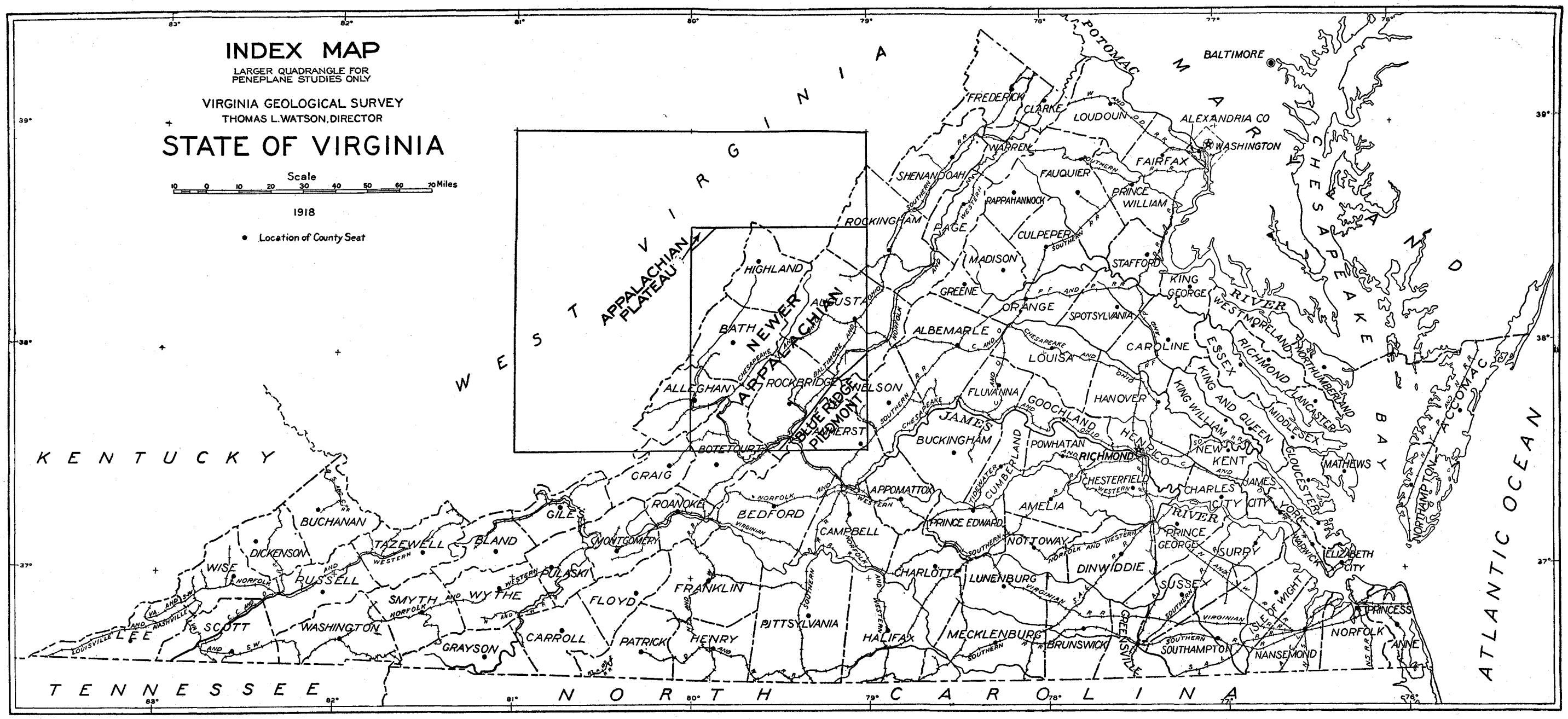


Fig. 1.—Index map showing location of area studied.

geology. Many of his contributions and those of his staff are published in a volume entitled "A reprint of annual reports and other papers on the geology of the Virginias," which appeared in 1884. He carefully subdivided the rocks of the Paleozoic column as they occur in western Virginia and ran many structure sections across the State, some of which were carried to Ohio River.

A journal called "The Virginias" was published in Staunton, Virginia, from 1880 to 1885 under the editorship of Jed Hotchkiss. In the numbers of this periodical, which was devoted primarily to mining geology, one may find descriptions of the area and structure sections.

Probably the most distinguished contributor to the "The Virginias" was Professor J. L. Campbell of Washington and Lee University. He spent considerable time in the study of the geology and mineral resources of the James River Valley, and published a book on this subject. To the American Journal of Science for the second half of 1879, he contributed several articles on the geology of the Valley and the Blue Ridge, especially in the Balcony Falls section.

In 1891 there appeared a discussion by Davis of the extent of the Cretaceous peneplane in the Southern Appalachians in an article on "The geological dates of origin of certain topographic forms on the Atlantic Slope of the United States." The occurrence of the peneplane in Virgina, however, is scarcely more than mentioned. A case of supposed piracy affecting the waters of Back Creek and Jackson River in the Monterey quadrangle was reported by Collier Cobb in 1893 in an article entitled "A recapture from a river pirate."

The following year Hayes and Campbell published their well-known essay entitled "Geomorphology of the Southern Appalachians." This is a comprehensive treatment of the physiographic development of all that portion of the Appalachian region lying south of the Ohio and Potomac rivers. The distribution of the Cretaceous remnants and the perfection of the peneplane are carefully considered. One important contribution consists in their recognition of the warped character of the peneplanes, both Cretaceous and Tertiary. Contour maps of these warped surfaces are published with the essay, and longitudinal axes of elevation and transverse axes of oscillation are located on the maps. Because of the large dimensions of the area considered, the contour lines could not be expected to convey more than a general idea of the nature of the warped surface. Their maps show no local domes, and their contours swing in nearly parallel lines across the area now being studied. The slope of the warped surface was represented

by them as not so steep and as more regular than it really appears to be. Hayes and Campbell also deal with drainage developments in the Southern Appalachians.

In 1895 Hayes again discussed "The Southern Appalachians," but the northern limit of the territory which he then covered did not reach the area now under consideration. He described two peneplanes, the upper being the so-called Cretaceous peneplane and the lower a valley-floor peneplane called Tertiary. "The Northern Appalachians" were described by Willis in the same year, but he scarcely does more than refer to the present area. He likewise recognized two peneplane levels, the Kittatinny and Shenandoah plains. The former, an upland surface, was regarded as Cretaceous in age. The name Shenandoah was used for the lower surface because of its broad development in the Shenandoah Valley of Virginia. The development of the Shenandoah River was traced by this author.

In his "Geology of the Catoctin Belt" published in 1894, Keith describes two periods of baseleveling earlier than the Tertiary. He also recognized one well defined Tertiary level and a less distinct later Tertiary level, as well as two Pleistocene peneplanes. Warping accompanied the uplift of both the later Cretaceous and the Tertiary peneplanes, but it was probably much stronger in the former case. In the present study only one peneplane of presumably Cretaceous age is distinguished. In addition, a distinct valley (Tertiary?) level and several lower less perfectly developed erosion surfaces are recognized in the region under discussion. The two peneplanes are believed to have been notably warped during uplift.

"Some stages of Appalachian erosion" is the title of an article by Keith which appeared in 1896. The peneplanes of Tennessee Basin are considered. He recognized four distinct peneplanes here, as compared with five well developed peneplanes and one less distinct level in the Catoctin Belt. As to warping the author says, "In some cases these planes have been warped from their original level, but far the greater portions of them retain nearly their original attitudes. . . . This view departs considerably from the theories of other authors, who have defined the peneplanes as dome-shaped or warped surfaces, making the warping the predominant feature of the uplift. Further differences of view exist in the distinction of many peneplanes instead of a few."

Although Massanutten Mountain is not within the limits of our study it is typical of a class of ridges that occur in the area. Consequently Spencer's "Geology of the Massanutten Mountain in Virginia" is of interest, especially since it deals with the Cretaceous peneplane. Surface in 1907 published

a popular description of the "Geography of Virginia," which treats the general features of the State. "Drainage changes in the Shenandoah Valley Region of Virginia" is the title of an article by Watson and Cline which appeared in 1913. This study deals with Potomac drainage and reviews the physiographic history of the region. According to these authors there have been four cycles, the Kittatinny (Cretaceous?), represented by remnants of a mountain top peneplane, the Tertiary (?), represented by certain groups of hills in the Great Valley, the Shenandoah represented by the Shenandoah Plain, and the Recent, represented by present streams.

A bulletin of the Virginia Geological Survey entitled "Manganese deposits of the West Foot of the Blue Ridge, Virginia," published in 1919, contains a discussion on Physiographic Forms by G. W. Stose. He describes four peneplanes: The summit, upland, intermediate and valley-floor. "The upland peneplane is regarded as Jurassic-Cretaceous in age and the summit peneplane is probably still older. The intermediate peneplane is regarded as Upper Cretaceous in age, the valley-floor peneplane as early Tertiary in age, and a lower valley-floor terrace, where present, as late Tertiary in age." In that report the author confines himself almost entirely to the Blue Ridge, whereas in the present work the peneplane studies were conducted for the most part in the Newer Appalachians. In the area now under consideration the writer did not find sufficient evidence to justify the recognition of a definite erosion surface older than the Upland Peneplane. Neither could he identify the intermediate peneplane which Stose describes as being "poorly represented on some of the tops of the foot hill ridges, spurs, knobs, and in some low divides of the Blue Ridge." The Valley Peneplane in the present work is correlated with the valley-floor peneplane of Stose. The present writer also agrees with Stose as to the presence of bench and terrace levels below the valley-floor peneplane.

Aside from the papers cited there has been no important physiographic treatment of the region as a whole, or any of its parts. The small group of papers published on the Southern Appalachians in the last decade of the nineteenth century dealt primarily with the region of southern Virginia and Tennessee. The middle western portion of Virginia has been neglected.

For a number of years before his death Professor Joseph Barrell made a study of the peneplanes of the Northern Appalachians. In 1920 the American Journal of Science contained a lengthy report of the results which Professor Barrell had accomplished in that area. The article was under the editorship of H. H. Robinson and was entitled "The Piedmont terraces of the Northern Appalachians." The author believed that the surface of

New England represents a series of marine terraces extending from northeast to southwest. The elevations range from 2,450 feet on the northwest to 120 feet on the southeast. There are in all two Cretaceous, one Oligocene, five Pliocene, and three Pleistocene marine terraces. In addition to these he recognized in his earlier studies two peneplanes at lower elevations than the higher marine terraces. These he thought were parts of the well-known "Cretaceous" peneplane. From oral statements made during his lifetime it is believed that these subaerial peneplanes were regarded as Eocene and Miocene in age. In the present study the writer did not discover any erosion features in this region which seemed to require marine agencies for their explanation.

Reference should be made to the paper presented by Davis in 1889 on "The rivers and valleys of Pennsylvania," from which helpful suggestions applicable to Virginia problems have been derived.

The United States Geological Survey has published folios for two of the quadrangles included in the present field of study, the Staunton and Monterey. These have been helpful to the writer, and the reader is referred to them for information of a geological nature. The various publications of the Virginia Geological Survey, including the Geological Map of Virginia, have been of great assistance.

Two large scale topographic maps have recently been published for the southern half of the old Natural Bridge quadrangle, the Natural Bridge Special for the southeastern quadrant, and the Eagle Rock for the southwestern. These recent maps represent the topography much more accurately than the earlier smaller scale maps.

ACKNOWLEDGMENTS.

I take pleasure in acknowledging the valuable suggestions and generous cöoperation of the late Professor Thomas L. Watson of the University of Virginia, who, as Director of the Virginia Geological Survey, assigned to me this problem. To Professor Douglas W. Johnson of Columbia University, who has had direct supervision of the work, I am indebted for suggesting the importance of this field of study, for helpful criticisms, and especially for a week spent with me in the region during which time we traversed nearly 400 miles of the more instructive routes within the district. My thanks are also due Professor Albert W. Giles, Acting Director of the Virginia Geological Survey, who has borne the editorial burden of publication, and to Mr. S. P. Holt, M. E., formerly of the University of Virginia, who spent a week with me determining terrace levels along the mountain streams.

THE INITIAL SURFACE

There is no element in the present topography of the Newer Appalachians, the origin of which dates back to the time of the Paleozoic oldland or to the period of deposition of sediments upon its flank. Likewise in the crystalline area of the Blue Ridge and Piedmont, post-Paleozoic erosion in successive cycles has been so extensive that all traces of the earlier features of the oldland have been completely obliterated. For these reasons it is not profitable to go into a consideration of the early physiographic history of the region. Of great interest and importance, however, is the surface formed by the folding and uplift of the sediments into a land mass. We must recognize the possibility that many of the present streams may have had their courses determined by the slopes of this early surface.

There are two methods of reconstructing the initial surface of the folded Appalachians. The first and most obvious is to assume that the great folds which now appear in the district had an appropriate and similar expression on the original surface far above the present level. This method has usually been employed in making restorations in folded regions. A very notable instance of its use is found in Davis' classical essay [1] on the rivers and valleys of Pennsylvania. Here he restores the former surface on the basis of structure in depth exposed by long periods of erosion. Thus he says: ". . . for our purpose and in view of the moderate relief of the existing topography it suffices to say that wherever the lower rocks are now revealed in anticlinal structures there was a great upfolding and elevation of the original surface; and wherever the higher rocks are still preserved, there was a relatively small elevation." On the basis of this restoration the author assumed the presence of longitudinal consequents flowing in synclinal troughs and lateral consequents coursing down the flanks of anticlines. The water found its way from one syncline to its neighbor across sags in the ridges or around the ends of pitching anticlines. Having determined the position and direction of flow of the initial streams, Davis traced through numerous changes the development of the present drainage of Pennsylvania.

The second method of restoring the initial surface is on the basis of the present drainage. If it were possible to determine which streams to-day

[1] Davis, W. M., Geographical Essays. The rivers and valleys of Pennsylvania, p. 450.

are original consequents we could use the present drainage pattern as a means of reconstructing the initial form which determined that pattern.

Neither method of reconstructing the initial surface necessarily gives dependable results. There are certain outstanding difficulties which make it necessary to use caution in applying either method. In the first place, folds in depth are not necessarily expressed on the orginal surface, which may instead show only a broadly arched or domed upland. Before the surface is reached the major structural features may have been reduced to minor undulations, or may have disappeared entirely. In the region under discussion there may have been many thousand feet of sediments overlying the youngest formations now observed in the portions of the folds still remaining, and the structure developed under this overburden cannot with any certainty be said to have had a corresponding topographic expression on the initial surface. A second difficulty is found in the successive drainage modifications due to the development of subsequent streams along belts of weak rocks. In dissected folded regions subsequent drainage is especially important and the adjustment of streams to structure is apt to be so complete that the early drainage pattern is totally obscured. Streams flowing down the pitch of synclines, and apparently consequent in position, may really have developed as subsequents. Lastly, the region, if it has been peneplaned and uplifted, was most probably warped during uplift so that a new set of streams may have been developed on the warped peneplane surface. The presence of new streams and the diversion of old streams on such a surface would seriously complicate the problem. These three difficulties confront the use of either of the two methods in any folded region.

In the Virginia-West Virginia area these difficulties are aggravated to an unusual degree. The folding is closer and on a smaller scale than, for example, in Pennsylvania. Furthermore, the folds seem to be more complicated than in the ridges of the latter state. Hence the probability of these folds being represented by appropriate topographic expression at the surface is much less than in regions of larger and more open folds. In many cases it is difficult to determine the initial pitch of some of the closely compressed synclines, especially after they have been affected by later warping. The enormous development of subsequent drainage in these close-set parallel valleys must have removed almost every trace of the original drainage.

In the light of the difficulties enumerated above, each of which has been encountered in the study of this problem, we conclude that it is impossible in this area to restore the initial surface or the original consequent drainage on the basis of either structure or present drainage pattern. It does not seem possible to trace the form or the drainage pattern farther back than the Upland Peneplane surface.

THE EARLIEST RESTORED SURFACE.

There is no topographic feature in the region that dates earlier than the Upland Peneplane and its monadnocks, with the possible exception of the Blue Ridge, whose topographic characters are not specially considered in this report. So far as we are able to determine there is no element in the drainage the explanation of which cannot be found in conditions which obtained during the cycle of erosion that formed this peneplane, or during later cycles.

When the Upland Peneplane was uplifted it was also warped. Hayes and Campbell recognized the warped character of this surface in their well known paper on the geomorphology of the Southern Appalachians. Furthermore, the uplifted surface is now to a great extent destroyed by valleys cut below it, and occasionally has monadnocks rising above it. These facts make difficult the ready recognition of the peneplane level. It is particularly difficult to locate in the region of the folds, because the hard rock formations there are relatively thin. Tilted thin formations do not resist erosion as long as thicker ones, and consequently the peneplane is not nearly so well preserved in this region as in some others.

In order to obviate these difficulties and to restore as well as possible the Upland Peneplane as it existed after uplift, a series of 26 projected profiles was constructed. On each profile were plotted the maximum elevations in a belt of country two miles wide, stretching from northwest to southeast normal to the trend of the folds. A two mile zone was selected because it appeared, from a study of the region, suitable to bring out most clearly the elevations rising to a common level, and not to obscure that level by including too many monadnocks. The 26 profiles after being plotted were cut from heavy paper strips and set up vertically in their proper relative positions on a level surface. By visualizing the assembled profiles from different viewpoints it was possible clearly to recognize the peneplane; and departures from it, due to monadnocks

rising above it and large valleys cut below it, could be eliminated more satisfactorily than in any other way. It is believed that the position of the peneplane in most of the area was determined with reasonable accuracy. The restored surface was contoured, and a reproduction of it is shown on the large map. (Plate I, in pocket).

THE UPLAND PENEPLANE.

Levels represented in the Upper James River Basin.

There are three levels which are remarkably distinct and well defined in this region. The Upland Peneplane, represented by the crests of many ridges in the folded mountains and in the Blue Ridge, usually stands at elevations of from 3,200 to 4,600 feet. It descends to 1,400 feet in Gilmer County of West Virginia. This first level is well above and entirely distinct from the second, represented by the floors of the Great Valley and of some of the larger valleys in the Alleghany Ridges. The Valley Peneplane is in turn dissected by streams to depths of 400 or 500 feet and their beds represent the third important level. Consequently there are five chief elements in the topography, which, beginning with the highest are as follows: a, Monadnocks on the Upland Peneplane; b, Remnants of the Upland Peneplane; c, Monadnocks on the Valley Peneplane; d, the Valley Peneplane; e, Trenches cut below the Valley Peneplane.

The Upland Peneplane is considered the equivalent of the highest peneplane in New Jersey and Pennsylvania, where it has generally been regarded as Cretaceous or Jura-Cretaceous in age. No attempt has been made to determine its age relations in the field under consideration for the reason that the necessary data do not appear to be available.

Dissection of the Upland Peneplane.

The Upland Peneplane has been strongly dissected. During the next later cycle the soft rock areas were reduced about 1,500 feet to an even surface representing a lower peneplane which has itself in subsequent time been trenched by streams to depths of four or five hundred feet. The resistant rock areas have, of course, withstood erosion much more successfully. Where the hard rock outcrops were narrow they have been reduced much more than where they were broad. Consequently there are ridges at all elevations between the Valley and Upland Peneplanes, their height depending chiefly upon the resistance and width of outcrop of the ridge-maker. The preserved remnants of the peneplane have a gently rolling topography, and when seen from a distance present a very even skyline.

Monadnocks on the Upland Peneplane.

In the central Appalachians the Upland Peneplane evidently reached a very high degree of perfection. At the close of the cycle in which it was formed very few erosion remnants were left standing above the general level. These monadnocks presumably owed their existence either to superior resistance of the rocks or to greater distance from main drainage lines.

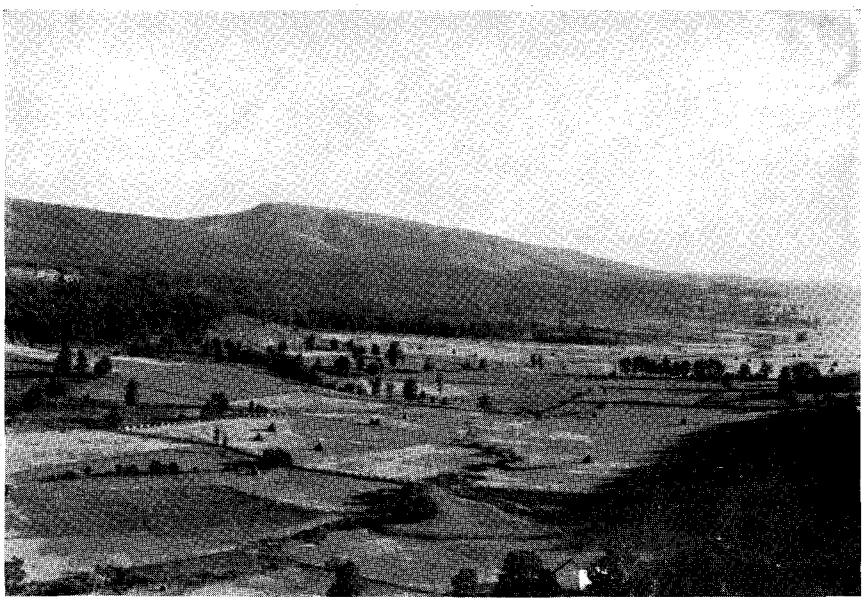
The more representative monadnocks occurring in the area under discussion may briefly be described.

Bald Knob.—There are at least five or six peaks in the area bearing the name of "Bald Knob." The present description applies to the Bald Knob on the Back Alleghany Mountain in the Plateau region, represented on the northwestern corner of the Monterey quadrangle. It stands about 200 feet above the upland surface which here reaches its maximum elevation of 4,000 feet. The resistant sandstone and conglomerate of the Blackwater formation, which is considered the equivalent of the Pottsville, is the country rock in Bald Knob as in much of the Plateau surface.

Sounding Knob.—Sounding Knob is located about four miles south of Monterey. Tuscarora quartzite, a subdivision of the Massanutten sandstone, composes the two monoclinal ridges representing the limbs of the anticline which unite in Sounding Knob marking the structural end of the Bolar anticlinal valley. The core of the knob is formed of basalt. This monadnock is not an imposing feature for it rises only 200 feet above the peneplane level which is here about 4,200 feet above the sea. (Plate II, A).

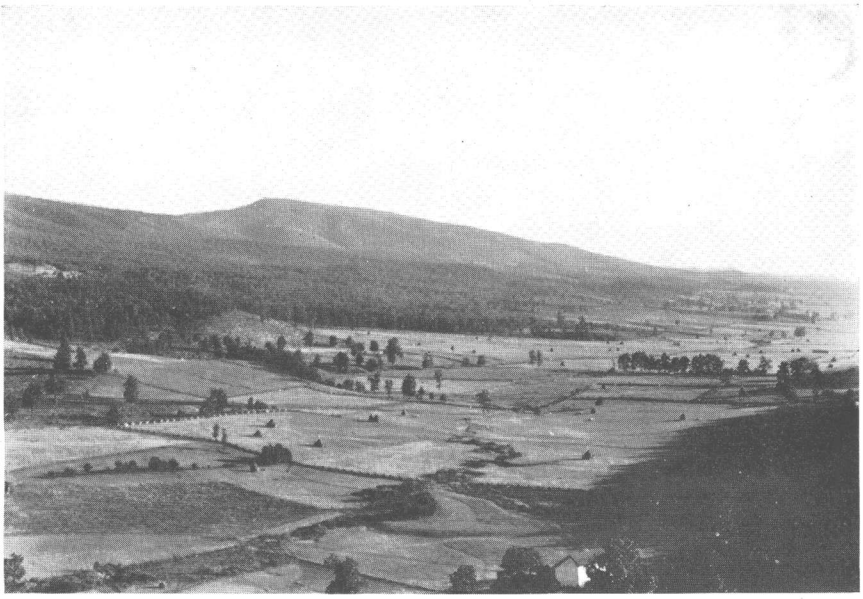
Elliott Knob.—The massive Elliott Knob stands in the western part of the Staunton quadrangle with an elevation of 4,473 feet and is the highest mountain in this portion of Virginia. Its summit is nearly a thousand feet above the peneplane, which here has an elevation of approximately 3,500 feet. Although it is impossible to know with certainty the position of divides in the early period it is possible that Elliott Knob suffered less from erosion because it was remote from main drainage lines. Resistant sandstone enters largely into its composition. Owing to its elevation it is a commanding object as seen from distant points in the Great Valley to the southeast.

Other Monadnocks.—Northeast Peak (3,800 feet) on the Shenandoah Mountain near the eastern border of the Monterey quadrangle appears to be a low monadnock, 400 feet above the peneplane, while Bald Knob (4,410 feet) near the Virginia-West Virginia line in the northwestern part of

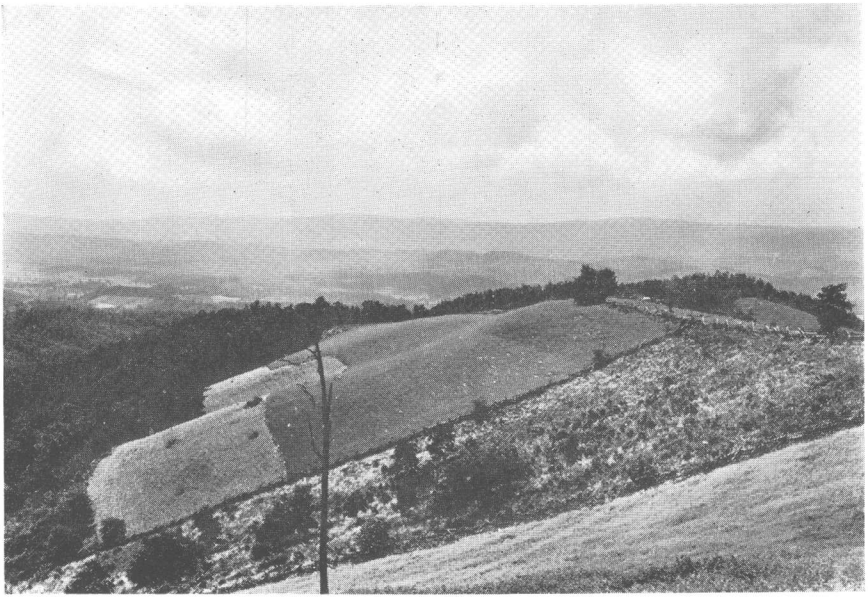


(A) Sounding Knob from Pyramid Hill about one-half mile south of Monterey.

(B) The "Alleghany Front"—looking west from a point near the "Top of Alleghany" on the Staunton-Parkersburg pike.



(A) Sounding Knob from Pyramid Hill about one-half mile south of Monterey.



(B) The "Alleghany Front"—looking west from a point near the "Top of Alleghany" on the Staunton-Parkersburg pike.

Augusta County is a better example, having a height of 600 feet above the peneplane. As a type of less prominent eminences on the peneplane surface we may cite Bald Knob on Warm Spring Mountain six miles north of Clifton Forge.

In studying the existing monadnocks one is impressed with their small number. Furthermore their slight elevation above the upland level shows that they must have been for the most part only low hills on this surface. The high degree of its perfection is thus one of the outstanding features of the Upland Peneplane.

Local Remnants of the Upland Peneplane.

Cheat Mountain.—Cheat Mountain is the local representative of the Back Alleghany Mountain whose precipitous eastern "Front" forms the boundary between the Appalachian Plateau and the Newer Appalachians. (Plate II, B). The Alleghany Front is a striking escarpment which marks the southeastern limit of the Plateau through most of the Appalachian states. The first fold adjacent on the southeast is usually an anticline which erosion has unroofed. A valley is developed on the anticline whose massive sandstone layers on the western flank of the fold maintain an imposing wall.

On the top of this mountain the peneplane is strongly developed at an elevation of from 4,400 to 4,600 feet in the Bald Knob region, which is the maximum for the whole district. The sandstone layers which form most of the surface have a gentle dip to the west, and their edges are beveled by the erosion surface thereby demonstrating its true peneplane character. Shaver's Fork of Cheat River flows in a shallow valley slightly intrenched below this upland level.

"Top of Alleghany."—One of the best remnants of the Upland Peneplane in the entire area is to be found on the summit of the Alleghany Mountain where it is traversed by the Staunton-Parkersburg pike about 15 miles west of Monterey. This locality is know locally as the "Top of Alleghany." The Alleghany Mountain in this region is erroneously designated the "Alleghany Front" in the Monterey Folio. The true "Front" is never located in the midst of the ridges but at the southeastern margin of the Plateau as explained in a preceding paragraph. The upland surface forming the top of the mountain is held up by the resistant Hampshire sandstone in the trough of a broad syncline. For several miles

across the strike of the fold the beds are essentially horizontal but on each side they are bevelled by the surface, which precludes the possibility of this level being a structural plane. It is a true peneplane. The mountain is in no sense a ridge but an upland surface several miles in width, moderately dissected, but preserving its uniform elevation and evenness of surface for a number of miles. (Plate III, A). The average elevation is about 4,400 feet. When viewed from a distance its even skyline is very striking. (Plate III, B).

Shenandoah Mountain.—The massive Shenandoah Mountain extending from Fort Lewis on Cow Pasture River to the northern limit of the Staunton quadrangle is synclinal in structure. It is an important drainage divide, and because of its massive character constitutes a great barrier to the movement of the population. Owing to mature dissection the ridge crests do not show upland remnants, but their general elevation indicates that through most of the Staunton area the Upland Peneplane is located at an elevation of 3,400 to 4,000 feet.

General Character of the Warped Upland Surface.

From our consideration of the character of the Upland Peneplane, it is evident that at the close of the cycle it was a vast lowland of remarkably slight relief. Today it stands high above sea level. In the process of uplift it was badly warped. We are now prepared to study the form of this warped surface and its effect on drainage.

In this study it is desirable to include an area sufficiently large to show the development of the peneplane in regions embracing different drainage systems and representing different types of structure. Furthermore a considerable area is necessary to show the effects of warping. Consequently 12 adjoining quadrangles were selected with the Lexington, Virginia, quadrangle occupying the southeastern corner. The area extends three quadrangles or 105 miles in a north-south direction and four quadrangles or 112 miles in an east-west direction.

The methods employed in securing the data for a contour map of the warped Upland Peneplane have already been outlined on pages 9 and 10. The great difficulties involved in the restoration of this peneplane in the folded mountain region of Virginia were also stated. The resistant formations or ridge makers are so thin that they usually do not preserve remnants of the peneplane, and in many cases do not even approach that level. Hence for local areas on the large map the contours representing the warped

Upland Peneplane surface must not be regarded as showing more than the general form of that upland where the difficulties are greatest. The restoration is probably much more accurate in the Plateau than elsewhere.

The zone of maximum uplift extends along an axis trending northeast-southwest in the region of the eastward facing scarp of the Appalachian Plateau. The slope of the peneplane descends toward the northwest and the southeast from this central uplift, the former slope being in general the steeper.

A second possible axis of uplift extends from High Knob near the northeastern corner of the map to Potts Mountain on the southern border. This axis is not as strongly developed as the preceding but the arrangement of the upland contours strongly suggests its presence.

Besides this general upwarping along more or less well-defined axes, there are apparently local areas of greater elevation of the peneplane level. These small districts are called domes. Three of these domes, the Bald, Spruce, and Job, are located on the axis of maximum uplift which follows in a general way the southeastern scarp of the Plateau. In like manner the High Knob and Potts Mountain domes lie on an axis running through High Knob and Potts Mountain.

The domes are more easily determined and stand out more clearly in the Plateau than in the other regions covered by the map. This is due to the fact that there are in the Plateau more remnants of the peneplane which make possible its more exact restoration. In the Newer Appalachians only ridge crests have survived. Consequently the preservation of broad domes in this region is to be expected only in rare cases.

Domes in the Plateau.

The following well defined domes are located in the Plateau: (1) Bald Dome, (2) Spruce Dome, (3) Job Dome, (4) Strouds Dome, (5) Fisher Dome. The above names are taken from prominent elevations near the summits of the domes.

Bald Dome.—This is a broad dome having an elevation of 4,600 feet with its longer axis running northeast-southwest, parallel to the axis of major uplift. The slope to the northwest is very much steeper than to the southeast. A secondary axis of uplift seems to run eastward from this dome to High dome. This uplifted zone constitutes the present divide between the James and Potomac drainage.

Spruce Dome.—Spruce dome is located in Pocahontas County about 20 miles southwest of Bald dome in the region of Big and Little Spruce knobs. It is 4,600 feet in elevation or about the same as the preceding dome.

Job Dome.—The axis of uplift appears to bend slightly to the southwest in passing from Spruce dome to Job dome which is 400 feet lower than its neighbor to the northeast. The distance between them is about 20 miles. On the northwest the slope is regular and about the same in degree as in the case of Spruce dome.

Strouds Dome.—The Webster-Nicholas county line cuts through Strouds dome about 25 miles slightly west of north from Job dome. In elevation it is only 2,800 feet. The contour lines swinging southwest on the surface of the Plateau are strongly deflected to the west around Strouds dome. In the Gauley River region to the southwest they again resume their normal courses.

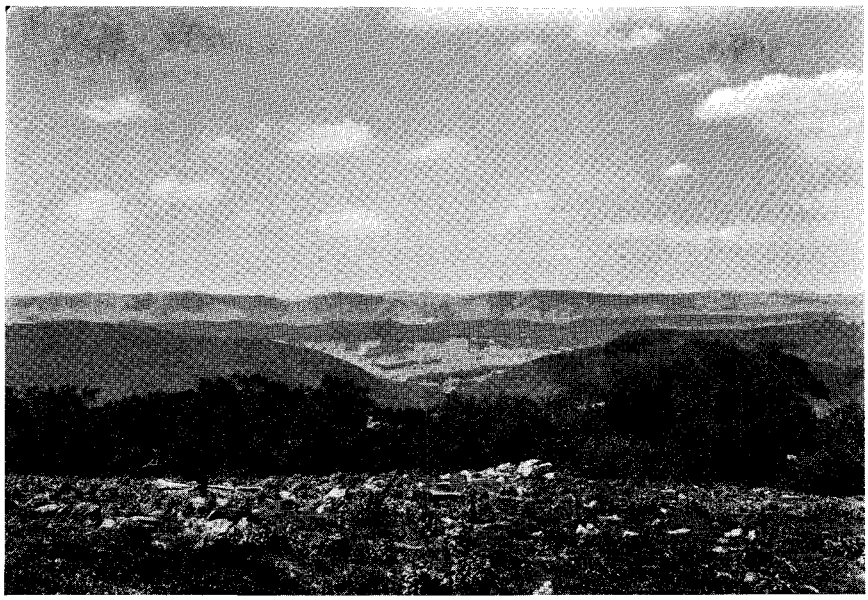
Fisher Dome.—Fisher dome is located in Braxton County midway between the Elk and Little Kanawha rivers. The 1,800 foot peneplane contour encloses its summit. The slopes are very gentle and its influence on the topography is not so marked. The contour lines swing around it in broad sweeping curves.

Domes in the Alleghany Ridges.

The difficulties involved in restoring the upland surface are much greater in the Alleghany Ridges region than in the Plateau. It has already been shown that this must be the case, because of the small areas of upland surface which can be preserved on the crests of linear ridges formed by resistant rocks having moderate thickness and steep dip. The agencies of erosion operating on each side tend to sharpen the crest and reduce the elevation below the upland level more rapidly than in areas like the Plateau where the outcrops of resistant rock are much broader. Nevertheless, with the aid of projected profiles it appears that we are able to recognize two areas in the Alleghany Ridges which show evidence of strong doming. The first is found in the northeastern section and will be called High dome; the second is in the southwest and will be called Potts Mountain dome.

High Dome.—High Knob is a peak on the Shenandoah Mountain on the Virginia-West Virginia state line in the southeastern part of the Franklin quadrangle. The possibility that this dome may have been asso-

(A) The dissected Upland Peneplane as it is developed on the Alleghany Mountain. View looking north from a point about two miles east of "Top of Alleghany." Faintly outlined in the distance is Spruce Knob, a monadnock.



(B) Photo taken from Sounding Knob looking west. The even-crested mountain in the background is the Alleghany which maintains the Upland Peneplane. Vanderpool Gap is a conspicuous feature in the middle ground. Little Mountain, with cleared fields extending far up its slopes as seen through the Gap, is clearly far below the upland level.

(A) The dissected Upland Peneplane as it is developed on the Alleghany Mountain. View looking north from a point about two miles east of "Top of Alleghany." Faintly outlined in the distance is Spruce Knob, a monadnock.

(B) Photo taken from Sounding Knob looking west. The even-crested mountain in the background is the Alleghany which maintains the Upland Peneplane. Vanderpool Gap is a conspicuous feature in the middle ground. Little Mountain, with cleared fields extending far up its slopes as seen through the Gap, is clearly far below the upland level.

ciated in origin with the zonal uplift running east from Bald dome should be admitted. They have the same elevation and their separation may be apparent rather than real.

Potts Mountain Dome.—Potts Mountain dome in the southwest is a broad uplift affecting a considerable area in Craig and Alleghany counties. The entire dome is not shown because it passes off the southern edge of the map.

Possible Blue Ridge Dome.

The profiles were carried across the Great Valley in an effort to locate the Upland Peneplane in the Blue Ridge. The results were not satisfactory for several reasons, chief among which was the very restricted area of the Blue Ridge upland that has been preserved. The profiles suggest the presence of a dome, which is shown on the map in broken lines. It is merely a suggestion and should be so regarded.

Relations between the domes.

Bald, Spruce and Job domes have already been referred to the same northeast-southwest axis. They are local domes situated on the zone of maximum uplift. In like manner High and Potts Mountain domes in the Ridges seem to lie on an axial line paralleling the one just described. Strouds and Fisher domes in the western portion of the map appear to be isolated and do not indicate a northeast-southwest alignment so far as this area is concerned.

It is interesting to note that a northwest-southeast line joining the northern end of Potts Mountain and Job domes is nearly parallel to a line joining Spruce and Strouds domes. Furthermore Bald and Fisher domes may be joined by a line which is roughly parallel to the two former. If there are domes in the Blue Ridge the northwest-southeast lines might be greatly lengthened toward the southeast.

These relations suggest the possibility of the existence of two series of axial lines of elevation and the occurrence of domes at the points of intersection. The fact must be kept in mind, however, that points scattered haphazard over any area can be connected by lines having no real significance. The writer merely points out the possibility that the domes may represent the intersection of two systems of upwarpings approximately at right angles to each other, the first and major series of undulations trending northeast-southwest and the second northwest-southeast.

Origin of the domes.

There are at least two ways in which these domes may have originated. They may represent unreduced headwater regions or hard rock areas on the original Upland Peneplane, or they may be due to warping. There are several lines of evidence which seem to discredit the first mode of origin and to confirm the second.

In the first place the slope of the peneplane as shown on the map is very steep. In a distance of 35 miles northwest from Bald dome the surface descends 3,000 feet, which means an average slope of more than 80 feet per mile. From Job dome the peneplane slopes down toward the northwest at an average rate of approximately 100 feet per mile for a distance of 25 miles.

Late mature streams sometimes have gradients as low as several inches per mile. Because of the high degree of its perfection we infer that the Upland Peneplane represented a very late stage in the cycle. Such slopes as those given above are wholly incompatible with the stage of development which streams must have reached so late in the cycle. Subsequent deformation alone, resulting in the formation of upwarpings and local domes can explain these very steep slopes on a former almost perfect peneplane.

The distribution and arrangement of the drainage lines seem to throw some light on the origin of the domes. Williams River heads against the slope of Spruce dome and instead of going down the slope of the peneplane surface it flows back across the summit of the dome which is some 400 feet high, and discharges on the opposite side. In a similar fashion Job Knob Fork rises on the eastern slope of Job dome, flows up the peneplane slope, and, after bisecting the dome, discharges to the south. If these domes were unreduced headwater regions or hard rock areas on the original surface it is not probable that streams would flow across them in the manner just described.

Webster County, West Virginia, lies on the northwestern slope of the major uplift. Eleven peneplane contours cross it from northeast to southwest. The geological map of this county published by the West Virginia Survey shows that the surface formations become progressively younger toward the northwest.[1] This is typical of the Appalachian Plateau. Although the surface in this County is formed respectively by four different formations there is little or no topographic expression of this fact. The

[1] Reger, D. B., Detailed report on Webster County. West Virginia Geol. Surv., 1920.

peneplane surface however is 2,000 feet lower on the western than on the eastern border of the County. The lack of topographic expression of the different formations is attributable to the lack of any considerable variation in the resistance of the material. In this portion of the Plateau there seems to be no ground for the assumption that the domes are due to rocks of superior resistance on the original peneplane. Similar conditions are found in Barbour, Upshur, and Fayette counties. By analogy we infer that in the remaining areas of the map resistant rocks are probably not responsible for the domes.

Drainage Development on the Upland Peneplane Surface.

The drainage lines in the Newer Appalachians province at the end of the Upland Peneplane cycle must have been in considerable degree adjusted to the structure of the underlying rock. But the presence of numerous windgaps just below the level of the peneplane indicates that the adjustment was by no means complete, or that many southeastward flowing streams were born on the upwarped Upland Peneplane. In the Plateau province the drainage must have been dendritic, the normal drainage pattern in horizontal rocks.

When the peneplane was uplifted and upwarped in such a manner as to produce domes the drainage was affected in several ways. Uplift caused a normal acceleration of the activity of those streams whose gradients were steepened and a retardation of those streams whose gradients were reduced. In consequence of this condition the rejuvenated streams lowered their channels much more rapidly than those which were affected adversely by the uplift. Stream captures were in this way facilitated. Perhaps also there were new consequent streams developed on the domal uplifts. Thus for two reasons we should expect to find streams flowing away from these domes in a radial fashion. Evidently this feature will be best shown in the Plateau area where the rocks are nearly horizontal. In the Alleghany Ridges all traces of early radial drainage may be entirely lost through the extensive development of subsequent streams on the weak rock belts.

Drainage of the domes.

One of the most striking features of the region is the arrangement of the main drainage lines with reference to the strongly uplifted zone on which are located Bald, Spruce, and Job domes. From this major uplift

the streams flow away in a radial fashion to the northeast, north, northwest, west, and southwest, and it is probable that streams once flowed east and south from this area.

Shaver's Fork of Cheat River rises in the heart of Bald dome and flows 50 miles northeast in a nearly straight course. Tygart River has a course nearly parallel to Shaver's Fork, Middle Fork and Buckhannon River flow almost due north and Little Kanawha River northwest. Elk, Gauley, Williams, Cranberry and Cherry rivers flow west. Greenbrier River heads about 25 miles northeast of the source of Shaver's Fork and parallels the latter stream but flows in the opposite direction to the southwest 100 miles to join New River. Thus through an angle of at least 180 degrees the major streams have a distinctly radial pattern.

The drainage down the eastern slope, which formerly was perhaps as pronounced as the western is at the present time, has been obscured by the enormous development of subsequent drainage. Some of the numerous windgaps through the ridges to the east may easily have been formed by these east and southeast flowing streams. They would be captured by the growth of subsequent streams which cut back along the eastern flank of the dome. Thus Greenbrier River has apparently cut back so far from the southwest that its head is now actually on the northeast side of Bald dome.

Strouds dome seems to stand in an interesting relation to the drainage lines. No stream, large or small, flows across this dome in the direction of the general slope of the peneplane. On the contrary two streams which are apparently headed for this region are for some cause diverted. Williams River, if continued, would bisect the dome, but from its junction with Gauley River it takes a course around the lower slope of the dome. Elk River makes an abrupt angle of about 90 degrees at a distance of ten miles from the dome, which it would traverse were it not for this change in direction. Within the 2,800 foot contour line, which marks the central portion of the dome, are located the heads of eight small streams which radiate in nearly all directions. This suggests very strongly the possibility of the dome having been responsible for the courses of these streams.

The doming appears to be a notable factor in controlling the drainage even in the Ridges, as is indicated by the fact that the axis of uplift extending eastward from Bald dome toward High dome is the main divide between northeast and southwest flowing streams in this region. One must consider the possibility that this uplifted zone may be explained, as in the case of the other domes, either as an unreduced headwater region on the peneplane or a product of subsequent warping. A divide established long

ago, during the development of the Upland Peneplane, might be considered as persisting to the present. This assumption would require a delicate balance between the north and south flowing streams continuing for an enormous lapse of time and in spite of the subsequent undoubted tilting of the peneplane. This seems more improbable than the explanation based on later warping. The average slope of the peneplane surface from this uplift toward the south is to-day about 30 feet per mile. This is altogether too steep for a peneplane surface in its original position, and its explanation must be sought in subsequent deformation.

Earlier versus later warping.

The warped form of the Upland Peneplane is the product of a first warping at the close of the Upland-Peneplane (so-called Cretaceous) cycle and a second warping at the close of the Valley-Peneplane (so-called Tertiary) cycle. In the areas where the Upland Peneplane is well preserved the Valley Peneplane is poorly developed, and vice versa. Consequently it is impossible to determine accurately the amount of warping which should be assigned to each of the two periods of deformation.

The warping of the Valley Peneplane is discussed on page 30. This surface has gentler slopes than the Upland Peneplane. The lower peneplane seems to descend from the northeast toward the southwest and also from the northwest toward the southeast. These slopes are identical in general direction with those of the higher level in the Appalachian Valley region. The degree of slope, however, is less. It seems, therefore, that if it were possible to subtract the later warping, from the combined earlier and later warping, the form of the upland surface would still be similar to the form it now possesses, although the steepness of its slopes would be less accentuated.

MONADNOCKS ON THE VALLEY PENEPLANE.

It is our purpose now to consider those ridges which rise notably above the level of the Valley Peneplane but which are lower than the Upland Peneplane. They range in elevation from about 1,300 feet up to levels slightly below that of the Upland Peneplane, and hence in no way form a series of accordant levels.

The Upland Peneplane beveled across the structure of the country in such manner as to expose hard and soft beds in every conceivable position with regard to the folds. Following the uplift of the peneplane, the rejuvenated streams set actively to work etching out the belts of softer material, leaving the more resistant beds in the form of ridges. These ridges present in many cases very level skylines, even when reduced below the Upland Peneplane level, while in other cases the crest is irregular, or even sawtooth in longitudinal profile. As to structure, we find every variety of anticlinal, synclinal and monoclinal ridge.

Anticlinal ridges.

Anticlinal folds furnish an important class of ridges having even crests below the Upland Peneplane level. In a number of cases a resistant layer in the arch has been denuded. The agents of erosion have swept away the non-resistant beds, but have not yet been able to make the surface of the hard formation irregular through dissection. Consequently the crest of the ridge presents an even skyline wholly unrelated to any peneplane surface, Walker's Mountain in the southwestern corner of the Staunton quadrangle furnishes an ideal example of such a ridge. (Plate IV, A). The resistant Massanutten sandstone forms the surface of this ridge and preserves its remarkably even crest at an altitude of 3,100 feet for a distance of six miles. The level of the Upland Peneplane in this section would be about 3,400 feet.

An even but sloping skyline maintained by a sandstone arch is presented by the northward plunging end of the Rich Patch Mountain anticline. The northern end of this arch was untouched by the erosion which formed the Upland Peneplane, but has been revealed by the stripping away of softer beds during subsequent dissection of the peneplane. In the Iron Gate gorge cut across the fold by James River the anticlinal structure is

clearly shown, and a succession of resistant sandstones separated by weaker beds are seen to preserve the arch, as shown in Plate IV, B.

Rich Patch Mountain presents a fine example of what may be called "core in core" topography. The main mountain near White Rock Gap is developed on an arched hard rock layer which was the core of a still greater anticline. Going north this rock seems to have been entirely removed, and there comes out at a lower level an inner anticlinal core formed by the persistent member shown at the top of Iron Gate gorge. From Iron Gate southwestward for several miles the mountain has a very even crestline unrelated to any peneplane but determined by the axis of the stripped inner hard rock core.

Synclinal ridges.

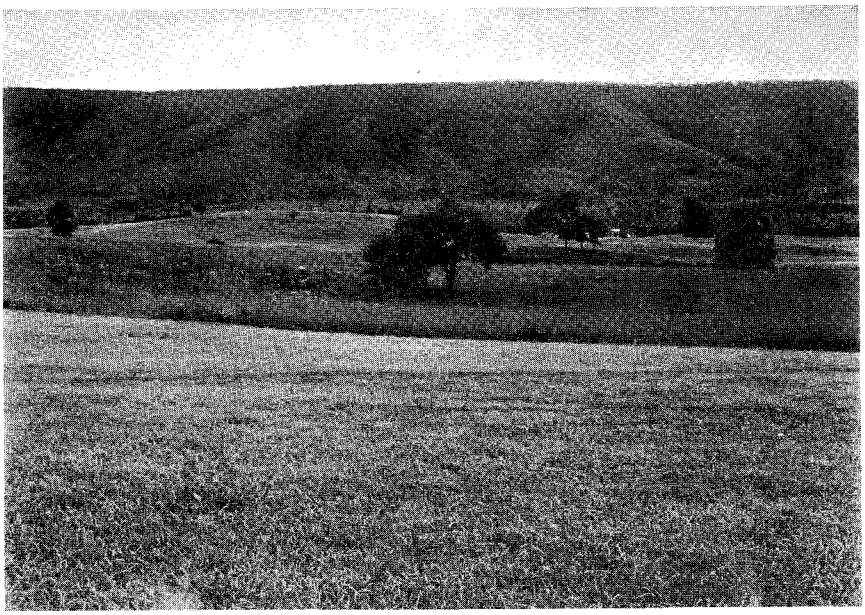
We have already seen that some of the best preserved remnants of the Upland Peneplane are held up by sandstone in the troughs of open synclines. Where the resistant member has been almost or entirely removed by erosion the underlying softer materials are dissected into a series of irregular ridges, having uneven crests. Thus the Pocono sandstone has been removed from some parts of the Shenandoah Mountain syncline and the result is a series of irregular ridges below the upland surface. This is particularly well shown in the northern part of the Staunton quadrangle.

A narrow syncline whose hard rock floor was below the level reached by the earlier cycle of erosion may present an even skyline below the peneplane. This would be true for instance where the relatively narrow outcrops of resistant rock in the sharply upturned limbs of the fold are worn down to the floor of the syncline which, because of its much wider exposure of resistant rock, would be able to maintain an even crestline at any given level.

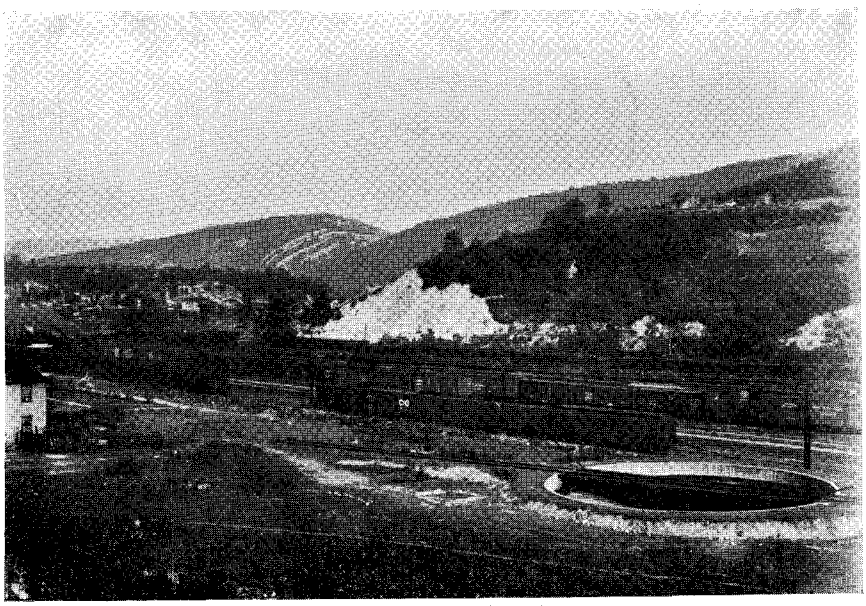
Short Hills, four miles west of Natural Bridge, apparently represent this type of ridge. At the southern end the floor of the syncline was high enough to be reached by the earlier erosion, while the main portion was probably not exposed until the following cycle.

Monoclinal ridges.

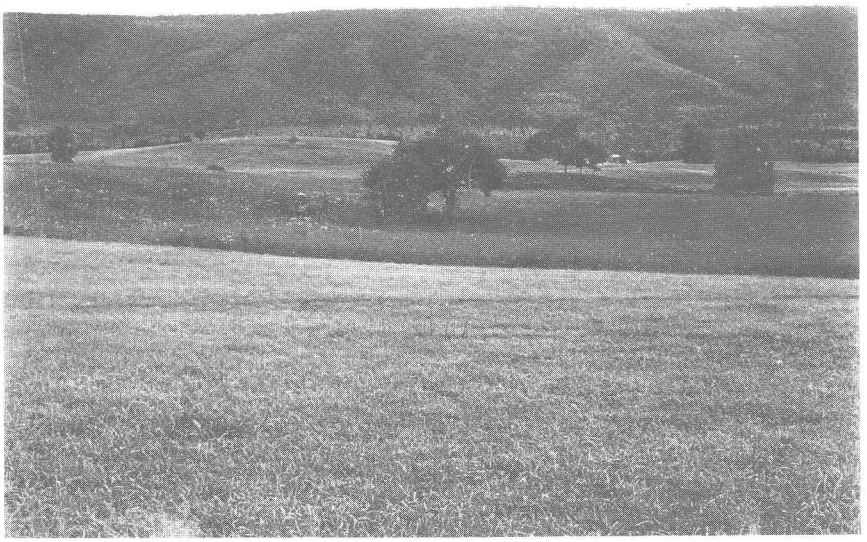
Ridges of monoclinal structure exceed in number all other classes. The ridge maker may be thick or thin, very hard or of moderate resistance, and



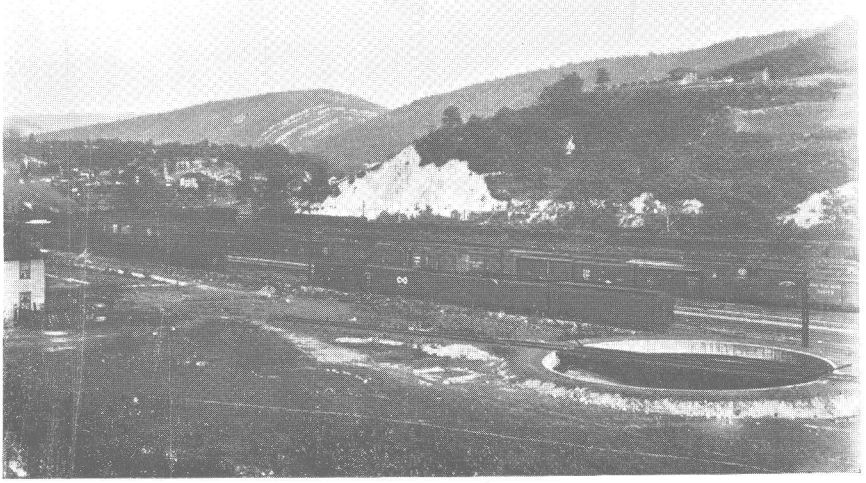
(A) Remarkably even skyline of Walkers Mountain, an unbreached anticline. The photo was taken about seven miles southwest of Deerfield, Virginia.



(B) Northeastward plunging anticline of Rich Patch Mountain at Clifton Forge, Virginia. Iron Gate gorge has been cut through this fold by James River.



(A) Remarkably even skyline of Walkers Mountain, an unbreached anticline. The photo was taken about seven miles southwest of Deerfield, Virginia.



(B) Northeastward plunging anticline of Rich Patch Mountain at Clifton Forge, Virginia. Iron Gate gorge has been cut through this fold by James River.

may be steeply or gently inclined. The present height of the ridges and the even or uneven character of their crests are determined largely by the above conditions.

If the ridge maker has a narrow outcrop the crest is usually uneven although the rock may be hard. This is to be expected, since small streams attacking the flanks of such a ridge meet comparatively little resistance, with the result that slight advantages acquired by this or that stream produce comparatively large results, the favored streams lowering the ridge more rapidly than less favored neighbors. In the monoclinal ridge bordering the Warm Springs Valley on the west the rocks stand in a nearly perpendicular attitude, and the resistant formation being thin, necessarily has a narrow outcrop. The unrestricted contest of erosive forces on either side of the ridge has produced a series of gaps or notches in the ridge crest.

If the ridge maker has a broad outcrop the crest is usually even, especially if the rock is very resistant. Ridges of this type are most apt to attain the upland level. The limbs of breached anticlines in the Monterey quadrangle probably best illustrate this group. Monterey Mountain represents the southeastern limb of the Back Creek anticline and, as seen in Plate V, A, shows only slight notches. This mountain rises higher and has a more even crest than Little Mountain which is the northwestern limb of the same anticline. The difference is due to the steeper dip and consequently narrower outcrop of resistant rock in Little Mountain.

Under favorable conditions equal erosion on both sides of a monoclinal ridge may reduce it fairly uniformly, giving a substantially even crest. The attitude and thickness of the ridge maker may remain practically the same for considerable distances in folded mountains of the Appalachian type, while the distribution of drainage is frequently fairly uniform on either side of such ridges. Under these circumstances we should expect to find long ridges with even or only slightly notched crests below the peneplane level. We may even find several ridges in a single locality the rocks of which have the same thickness and dip, and the crests of which would therefore be reduced at the same rate. Their crests would therefore be accordant, and yet not indicate the level of a former peneplane.

In the region under discussion we have found even-crested anticlinal, synclinal and monoclinal ridges below the level of the Upland Peneplane. We have also found even crests of both accordant and discordant elevations,

as well as uneven crests. The position of the peneplane, therefore, could not be determined from isolated even crests, or from local groups of such crests, but had to be established by profiles and comparisons extended over broad areas.

THE VALLEY PENEPLANE.

The Valley Peneplane is the equivalent of what is frequently called the "Tertiary peneplane." There has not been entire uniformity in the method of employing the term "Tertiary Peneplane." Other terms such as Harrisburg and Shenandoah have been introduced into the literature, and they have not always been used synonymously with Tertiary. Spencer in his "Geology of the Massanutten Mountain in Virginia" employed the name "Shenandoah" to designate the "floor of the Great Valley" represented by the summits of the gently rolling hills into which the lowland is dissected. Watson and Cline in their paper on "Drainage changes in the Shenandoah Valley Region of Virginia" restrict the term Tertiary to "the rounded monadnocks and low linear ridges," and apply the name "Shenandoah" to the undulating surface of the Valley which was "completed probably in Lafayette time."

In the present discussion the so-called Tertiary of Watson and Cline will be regarded as unreduced areas or monadnocks on the Valley Peneplane. It must be kept in mind, however, that a higher erosion level than the Valley Peneplane, corresponding to the Tertiary of Watson and Cline, may be demonstrated after many levels in the Valley region have been determined. In any case there can be no doubt that the rolling surface of the Valley is a peneplane, with ridges and hills rising above it as monadnocks. The rolling surface is here called the "Valley Peneplane."

The occurrence of stream gravels at widely separated points in the Valley, at elevations intermediate between the present stream levels and the Valley Peneplane surface, is taken to indicate stages in the present cycle which were prematurely closed by uplift.

Extent of development.

In comparison with the wholesale baseleveling produced by the erosion of the former cycle, the Valley Peneplane presents a striking contrast. It is only the softer rocks that have been reduced to the condition of a peneplane during this second cycle. Limestone and shale regions are apt to show effective bevelling while the sandstone and quartzite areas stand as ridges or uplands, some of which rise to the main upland level. Since sandstone outcrops so abundantly in the Alleghany Ridges subprovince, the Valley Peneplane is there very slightly developed. In the entire Monterey quad-

rangle it can be identified with certainty in probably not more than a half dozen localities, in shale valleys which have sufficient width to preserve remnants of the surface.

The erosion of the earlier cycle, bevelling across the folded beds, exposed one very broad belt of limestone and shale to the destructional forces which began vigorous work with the inauguration of the uplift which terminated the cycle. This made possible the development of a lowland, the "Great Valley," and its reduction to a peneplane in the comparatively short period of the second cycle. The Valley region is unquestionably the district in which the Valley Peneplane surface was developed most extensively. The triangular area defined by the towns of Buchanan, Eagle Rock, and Fincastle shows typical peneplane topography, with some monadnocks rising above it and valleys cut below. The extensive shale country centering around Gala on James River has also been reduced to this level. A prong of the Valley Peneplane extends up Craig Creek Valley to the margin of the Natural Bridge quadrangle, while another prong reaches up Cow Pasture River a considerable distance, perhaps as far as Millboro Springs. Around Clifton Forge are evidences of the Valley level in the form of gravels and rock benches. The broad open valley of Calf Pasture River, especially in the vicinity of Deerfield, presents features suggestive of peneplanation.

Degree of perfection.

In the Alleghany Ridges subprovince the degree of baseleveling during the second cycle was very imperfect. Small areas only were reduced to the peneplane level, and they are separated by numerous massive ridges, some of which reach the upland level, 1,500 feet or more above the Valley Peneplane. If this region alone were under consideration it would indeed be difficult to get a very good conception of the topography of this lower peneplane. Its best development in the Ridges subprovince is to be found in the district around Gala on James River. There the accordant level maintained by the hilltops is quite striking. The Devonian shales were readily susceptible to erosion, and a peneplane was rapidly carved upon them, while the sandstone ridges to the northwest and southeast stood up in defiance of the agents of destruction.

The Great Valley presents a striking contrast with the region just described. With the exception of an occasional prominent ridge the area as a whole is one of slight relief. It stretches as an undulating plain from the sandstone ridges on the northwest to the Blue Ridge on the southeast. This Valley Peneplane is developed throughout much of the Great Ap-

(A) Monterey Mountain from Sounding Knob. Note the even skyline.

(B) View of the Valley Peneplane in the vicinity of Mt. Solon (Staunton quadrangle), showing several low monadnocks.

(A) Monterey Mountain from Sounding Knob. Note the even skyline.

(B) View of the Valley Peneplane in the vicinity of Mt. Solon (Staunton quadrangle), showing several low monadnocks.

palachian Valley, not only in the region under discussion but also far to the northeast and southwest. The rocks which have been worn down to this lowland surface are chiefly the limestone and shale of the Shenandoah and Martinsburg horizons. The low relief and fertile soils are favorable to agriculture, which is so highly developed as to make this belt the most important farming district in the State. The present streams are incised below the peneplane, in some cases as much as several hundred feet. Thus James River is at many places over 200 feet below the general surface of the Valley floor, a condition particularly well seen between Natural Bridge and Buchanan.

Monadnocks in the Valley.

If one takes into consideration the high ranges bounding the Valley on the west and east, two distinct types of monadnocks are recognizable: (1) Massive ridges of sandstone or crystalline rocks which often rise nearly or quite to the upland level, and (2) smaller ridges, composed chiefly of cherty limestone, and usually rising from 100 to 400 or 500 feet above the general level of the Valley Peneplane. With few exceptions the monadnocks of the first type described on pages 23-26 are restricted to the areas to the northwest and southeast of the Valley proper. The exceptions occur where hard rock layers in synclines came below the level of the Upland Peneplane and so remained to cap ridges which effectively resist subsequent erosion. The Massanutten sandstone is the resistant rock which by virtue of its position in the troughs of synclines was spared to form the crests of high monadnock ridges like Purgatory Mountain near Buchanan, Big and Little House Mountains, and Short Hills. The uneven surface of Purgatory Mountain is probably due to dissection below the upland level.

The monadnocks of the second type are far less conspicuous features of the topography. They are small linear ridges most frequently developed on cherty members of the Shenandoah limestone, and run in parallel lines trending with the strike of the beds. In many cases they form important and persistent divides between the subsequent streams. Where the streams cross the strike these cherty horizons usually cause rapids, and their valleys are notably constricted. In a view from one of the higher monadnocks these low ridges are scarcely perceived, and the country appears much more nearly level than is actually the case. Even when one is down on the Valley floor he may not appreciate the extensive development of these minor ridges if he travels in a northeast-southwest direction, with the strike of the rocks. Only when he crosses the "grain" of the country does he realize

what an important element in the topography these ridges constitute. They do not rise to a uniform altitude and their continuity is often interrupted by cross streams. In some cases they consist merely of conical hills aligned in the direction of strike.

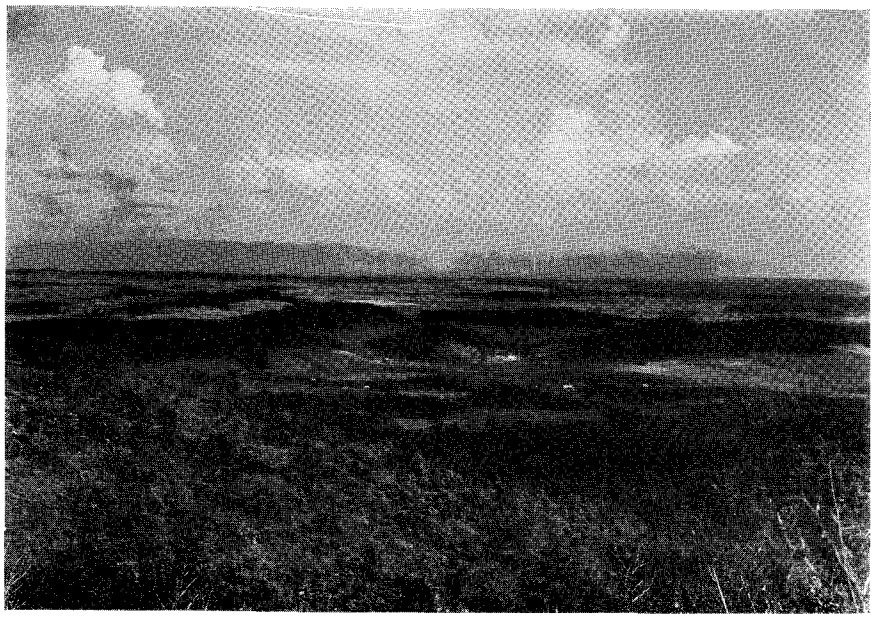
Sugar Loaf, located about eight miles southwest of Staunton, is a small but beautiful conical monadnock belonging in the second group. The twin hills, Mary Gray and Betsy Bell, just southeast of Staunton are also good examples. Because of steeper slopes and poorer soils many of the chert ridges are partly or entirely wooded, as seen in Plate V, B. Mole Hill, Plate VI, A, is a monadnock of peculiar interest because, although it is in a line of chert hills, it has recently been found to have a basaltic core showing splendid columnar jointing. Since most of the minor ridges do not rise more than 200 feet above the surface of the Valley, and many do not exceed 100 feet, while the topographic quadrangles usually have a contour interval of 100 feet, this class of monadnocks is very inadequately represented on the maps.

Warping.

In addition to the projected profiles extending across the entire area from northwest to southeast made to determine the character of the upland surface, a series of 10 was constructed which were confined to the Valley region. In the case of the latter a larger vertical scale was used in order to bring out the different elements in the Valley topography. With the exception of the Gala district the Valley Peneplane remnants in the Alleghany Ridges subprovince to the west, are so small that warping would not be revealed by the profiles. It is obvious that the determination of warping cannot satisfactorily be made if observations are restricted to too small an area. Even in the Great Valley the problem is a difficult one, for a region of folded rocks exhibits the characters of warping less faithfully than one of horizontal beds, while a narrow belt is also unfavorable because if the axis of uplift is parallel with the longer direction of the belt, the width is not sufficient to show appreciable effects.

The profiles across the Valley show that the peneplane surface rises in going from Balcony Falls northeast to the divide between the James and Potomac Rivers. Successive elevations are about as follows: Natural Bridge, 1,100 feet; between Natural Bridge and Lexington 1,200 feet; Fairfield, 1,600 to 1,700 feet; Middlebrook, 2,000 feet. Continuing northeast across the divide between the James and the Potomac the elevation descends to 1,600 feet at Staunton and Churchville, and 1,500 feet at Mt. Solon.

(A) Mole Hill near Harrisonburg, a monadnock on the Valley Peneplane.



(B) Well developed Valley Peneplane surface in the Middlebrook region with the Blue Ridge in the background. Photo looking east from crest of Little North Mountain near Pond Gap.

(A) Mole Hill near Harrisonburg, a monadnock on the Valley Peneplane.

(B) Well developed Valley Peneplane surface in the Middlebrook region with the Blue Ridge in the background. Photo looking east from crest of Little North Mountain near Pond Gap.

The greatest elevations are seen to occur near the chief divide. The question arises whether the slopes of the peneplane surface are the normal product of erosion, or result from warping. From Middlebrook to Balcony Falls the upland surface drops about 900 feet, while the fall in the present drainage is about 1,200 feet. As a slope of 900 feet in 33 miles is too great for a normal peneplane surface in its original attitude, it seems most likely that the observed gradient is at least partly due to warping.

Hayes and Campbell in their map of the Tertiary surface of this region show contour lines running parallel to the axis of the Valley, and indicating a slope to the southeast of 20 to 30 feet per mile. In two of the writer's profiles there did seem to be a distinct slope from the northwestern to the southeastern side of the Valley as a whole, but one of these passed through the vicinity of Stuarts Draft, 10 miles south of Staunton, where there is a lower level probably representing a more recent cycle or stage. A general slope to the southeast across the Valley as great as that indicated in the map of Hayes and Campbell referred to above, does not appear to exist in this area, although the peneplane which stands at an elevation of 1,100 feet at Natural Bridge rises in the west to 1,200 feet at Fincastle and to 1,250 feet near Gala.

Typical areas of the Valley Peneplane.

Middlebrook Region.—The highest elevation which the Valley Peneplane attains in the Valley region is in the vicinity of Middlebrook, 10 miles southwest of Staunton, where it reaches a height of about 2,000 feet. Such monadnocks as occur here are low ridges and therefore not imposing. Exception should be made of Sugar Loaf whose pointed summit rises 300 feet above its surroundings. Taken as a whole the region may be said to be almost completely reduced to the peneplane level, and may be regarded as typical of the more perfectly peneplaned portions of the Valley region. A view of this section of the Valley is shown in Plate VI, B.

Buchanan Region.—If one climbed to the top of one of the low monadnock ridges west of Buchanan he could get a typical view of the Valley Peneplane as it is developed south of James River in the region between Buchanan and Eagle Rock. It is a sweeping, gently undulating surface extending eastward to the base of the Blue Ridge and southwestward almost to Roanoke. Little Timber Ridge, Timber Ridge, and Cedar Ridge are monadnocks.

Fincastle Region.—West of the town of Fincastle the Valley Peneplane is extremely well developed. Dissection has been relatively slight, and wooded hills near the base of the Alleghany ridges preserve the surface in a striking manner. (Plate VII, A).

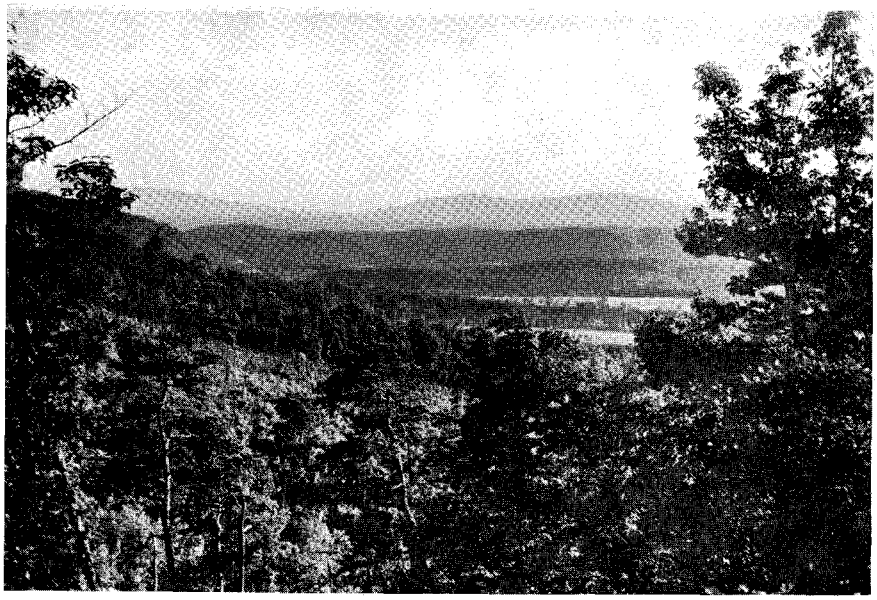
Gala Region.—Extending in all directions from the station of Gala on the Chesapeake and Ohio Railroad along James River, is a section of country with low relief in which the hilltops reach an average elevation of about 1,250 feet. There are prongs of this low surface extending up Craig Creek and Cow Pasture River. Shale is the dominant rock type, and it was because the shale is not very resistant that the country was worn down to an unusually even surface by the close of the cycle. Big Hill is a typical monadnock rising a little more than 500 feet above the peneplane.

The limestone and shale of the Valley do not give quite such a perfect surface as the areas in which shale alone occurs, as a comparison of the Buchanan and Gala regions will show.

Covington Region.—In the region west of the confluence of Jackson River and Potts Creek there is a large expanse of shale country. An especially good view of the resulting topography is to be had from the Covington-Hot Springs Road, about five miles north of Covington. Looking south from this point one sees the Valley Peneplane represented by the summits of a complex of hills giving a remarkably accordant skyline between the high bounding ridges which rise sharply as monadnocks above the valley level. The peneplane is so striking that the hilltops look no more uneven than the waves of a choppy sea. (Plate VII, B).

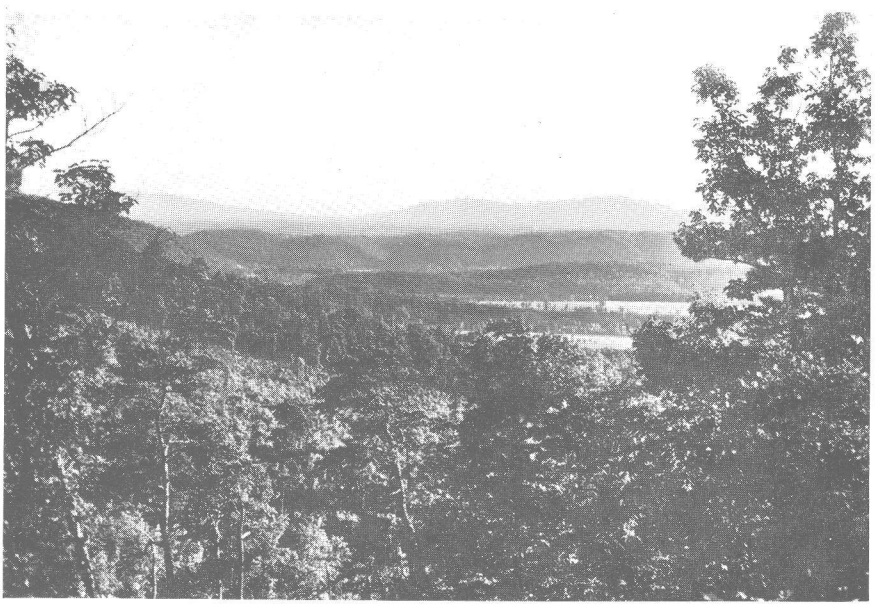
In addition to the accordant hilltops we find further evidence of the development of a peneplane in the valley of Craig Creek. This creek flows in an entrenched meandering valley. The meander spurs exhibit on their down-valley sides the gentle slip-off slopes and on their up-valley sides the steep undercut slopes characteristic of valleys of this type. The contrast in slopes is further emphasized, as so often happens, by reason of the fact that the undercut slopes are usually wooded, while the slip-off slopes have been cleared. The road in crossing over the meander spurs frequently exposes bedrock, generally shale, proving that the flat-topped spurs are rock benches. The elevation of these spur uplands corresponds to those in the shale country around Gala. Floodplain sands and gravels are strewn over the summits of the flat-top meander spurs at an elevation of about 1,250 feet. The water worn pebbles are sometimes deeply pitted, indicating great age. Near Slash School a good exposure of river sands was found where

(A) The wooded Valley Peneplane surface west of Fincastle. The background shows the somewhat irregular crestline of the Newer Appalachians.



(B) View looking south from the Covington-Hot Springs road showing in the near background the "Valley" level as it appears west of Covington. The irregular Alleghany ridges appear in the far background while the valley of Jackson River occupies the middle ground.

(A) The wooded Valley Peneplane surface west of Fincastle. The background shows the somewhat irregular crestline of the Newer Appalachians.



(B) View looking south from the Covington-Hot Springs road showing in the near background the "Valley" level as it appears west of Covington. The irregular Alleghany ridges appear in the far background while the valley of Jackson River occupies the middle ground.

the road cuts across one of the meander spurs. It appears that Craig Creek acquired its meandering course in a broad valley on the surface of the Valley Peneplane, and that the uplift of the region permitted both the entrenching of the meanders and the dissection of the peneplane.

Degree of dissection.

The streams of the Valley region have entrenched themselves notably into the Valley Peneplane since the beginning of the present cycle. In some places the upland surface is much dissected by valleys and gorges. In few cases, however, could one say that the peneplane is maturely dissected; often the stage of submaturity is scarcely reached.

Along James River steep valley walls lead from the narrow flood-plain up to the peneplane surface several hundred feet above the stream level. Thus even the major streams possess valleys youthful enough to have walls which roads must ascend by steep gradients.

Some regions showing a slight amount of dissection were described and illustrated in the section dealing with "Typical areas of the Valley Peneplane."

The presence of gravels in the Valley at levels lower than the Valley Peneplane was referred to on page 27. Whether or not these gravels occupy definite horizons capable of correlation will have to be determined by a detailed study involving many accurate measurements. If such definite intermediate horizons are established they should be regarded as terraces or benches representing partial cycles that were prematurely brought to an end. To apply the term "peneplane" to levels which had so restricted a development even in weak rocks would seem inappropriate.

THE TERRACES.

Stream terraces occur in many localities throughout the region under discussion. They are best developed in the longitudinal shale valleys of the Alleghany Ridges, but are not wanting in the Appalachian Valley. Well defined examples were located in the western part of the Monterey quadrangle along Knapp Creek at Frost and Driscol; along tributaries of Greenbrier River at Greenbank and Dunmore; along the valley of Jackson River at various points from its head near Monterey to Covington; along the valley of Cow Pasture River at numerous points from McDowell on Bullpasture River (a tributary of the Cow Pasture), to its confluence with Jackson River below Clifton Forge; along Jackson River above and below Glen Wilton; and in the valleys of tributaries of these larger streams.

Origin and characteristics of terraces in general.

Several kinds of stream-formed terraces may be recognized as follows:

I. Floodplain Terraces. This is the most common type. They are formed by a degrading stream operating in a valley which it has previously aggraded. The stream cuts its channel into the alluvial materials which make up the floodplain, and the floodplain remnants left after the downcutting remain as benches or terraces. The entrenchment of the stream in its floodplain may be due to

(a) an increase of stream volume, or
(b) a decrease in load of debris, or
(c) an increase of stream gradient due to tilting, or
(d) successive uplifts of the land permitting the stream to cut successively to lower and lower levels.

In the first three cases the stream, although cutting uniformly downward, produces not only the two terraces of equal height on the two sides of the valley representing the original floodplain level, but in addition a series of lower terraces of discordant elevations, due to the fact that the stream, in swinging from side to side across the valley floor, repeatedly encounters the rock wall of the valley side at varying elevations.[1] Above each

[1] Davis, W. M., Geographical Essays. Ginn & Company, 1909. River Terraces in New England, pp. 514-586.

point of contact a rock-defended portion of the floodplain, in other words a "rock-defended" terrace, is preserved, as shown in Figure 2.

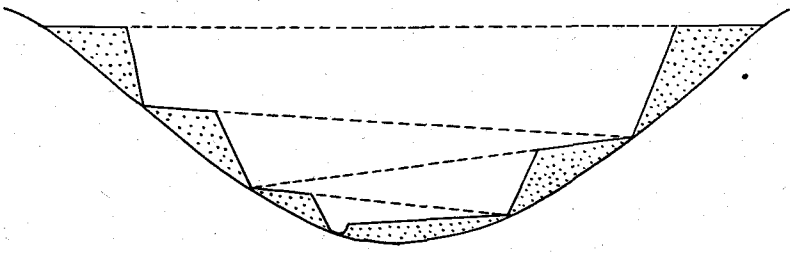


Fig. 2.—Rock-defended floodplain terraces.

In the last case, (d), successive uplifts alone will cause terraces, one set for each uplift, providing the period of stability following each uplift is not sufficiently long to permit the stream to remove earlier formed higher terraces. The elevations of the members of each set of such terraces should correspond. If during any period of downcutting the swinging stream should encounter the solid rock of the valley wall a rock-defended terrace of the type described above would be formed at an intermediate level. In a series of floodplain terraces it would be possible, therefore, to find two types, some in sets having accordant levels, others not correlatable, some due to successive uplifts and others due to rock defense. (Figure 3).

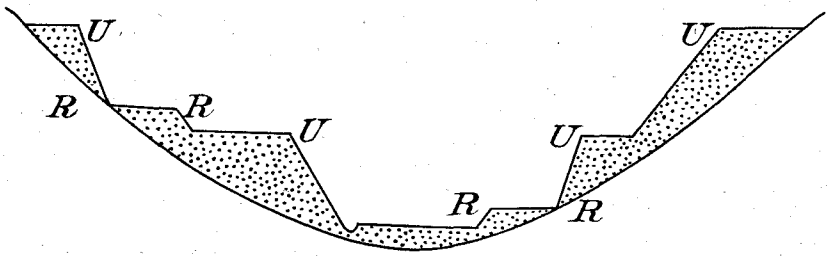
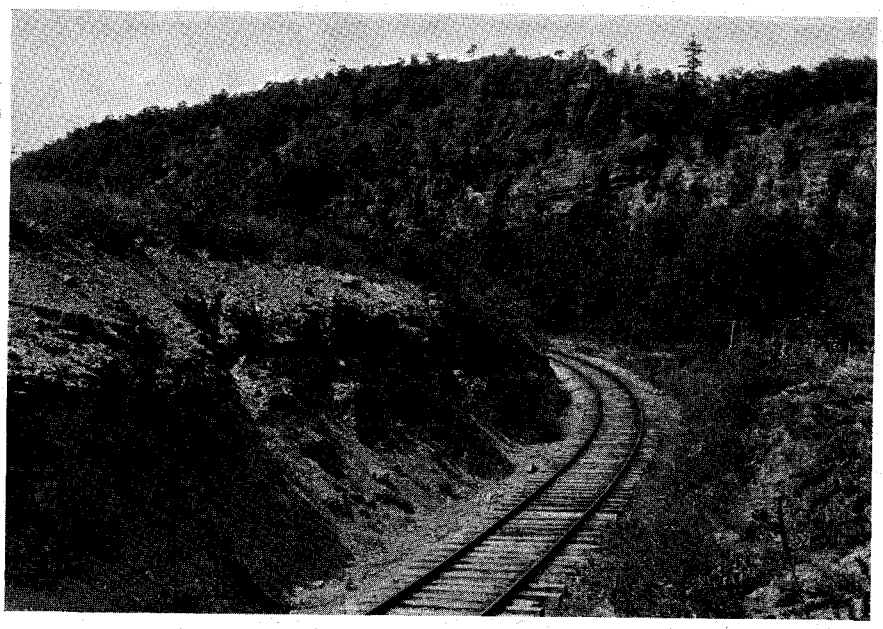
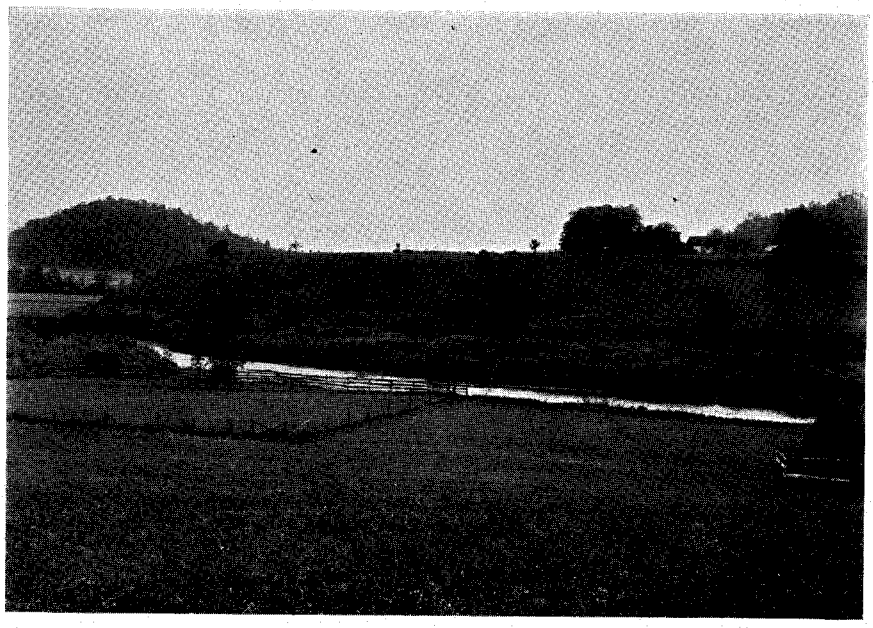


Fig. 3.—Floodplain terraces. U, terraces due to uplift; R. R., terrace levels preserved by rock defense.

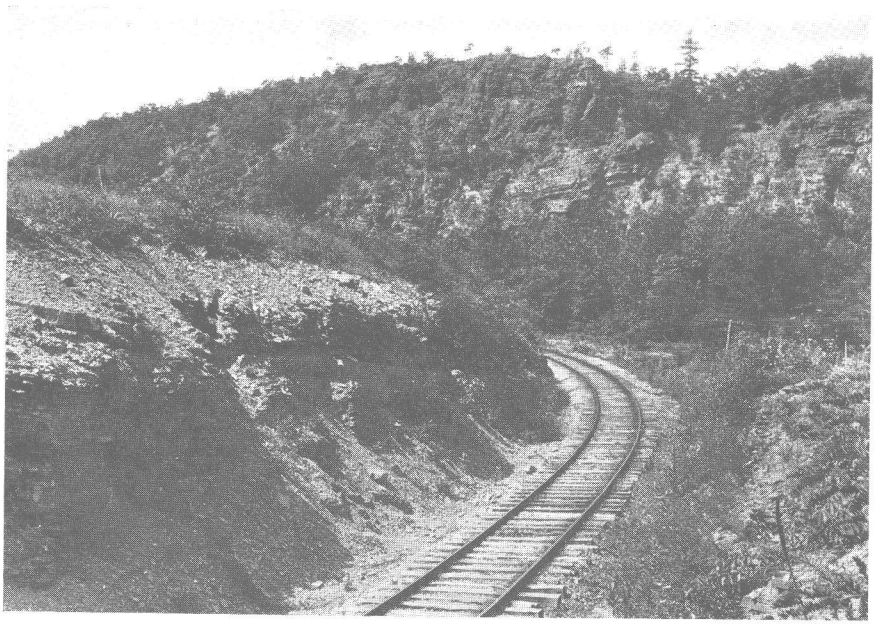
II. Rock Terraces due to differential erosion. Terraces or benches of this type are common in regions of horizontal, or nearly horizontal, structure, where there are alternating layers of weak and resistant rocks. The Esplanade of the Grand Canyon of the Colorado is an excellent illustration



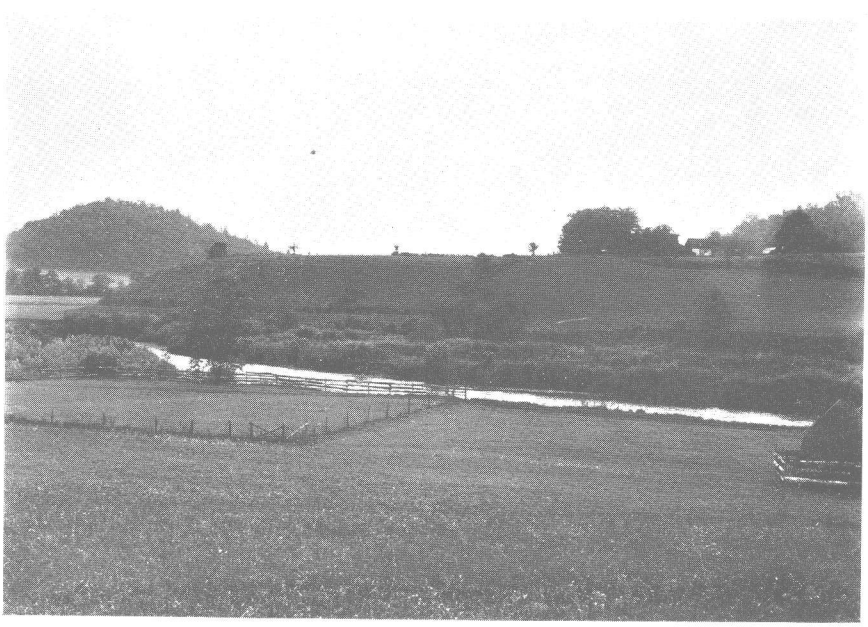
(A) The lowest member of a series of three terraces three miles north of Covington. The railroad cuts off a little strip of the terrace on the right. The overhanging bluff, rising about 150 feet in the background, is the undercut slope of a meander spur with Jackson River at its base. The face of the terrace scarp is very little steeper in the railroad cut than in many other places along its course. Solid rock occurs abundantly in the scarp.



(B) Striking terrace one mile west of Millboro Springs, Virginia.



(A) The lowest member of a series of three terraces three miles north of Covington. The railroad cuts off a little strip of the terrace on the right. The overhanging bluff, rising about 150 feet in the background, is the undercut slope of a meander spur with Jackson River at its base. The face of the terrace scarp is very little steeper in the railroad cut than in many other places along its course. Solid rock occurs abundantly in the scarp.



(B) Striking terrace one mile west of Millboro Springs, Virginia.

on a grand scale.[1] and [2] When terraces of this type appear on both sides of the stream their elevations correspond more or less closely. (Figure 4).

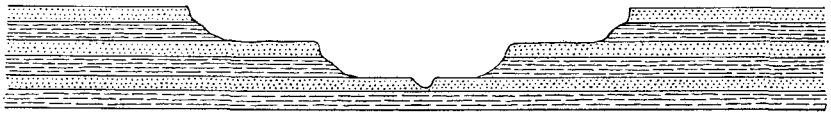


Fig. 4.—Rock terraces.

III. Rock terraces due to successive uplifts. Terraces formed by uplift may occur in any region without regard to the structure or attitude of the rocks. A veneer of floodplain gravels and sand may cover the rock benches, but this is purely incidental, as the terrace form is fully developed by erosion of the solid rock at successively lower and lower levels. (Figure 5).

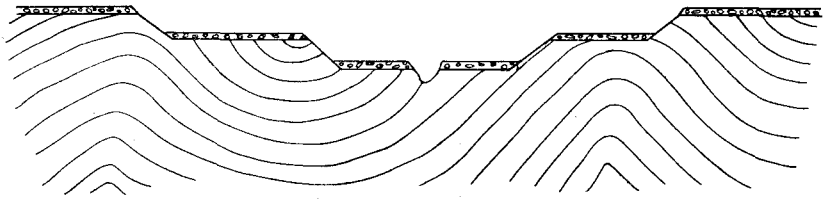


Fig. 5.—Rock terraces due to successive uplifts.

In the case of entrenched meandering streams, in which the stream at each meander migrates rather uniformly outward and down-valley, the terraces due to uplift may appear only on one side of the valley at any given point. This will be the slip-off slope of a meander spur. The undercut slope will show a single steep scarp because the stream is continually undercutting and undermining that slope.

IV. Rock-defended rock terraces. Theoretically we might expect to find a fourth type of terrace, not hitherto described so far as the writer is aware. In a series of non-resistant rocks like shales, which contain occasional resistant members of any form (large concretions, sandstone lenses or beds, etc.), a normal degrading stream will from time to time discover the resistant elements, suffer deflection, and leave distinct terraces of the nonresistant material. Thus terraces cut in rock like shale may be

[1] Dutton, C. E., Tertiary History of the Grand Canyon District. U. S. Geol. Surv. Mon. No. 2, p. 87, 1882.

[2] Davis. W. M., Notes on the Colorado Canyon District. Am. Jour. Sci., 4th Ser., Vol. X., pp. 251-259, 1900.

"defended" by a more resistant rock such as sandstone. In many respects such terraces would be similar to the rock-defended alluvial terraces of Davis. In a region of complex folding and faulting they would perhaps be more irregular in number and pattern than those developed in floodplain materials. Terraces of this type, like those of Class III above, would be most apt to occur on the slip-off slopes in the case of an entrenched meandering stream. (Figure 6).

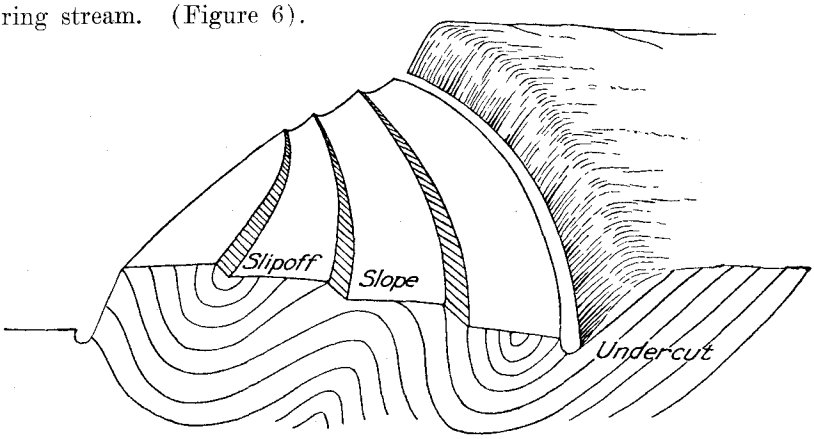


Fig. 6.—Rock-defended rock terraces.

Characteristics of terraces in the valleys of the Alleghany Ridges sub-province.

One of the most significant characteristics of the terraces in this region is the fact that they are rock terraces cut in shale. The presence of the shale on the treads and scarps of typical benches was repeatedly determined in many localities. A typical scarp showing solid rock is seen in Plate VIII, A. The rock on which most of these terraces is developed is the Romney shale, a dark-colored relatively soft Devonian formation. The scarps are peculiarly sharp and well defined, doubtless because the shale maintains its position better than the unconsolidated sands of alluvial terraces. (Plate VIII, B).

Although shale is the prevailing rock type in the terraces here described, sandstone layers are occasionally encountered. Near Driscol in the southwestern portion of the Monterey quadrangle a striking terrace rises more than 70 feet above the level of Knapp Creek. Shale occurs in the terrace, but the scarp in part at least is formed of sandstone. About one-half mile south of the bridge at Glen Wilton (six miles south of Clifton

Forge), on the east side of Jackson River Valley there is a strong and sharply defined terrace in the front of which sandstone outcrops abundantly.

The upper surfaces of the terraces are occasionally very broad, and usually quite flat. Sometimes, however, the surface rises gradually from front to back, as in the case of the first and second terraces in the series one mile south of Frost in the western portion of the Monterey quadrangle. In this instance the back part of the first terrace is eight feet higher than the front, while the third terrace rises approximately 14 feet from front to back. Occasionally, however, this condition is reversed. The second terrace in the series one mile north of Glen Wilton slopes backward, after the manner of some floodplain terraces.

Floodplain gravels are commonly found on the surfaces of the terraces. Occasionally the gravels reach a depth of six or eight feet, as in the case of the highest terrace in the series one mile north of Glen Wilton. More frequently they form merely a thin veneer, or are scattered promiscuously about over the terrace, as in the splendid series about three miles north of Covington. The nature of gravel distribution is entirely incidental, there being no regularity in the mode of occurrence of this deposit.

The number of terraces at any given point usually varies from one to three. Just north of Covington there is a series of three terraces on the east side of the valley, while diagonally across Jackson River but one was found. Variation in the number of terraces in closely situated localities is more common than uniformity.

Not only is there frequent variation in the number of terraces, but their elevations likewise show considerable diversity. A great number of levels was determined, some of which were made by an engineer using a Wye level. They range all the way from 10 to 150 feet above stream level, and do not seem to be capable of correlation into definite groups or series.

The following terrace levels as determined by careful surveys at a point on Jackson River three miles north of Covington, show the difficulty of making correlations even over short distances. All elevations are in feet above stream level.

	South slope south meander	Dif.	North slope south meander	Dif.	North meander	Dif.
Floodplain	15.24		12.41		15.24	
First terrace.....	55.97	40.73	43.20	30.79	57.78	42.54
Second terrace....	94.67	38.70	91.70	48.50	104.30	46.52
Third terrace.....	122.60	27.93	122.60	30.90	156.20	51.90

Glen Wilton is located approximately six miles south of Clifton Forge, on James River, and Driscol thirty miles away, on Knapp Creek, in the southwestern part of the Monterey sheet. The levels at these points as determined by careful surveys were as follows:

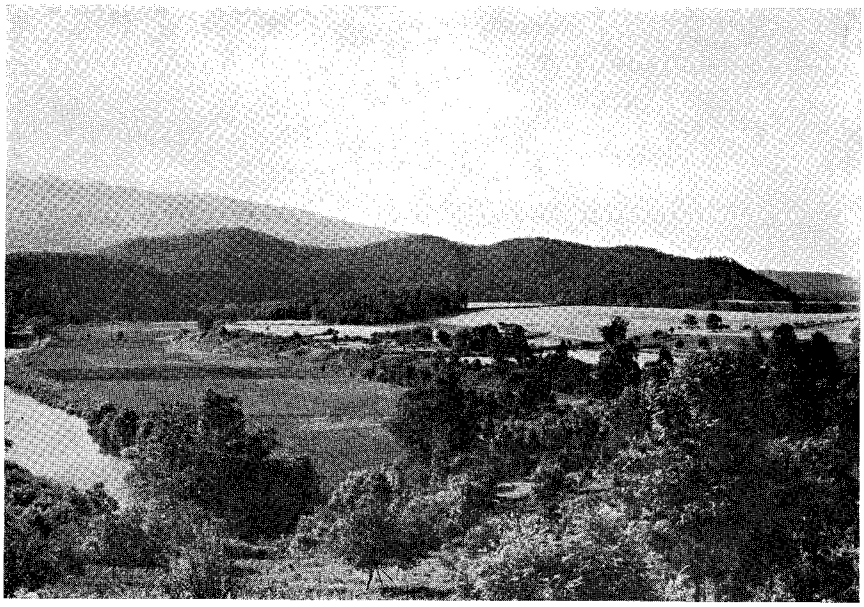
	Glen Wilton	Differences	Driscol
Floodplain	14.34		8.82
First terrace	30.29	15.95	73.27
Second terrace	50.41	20.12	None
Third terrace	84.80	34.39	None

Other terrace elevations determined by barometer (excepting those at Frost which were determined with a Locke level), follow:

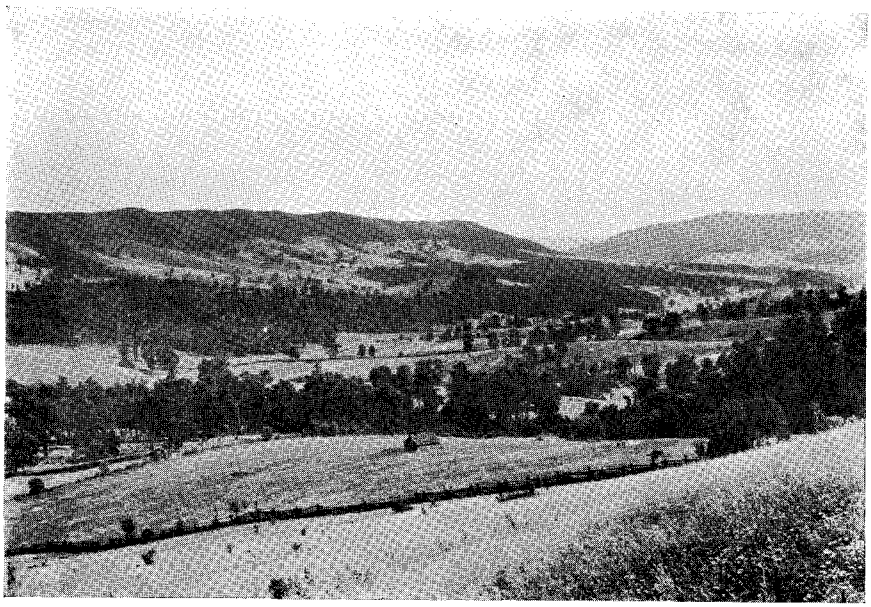
	One mile south of Frost	Dif.	Frost	Dif.	Four miles north of Frost	Dif.
Floodplain	6		5.05		10	
First terrace	22	16	16.40	11.35	20	10
Second terrace	66	44	61.45	45.05	60	40
Third terrace	101	35	109.65	48.20	70	10
	Ten miles south of Millboro Springs on Cowpasture River			Dif.	Balcony Falls	Dif.
Floodplain	10				14.83	
First terrace	35			25	36.19	21.36
Second terrace	52			17	105.96	69.77
Third terrace	70			18	None	

In entrenched meandering valleys terraces are restricted to slip-off slopes. This point is particularly well shown in the case of the meanders of Jackson River about three miles north of Covington, where are found some of the finest series of terraces in the district. The photograph, Plate IX, A, shows the slip-off slope of a meander spur on which three terraces appear.

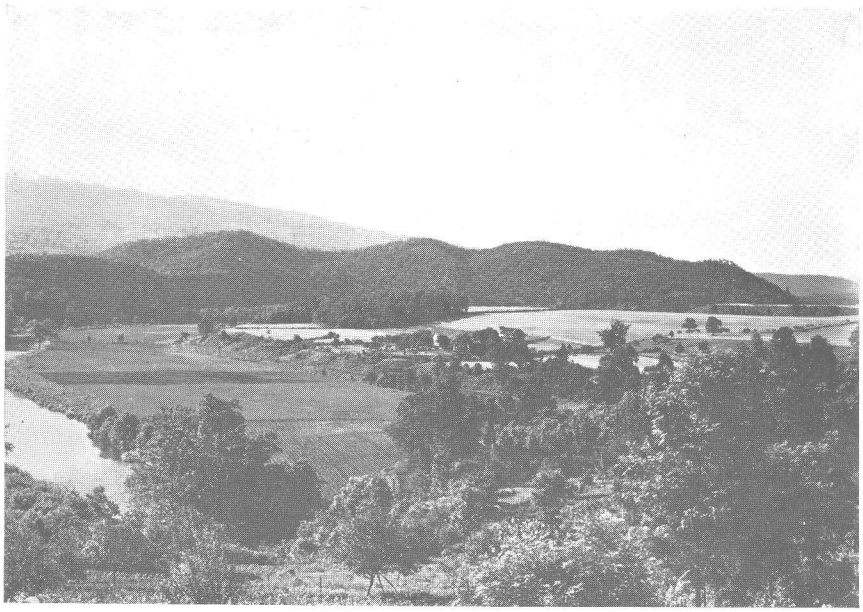
The detailed pattern of these rock terraces was studied in several localities and was found to be essentially similar to that exhibited by some of the rock defended alluvial terraces described by Davis.



(A) Terraces on Jackson River three miles north of Covington. The modern floodplain of Jackson River occupied only by cultivated fields is 15 feet at its front above the level of the stream. Next above comes the first terrace, sharply marked and with railroad at its base. Its surface, elevation 40 feet above the floodplain, is occupied by a house and barn surrounded by an orchard with wheat fields beyond. Back of the barn rises the second terrace with a gentler slope to a height of 40 feet above the first terrace. It is best seen where the road crosses it to the right of the house. A fence runs along the crest of the scarp to the right margin of the picture. Back in the broad open cornfield behind the barn there is a distinct slope upward to the crest of the hill which is the surface of the third or highest terrace. The second and third terraces grade into each other at the corner of the woods directly behind the house. The third terrace is 27 feet higher than the second and stands at an elevation of 122.6 feet above stream level. As seen in the photograph the surfaces of the terraces are notably flat and give no suggestion of a normal slipoff slope.



(B) Monterey Mountain on the left separated from Back Creek Mountain by Vanderpool Gap. The fertile Crabbottom valley lies in the foreground. Photo taken one mile west of Hightown looking southeast.



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(B) Monterey Mountain on the left separated from Back Creek Mountain by Vanderpool Gap. The fertile Crabbottom valley lies in the foreground. Photo taken one mile west of Hightown looking southeast.

Conclusion.

From the foregoing description it will be seen that the terraces of the Alleghany Ridges are rock-cut terraces which are best developed on the slip-off slopes in valleys which have entrenched meandering courses. As they are not floodplain terraces, they cannot come under any of the four subdivisions of Class I in the general classification of terraces given on pages 35-37.[1] The rocks of the region are complexly folded, and consequently the terraces do not fall in Class II, which includes only terraces developed on horizontal structures. They must fall therefore in either Class III or Class IV. If they owe their origin to successive uplifts, there should be some degree of uniformity in terrace levels, and in any given locality the terraces on successive meander spurs should closely correspond in number. The terraces of this region show no such regularity. Consequently the writer is inclined to regard them as rock-defended rock terraces of the type described in class IV. If this conclusion is correct, any attempt to correlate these terraces with cycles or partial cycles in the Appalachian Valley must necessarily prove futile.

[1] The writer does not desire to leave the impression that there are no floodplain terraces in the region, but believes that in the Alleghany Ridges subprovince the only terraces of any importance are those of the rock-cut type described.

DRAINAGE

DRAINAGE DEVELOPMENT.

In an earlier chapter, an attempt was made to restore the initial drainage of the Upper James River region with the result that in the Appalachian Plateau some of the streams were found to have consequent courses on the warped upland surface, while in the Newer Appalachians province the older drainage lines could not be traced because of almost complete later readjustment of streams to rock structure. If the early major streams flowed down the pitch of the synclinal troughs, there must have been since that time a striking reversal in direction of flow, because most of the larger synclines seem to pitch to the northeast, while at present such streams flow southwest. Numerous windgaps not far below the upland level are strong evidence in favor of an early southeastward direction of flow for many streams. Apparently the so-called Tertiary cycle opened with many of the major streams and some smaller ones flowing in this direction transversely across the Alleghany Ridges, presumably consequent upon the warped surface of the Upland Peneplane or possibly upon a thin overlapping westward extension of some part of the coastal plain series. Once the shale and limestone belts became widely exposed, however, streams working rapidly northeast and southwest along these belts captured the transverse streams and led their waters off along the more favored subsequent courses.

The present cycle has had a relatively slight effect upon stream development. The drainage has experienced a normal rejuvenation through the uplift which inaugurated the cycle. Those streams which had developed meanders in the so-called Tertiary cycle have so entrenched themselves as to produce incised meanders with well-marked slip-off and undercut slopes. In a few cases minor readjustments of stream courses have been effected.

Importance of the subsequent drainage.

The remarkable development of subsequent drainage is one of the outstanding features of the region. No stream now flows transversely across the entire belt of ridges in a course consequent upon the warped Upland Peneplane. The master stream of the area is the James, and its course appears to have been determined more by the character of underlying rock than by the slope of the peneplane surface. Beginning just southeast of

Covington as Jackson River it follows a line of weak rocks to Clifton Forge where it was superposed across the Rich Patch Mountain anticline. Then it strikes a belt of shale on which it flows to a point several miles below Glen Wilton where it swings across the shale belt to cross the last barrier of the Alleghany Ridges at Eagle Rock. From this point it meanders across a limestone belt to Buchanan where it would be expected to cross the Blue Ridge. Instead, it flows along the strike of the Shenandoah limestone for an airline distance of fifteen miles, to discharge across the Blue Ridge at Balcony Falls where there is a low sag in the upland surface. Thus it is seen to cross only three obstacles, one at Clifton Forge, another at Eagle Rock and a third at Balcony Falls. Its gorge through the Blue Ridge exhibits a good geological section and is a beautiful scenic feature.

Two important streams have courses which appear to be consequent upon the warped upland surface. Buffalo Creek heads against North Mountain on the Natural Bridge quadrangle and flows southeast to join North River a few miles north of Balcony Falls. North River itself is a better example, as seen in the northwestern corner of the Lexington quadrangle.

Furthermore, the course of the James through the Blue Ridge may have been consequent on the Upland Peneplane surface. The general surface of the Blue Ridge probably represents the upland level. The question at once arises whether the James crosses the Blue Ridge mass at an upwarped arch, at a downwarped sag, or at a point having an average elevation. If its gorge is cut in an upbowed arch the stream certainly cannot be said to have a consequent course, but rather must be antecedent or superposed. If, however, the gorge is cut in a downwarped portion of the range we may with some reason suppose that the slope of the Upland Peneplane was the controlling factor in determining its course.

To ascertain this point a distant view is essential. From the top of Short Hills west of Natural Bridge 10 miles away it is evident that the gorge of the James is cut in a sag of the Blue Ridge, Figure 7, and that this portion of the James is presumably consequent on the Upland Peneplane.

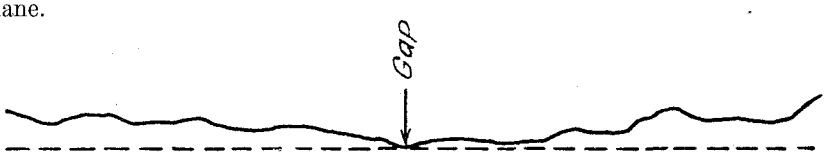


Fig. 7.—Sketch from photo showing sag in the Blue Ridge through which James River flows.

With the exceptions noted the main streams have subsequent courses. Beginning with South River on the southeast and going northwest we find the Calf Pasture, Cow Pasture and Jackson rivers, Back Creek and Greenbrier River flowing in nearly parallel lines along belts of relatively weak rocks. Taking the region as a whole the drainage may be said to be dominantly subsequent.

Principal ridge and valley makers.

The monoclinal ridges representing the limbs of three major anticlines in the Monterey quadrangle are formed by the steeply upturned edges of the Massanutten sandstone.[1] Plate IX, B, shows a photograph of Monterey Mountain and its southern continuation called Back Creek Mountain. This ridge is made of the Massanutten formation and represents the eastern limb of the Back Creek anticline. The valley in the foreground is a portion of the fertile Crabbottom Valley. The soil is derived from the weaker Shenandoah limestone which has been exposed by erosion in the core of the anticline. This longitudinal valley shut in by the rimming hard rock ridges is one of the finest grazing sections of Virginia.

Walkers Mountain in the southwestern portion of the Staunton quadrangle, and Jack Mountain in the northwestern corner of the same quadrangle, are unbreached anticlines in which the Massanutten sandstone forms the arch. The former has been held up at an altitude of 3,100 feet, the latter at 4,000 feet. The Massanutten sandstone also makes a limited number of synclinal ridges. Massanutten Mountain whose southern end is only about 30 miles northeast of Staunton is the type example, and the formation was named because of its occurrence in this synclinal mountain. Short Hills constitute an excellent example of this type of ridge in the district under consideration.

The massive ranges such as the Shenandoah and Alleghany mountains are broad synclines in which are exposed the Jennings and Hampshire formations with here and there a capping of Pocono sandstone. The sandstone members of the Hampshire and Jennings are the ridge makers of the group. Owing to the broadly open character of the synclines the beds are nearly horizontal for considerable distances. This fact, together with variations in the lithological character of the beds, serves to make these mountains so irregular when dissected that their true ridge character is nearly lost. The Marlin Mountain-Sandy Ridge range in the western portion of the Monterey quadrangle is formed by monoclinal beds of the Jennings.

[1] Monterey Folio, U. S. Geol. Survey, Folio 61.

Other formations make occasional ridges, but the Massanutten, Jennings and Hampshire are by far the most important.

The two most important valley makers are the Shenandoah limestone of Cambrian and Ordovician age, and the Romney shale belonging to the Devonian. The Martinsburg shale immediately overlying the Shenandoah limestone is nearly everywhere associated with the latter formation. The Great Valley is not the valley of any one stream, but a broad lowland, formed by the rapid removal of the non-resistant Shenandoah and Martinsburg beds. This lowland is typically developed in the belt of country in which are located the city of Staunton and the towns of Lexington, Buchanan and Fincastle.

Long, narrow valleys on the Shenandoah limestone are found in the cores of the major anticlines such as Warm Springs, Back Creek, and Jack Mountain. These valleys have fertile soils, are highly cultivated and are scenically very beautiful, shut in as they are by mountain rims, with no outlets except a few narrow water gaps.

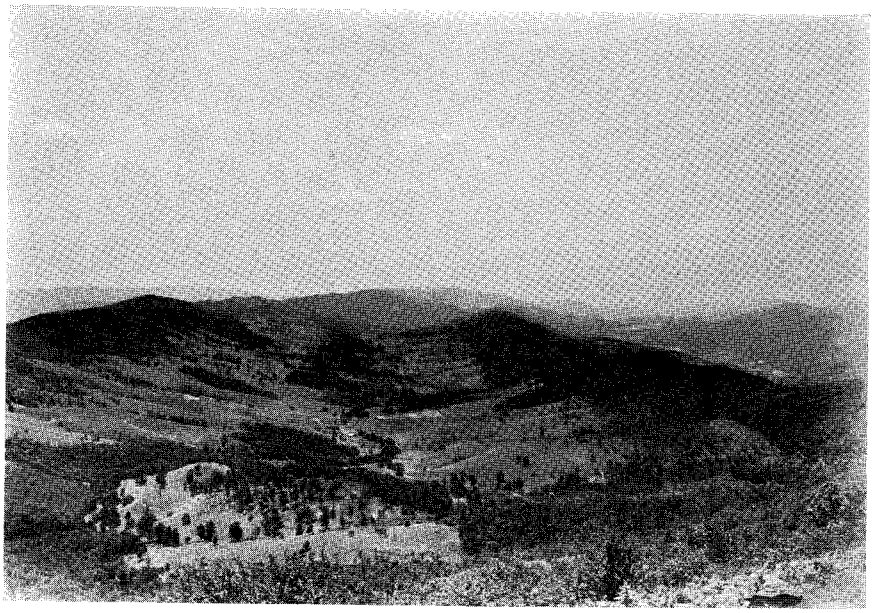
The Romney formation is a dark colored shale offering slight resistance to erosion. The valleys of a number of the larger subsequent streams are located on belts of this shale, as for example those of Jackson and Cow Pasture rivers. At a few points along the courses of these two rivers other formations are encountered.

Of some importance as a valley maker is the Lewistown limestone which underlies the low country in the vicinity of Burnsville 18 miles south of Monterey.

Origin of the anticlinal valleys and synclinal ridges.

The three anticlinal valleys in the Monterey quadrangle already mentioned and the Short Hills synclinal mountain deserve a further word as to their origin.

In view of the fact that the folds observed in the region under discussion were probably formed under a thickness of perhaps 10,000 feet of overlying strata, it may be considered doubtful whether the anticlines and synclines found at the level of the present surface were represented by corresponding anticlines and syclines on the initial surface. Many folds closely compressed in depth may be represented at the surface by a simple broad arching of higher beds, or by a few arches of simple type. Hence the difficulty already discussed (pp. 7-9), of deriving the present drainage pattern from a simple and easily determinable initial consequent drainage system. Certainly we cannot regard the present anticlinal valleys as direct



(A) Bolar anticlinal valley looking south from Sounding Knob. The rims of the valley are seen to unite in the distance to form Duncan Knob.

(B) Boner Mountain in the center background makes the structural northern end of the Warm Springs anticlinal valley. The gentle slope on the right, running down to the main stream on the left or western side of the valley, is significant.

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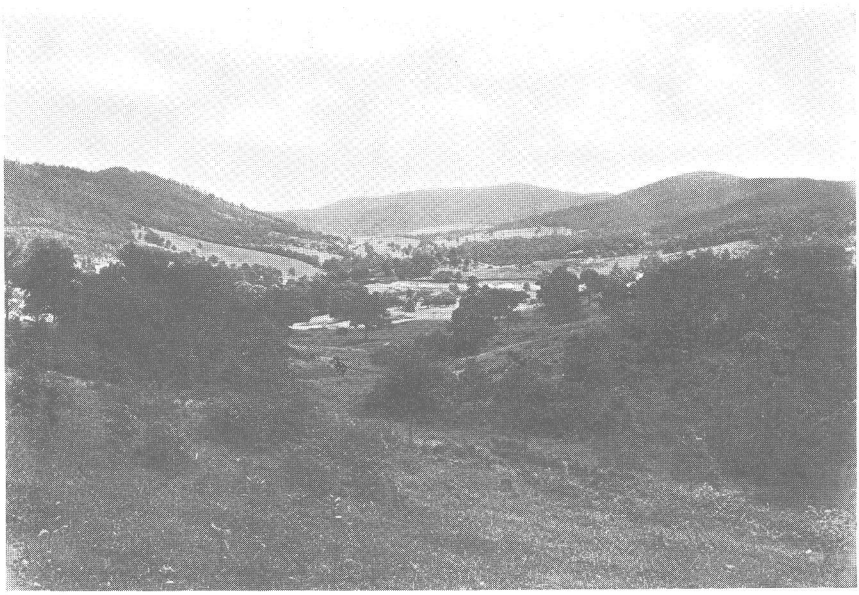


(B) Boner Mountain in the center background makes the structural northern end of the Warm Springs anticlinal valley. The gentle slope on the right, running down to the main stream on the left or western side of the valley, is significant.

descendants from anticlinal valleys developed by the breaching of initial anticlines after the manner described by Davis.[1] In the same way, it must be regarded as doubtful whether fracturing and fissuring of anticlinal crests, so often appealed to as an aid of the erosion of anticlinal valleys, played any essential part in shaping the present topography. Under the pressure of superincumbent beds the layers now observed probably folded without extensive fracturing.

In any case there seems no reason to doubt that the bevelling of the folded mass by the Upland Peneplane was a dominant factor in determining the topography of later cycles. This peneplane truncated the structure of the beds affecting anticlines and synclines alike. Where the peneplane surface passed above the Massanutten sandstone in the cores of low anticlines, later removal of weak beds left anticlinal ridges, such as Walkers Mountain, formed by the arched and unbreached resistant member in question. Where the anticline rose a little higher, the plane of the upland surface cut below the sandstone member in the crest of the arch, thus exposing the Martinsburg shale immediately below. Subsequent erosion would then remove the shales from the core of the anticline, forming an anticlinal valley. Jack Mountain shows these relations extraordinarily well. From Sounding Knob on the north to Duncan Knob on the south erosion in the earlier cycle cut below the sandstone member, and we have the Bolar anticlinal valley; while from Sounding Knob north and from Duncan Knob south the anticline is still unbroken and sandstone forms the arch. In other cases the level of the peneplane cut a syncline in such manner as to permit the removal of all of the Massanutten formation with the exception of a remnant in the floor of the syncline. When later erosion set to work the weak rocks on either side were readily removed, and the sandstone stood up prominently as a synclinal mountain. We have already seen that Short Hills near Natural Bridge have had such an origin, forming a typical synclinal mountain, and that the far more impressive Massanutten Mountain is one of the best examples of this type of ridge to be found in the country.

Drainage of the anticlinal ridges.

The drainage associated with the anticlinal ridges appears more simple than is really the case. The many small streams flowing down the flanks of the anticlines resemble initial consequents, but except in rare and doubtful cases are more probably resequent streams which have acquired their position during the gradual exposure of the ridge by subsequent erosion.

[1] Davis, W. M., Geographical Essays, pp. 434-441.

Drainage of the synclinal ridges.

For reasons already explained it is doubtful whether streams following the axes of synclinal ridges, such as Cedar Creek on the Short Hills, can safely be regarded as consequents even when they flow with the pitch of the synclines. It is quite possible that they are resequents or in some cases even subsequents developed by headward erosion on the small shallow belt of weak rock left in the core of the syncline at the end of the first period of peneplanation. Streams on the axis of a synclinal mountain, whatever their origin, are soon captured by the headward growth of the short obsequents which cut back into the flanks of such mountains.

Drainage of the anticlinal valleys.

In all three of the major anticlines of the Monterey area there have been developed valleys. The one in Jack Mountain which we have called the Bolar valley, is probably the most perfect example. The resequent streams which flowed away from the axis of the Jack Mountain anticline, at an early date acquired subsequent tributaries on the weak rock belt exposed by the removal of the crest of the fold, and the valleys which these subsequents excavated in shale and limestone are of course disproportionately large, when compared with the narrow gaps in the rimming sandstone ridges. As two of the resequent streams early in the second cycle gained a marked advantage in the struggle for existence, only two water gaps are found cutting through the rim of this valley; but a prominent wind gap marks the course of a third stream that lost in the battle for drainage area. The latter stream flowed eastward while the successful streams on the other side drained toward the west. In this connection it should be noted that owing to the steeper dip on the western limb of the anticline, the width of outcrop of the resistant bed is less there than on the east. The two streams which flow out through the gaps near Trimble and Bolar not only carry the entire drainage of the valley, but the divide between them is very low and inconspicuous. The southern gap is cut about two hundred feet lower than the northern, which gives its stream, Wilson Run, some advantage, and we may therefore expect it to gain drainage area in the future at the expense of its northern neighbor. That it has done so in the past is indicated by the fact that it is twice as long as the northern stream. The floor of the valley is formed of Shenandoah limestone and the soil is therefore fertile. (Plate X, A).

The Warm Springs anticlinal valley is well known as the seat of the famous resorts, Hot Springs, Warm Springs, and Healing Springs. In all

essential points it is similar to the Bolar Valley except that it is somewhat longer, being about 17 miles in length as compared with 12 miles in the case of the other. Six resequent streams flow out through gorges cut in the western limb. Each road leading into the valley along these streams has a steep gradient and the scenery is picturesque. (Plate X, B). Falling Springs, the southermost stream, discharges over the resistant sandstone of the rimming monoclinal ridge by a waterfall about 200 feet high. Above the fall the valley has a subdued topography and represents the approach to a local baselevel. The topography and fertility of soil combine to make the Warm Springs Valley a beautiful and rich region, the value of which as a health resort results mainly from the development of thermal springs. These are found both at Hot Springs and Warm Springs, and result from the issuance of water from great depths along a fissure. Darton in the Monterey folio estimates that the source of the water must be located about 3,200 feet below the present surface. The water from these springs has long been renowned for its medicinal qualities.

Drainage of the synclinal valleys.

The long valley of Jackson River is located in a syncline. (Plate XI, A). The slopes of the walls are gentler than those of anticlinal valleys, and as a rule the valley is broader and more open. Although Jackson River occupies a synclinal basin it does not seem to be a consequent stream, because the syncline apparently pitches opposite to the direction of drainage discharge. It is most probably a subsequent, and its lateral tributaries resequents. Bullpasture River from McDowell to Williamsville flows for the most part in a similar valley and shows similar relations.

Drainage of the monoclinal valleys.

The valley of Back Creek in the Monterey quadrangle is typical of the group of monoclinal valleys. The stream is a subsequent developed on a belt of Romney shale, while tributaries entering from the east are resequents developed on the slopes of the Back Creek anticline, those from the west obsequents. The upper portion of the valley of Cow Pasture River in the Staunton and Monterey quadrangles is another good example.

Asymmetrical topography.

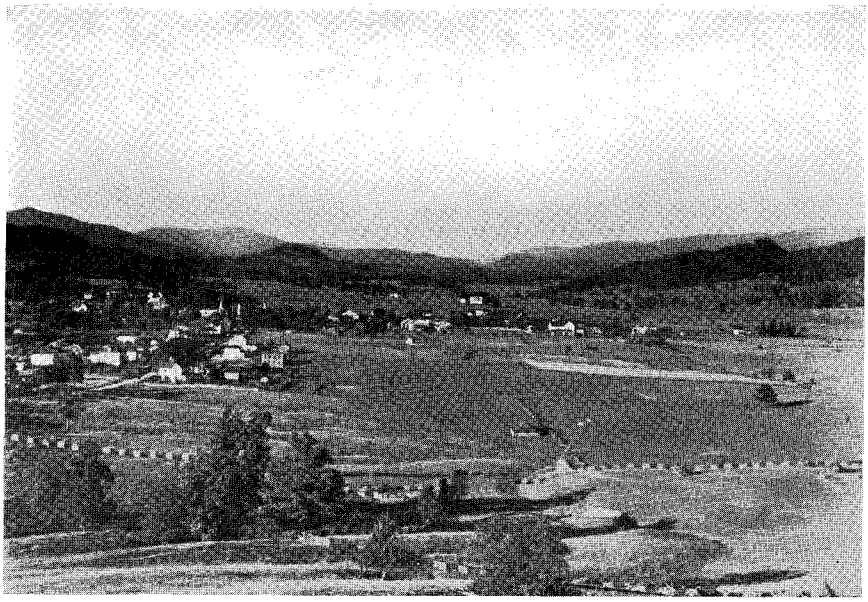
Asymmetrical topography due to asymmetrical structure is clearly seen in the anticlinal valleys already described. (Plate X, A and B). The dips are often steeper on the western than on the eastern limbs of the anti-

clines. The result is the location of the major streams on the western sides of the anticlinal valleys and other topographic features are developed accordingly. All the water gaps associated with the Warm Springs and Bolar Valleys are cut through the western limbs of the anticlines. This is believed to be due to the combined effect of steeper slope and reduced width of outcrop of the resistant rocks which are natural consequences of the asymmetrical character of the folds.

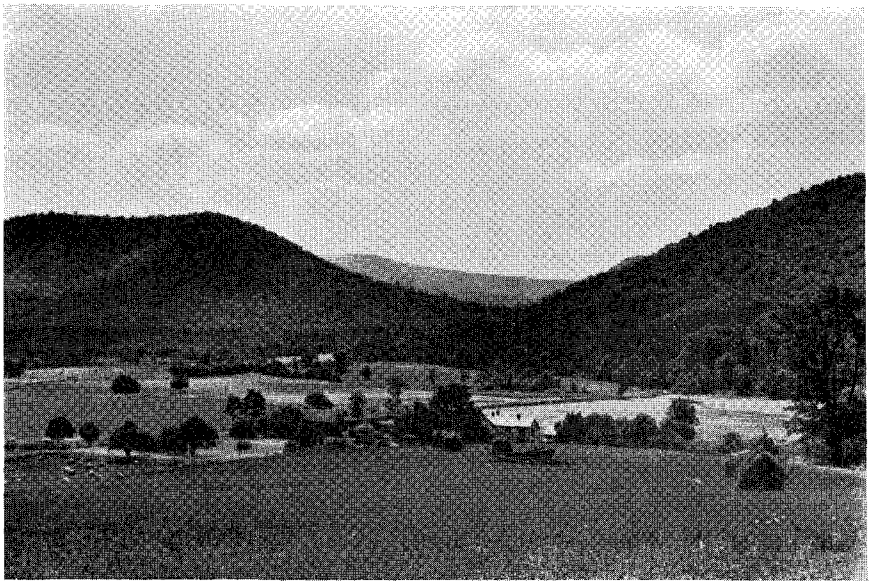
DRAINAGE MODIFICATIONS.

The drainage pattern developed on the initial surface in this region and the nature of the stream adjustments which took place in the earliest cycle are unknown. At the beginning of the so-called Tertiary cycle many streams were flowing southeast on the warped surface of the Upland Peneplane. As evidence of this more than a score of windgaps occur in the linear ridges of the Monterey quadrangle. The elevations of these are highly variable, ranging from 3,000 feet up to more than 4,000 feet, there being quite a number between 3,500 and 4,000 feet. This variation is not primarily due to differences in depth of stream cutting, because the gaps are all very shallow, but rather to the warping of the peneplane. At all points the gaps appear just below the peneplane level which in the Monterey region varies in elevation from about 3,200 to 4,600 feet. Apparently it was shortly after the beginning of the Tertiary (?) cycle that most of the captures took place. The earlier cycle of erosion had reduced hard and soft rocks almost to a common level, with the exception of a few monadnocks. Some transverse streams may have persisted from the earlier cycle, but others, and probably the greater number, were now formed by a southeast tilting or warping of the peneplane during uplift. The exposure at the surface of alternating belts of weak and resistant rocks furnished ideal conditions for the development of subsequent drainage. Lateral tributaries on weak rocks opened their valleys more easily and rapidly than the main transverse streams, because the latter were handicapped by having to cut through resistant sandstone. As these longitudinal subsequent streams grew, they early tapped their less favored transverse neighbors. It is thus seen that the early part of this cycle was a time when conditions were such as to make piracy a common occurrence.

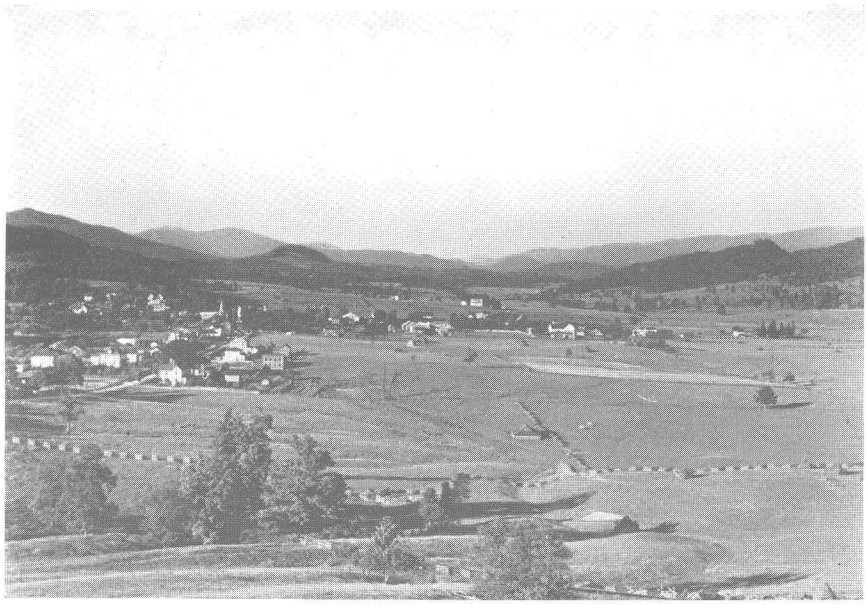
The four most important tributaries of the James on the north are Calf Pasture, Cow Pasture and Jackson rivers and Back Creek, and they all have subsequent courses. It is probable that each grew northeastward by headward erosion, thus tapping the waters of transverse streams. The



(A) Synclinal valley of Monterey. Photo taken from Pyramid Hill looking north across the town of Monterey, located on the divide between the James and Potomac drainage.



(B) Wind Gap in Sallings Mountain near Natural Bridge. The Blue Ridge appears in the distance through the gap.



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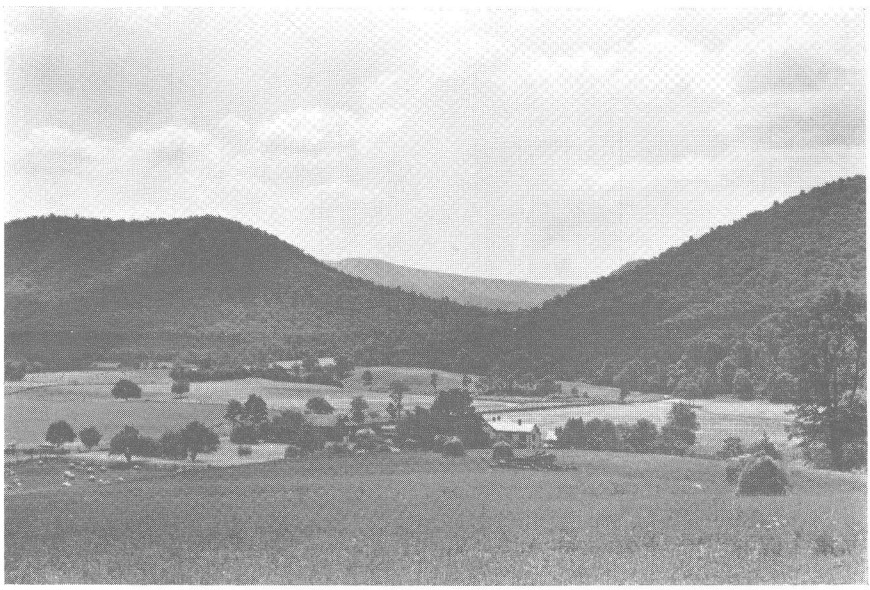


(B) Wind Gap in Sallings Mountain near Natural Bridge. The Blue Ridge appears in the distance through the gap.

series of changes involved must have been quite complex because there are a half dozen main ridges in the area of the James basin in the Staunton and Monterey quadrangles. The development of the subsequent streams must have gone forward in a manner similar to the growth of the Shenandoah southward from Harpers Ferry, West Virginia, as described by Willis,[1] and elaborated by Watson and Cline.[2] The capture of the headwaters of Beaverdam Creek by the Shenandoah is a classical example of river capture. But in the region under consideration there were four main subsequent streams and six ridges, instead of one stream and a single ridge as in the case of the Shenandoah.

Quite a number of the windgaps were examined in search for gravels but without success. The great age of the gaps, coupled with the narrowness of ridge crests in most cases, would easily explain the removal of the gravels by long-continued erosion.

Minor drainage changes.

A short article bearing on the subject of minor drainage changes appeared in Science in 1893.[3] The relations beween Jackson River and Back Creek on the southwestern part of the Monterey quadrangle are explained in the following manner: Back Creek-Meadow Fork (then forming a single large river) and Jackson River formerly flowed in parallel southwesterly pitching synclines separated by an anticlinal ridge. The syncline in which Jackson River was located was higher than the other. A tributary of Back Creek gnawed through the intervening anticline and tapped the upper portion of Jackson River, carrying its waters through the gorge across the anticline into the channel of Back Creek. Later a tributary of the beheaded Jackson River cut through the anticline at the present point of junction, and drew away the waters of Back Creek, giving conditions as we now find them.

There are very serious objections to the above interpretation of the drainage relations, which as Professor Cobb states is based on an investigation made by two of his students. In the first place, the actual drainage relations are so entirely different from those represented on the sketches

[1] Willis, Bailey, The Northern Appalachians. Nat. Geog. Soc., Mon., Vol. 1, No. 6, pp. 169-202, 1895.

[2] Watson, Thos. L., and Cline, J. H., Drainage changes in the Shenandoah Valley Region of Virginia. Univ. of Va. Pub., Philos. Soc., Bull., Scientific Series, Vol. 1, No. 17, pp. 349-363, July, 1913.

[3] Cobb, Collier, A recapture from a river pirate. Science, Vol. XXII, p. 195, 1893.

accompanying Professor Cobb's article, that one must conclude that the sketches were based on very inaccurate maps or on an imperfect knowledge of the topography. Meadow Fork and Back Creek are not located in the same valley, as shown on Cobb's sketches, but in parallel valleys with a high mountain ridge between them; and consequently they could never have formed a single continuous river as required by the theory. In the second place, Jackson River does not turn abruptly westward through the anticline into the valley of Back Creek, then back again through the anticline into its former valley, as represented on the sketches. Instead, Jackson River maintains its course southwest along the syncline unchanged, while Back Creek cuts obliquely southward across the intervening anticline to join Jackson River. Jackson River does cut across the axis of the disappearing Collison Ridge anticline to the east, but this is a different anticline and a different drainage problem. Back Creek alone crosses the anticline to which Cobb referred, and its course is readily explained without invoking capture across an anticlinal ridge of hard rock, at best a most unlikely proceeding. The southern portion of the south-pitching anticlinal arch of hard rock would not be exposed at the surface until early adjustments of the so-called Tertiary cycle were largely completed. Back Creek was doubtless superposed across this ridge probably near the beginning of the later or possibly at the close of the earlier cycle.

Slash School Marsh.

Reference has already been made to the beautiful series of intrenched meanders of Craig Creek in the west central portion of the Eagle Rock quadrangle. Craig Creek was a maturely developed meandering stream occupying a shale valley when uplift terminated the Valley Peneplane cycle. During subsequent time the stream has intrenched itself nearly 250 feet. Well developed undercut and slip-off slopes are exhibited by the several meander spurs.

Near Slash School on Craig Creek about two miles northeast of Oriskany on the Eagle Rock quadrangle there is a crescent marsh which evidently represents the floor of an abandoned entrenched meander of Craig Creek. The presence of the marsh in the abandoned area indicates that the change has been recent.

At Slash School there is a notch showing that the western meander was about to be cut off at this point. A similar notch, due to the same cause, occurs at the eastern end of the marsh. The railroad utilizes both notches, as does also a country road.

Drainage relations northwest of Eagle Rock.

In the shale country between the confluence of James River and Craig Creek there are several interesting drainage features. From the topographic relations as shown on the Eagle Rock quadrangle it would appear that the headwaters of Black Lick have in part been captured by Shirky Mill Branch. Gravels occur near the suggested elbow of capture, but cannot be differentiated from the gravels so widely distributed over the Valley Peneplane, of which the present divide seems to form a part. No distinct notch across the divide is to be found. The slope is apparently the same in each direction and is steep in both cases. If capture took place it must have occurred very early in the present cycle or near the close of the former cycle.

In the same locality it appears from the map that the head of Dutchman Branch has been cut off by Saville Branch. The entire area is forested and on this particular divide the brush is so thick that one can scarcely get through it. The upland surface represents the Valley Peneplane level and gravels are scattered over it, no more abundantly on the divide than elsewhere so far as could be found. The contour map shows a faint notch on the divide, which is so flat that a wet weather pond exists there.

Windgap in Sallings Mountain.

Sallings Mountain is located just west of Balcony Falls, on the Lexington quadrangle, where the James enters the gorge through the Blue Ridge. The most perfect windgap seen in the entire area is cut in this mountain. (Plate XI, B). The floor is about 400 feet above the floodplain of the James and has about the same elevation as the Valley Peneplane surface in this vicinity. On the floor of the gap are many waterworn boulders up to six and eight inches in diameter. Much larger ones are seen in the road cuts leading up to the top, some of which were not far from the summit. An excavation by the roadside revealed many boulders, some of which are deeply pitted, showing great age. The only plausible explanation for the facts observed is that a good sized stream formerly flowed through the gap. It is as well marked as if a stream the size of Buffalo Creek had once occupied it. Since the floor of the gap has about the same elevation as the Valley Peneplane, the capture must have taken place near the close of the cycle in which the peneplane was produced. The probability is that it happened as a consequence of rejuvenation through uplift at the beginning of the present cycle.

It is natural to inquire as to what stream formerly flowed through this gap. It is not impossible that Buffalo Creek may once have taken this course to North River, and have been later diverted to its present position by a stream more favorably situated on weak rocks, working back toward the northwest along the present sites of Buffalo Forge and Buffalo Mills (Lexington quadrangle). Or it may be that the present headwaters of Cedar Creek, including much of the Short Hills drainage, formerly flowed eastward through a stream which cut the Sallings Mountain gap, but which disappeared as a result of capture by the stream now forming the lower course of Cedar Creek and by other streams equally favorably situated.

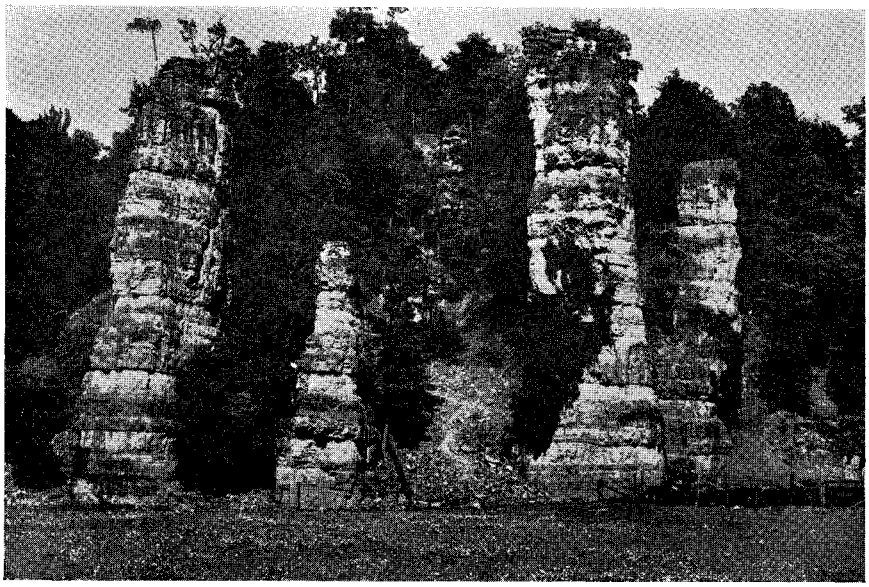
Some evidence in favor of a piracy affecting Cedar Creek is seen in the gorge of the latter stream. Rejuvenation at the beginning of the present cycle will not explain why the valley of this stream should be so much more gorge-like than the valleys of other similar streams in the vicinity. The addition of a considerable volume of water by capture, however, would enable Cedar Creek to incise itself rapidly to a considerable depth. With a corresponding reduction in volume the stream flowing through the gap in Sallings Mountain could not lower its bed fast enough to prevent its suffering further capture by subsequent streams working back from Buffalo Creek, North River, and James River, and in a short time the gap would be completely abandoned by the waters which formerly drained through it. It should be noted that the supposed capture by lower Cedar Creek would explain the falls required in Walcott's explanation of the origin of Natural Bridge.[1]

Cases of imminent capture.

The portion of Cedar Creek on the summit of Short Hills is in immediate danger of capture at Spring Gap. A tributary of Cedar Creek has reached the top of the mountain by headward erosion. The Natural Bridge Special topographic map incorrectly represents the position of the head of the stream, because a stream empties across the eastern crest of the mountain. It rises in the marsh area indicated on the map. So far as the writer was able to determine the marsh covers the entire interstream area so that the capture is just really taking place and some of the water which formerly flowed down the synclinal trough now flows eastward across the rim. The gap is at least 100 yards wide and is cut in sandstone.

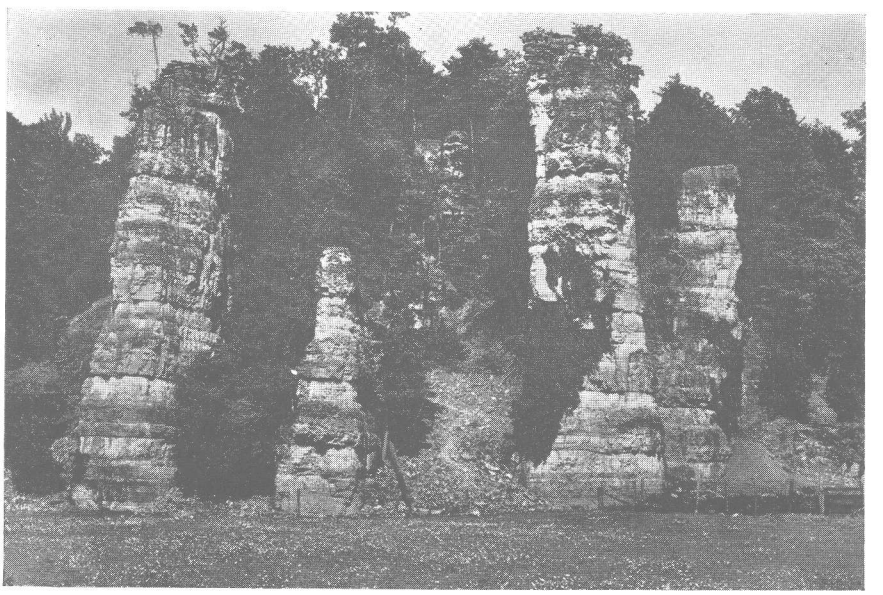
[1] Walcott, Charles D., The Natural Bridge of Virginia. Nat. Geog. Mag., Vol. V, pp. 59-62, 1893.

(A) Sinkholes near Eagle Rock, Virginia. The telephone pole in the foreground gives an idea of the size of the depressions.



(B) Natural Chimneys near Mt. Solon, Virginia,—erosion columns in limestone.

(A) Sinkholes near Eagle Rock, Virginia. The telephone pole in the foreground gives an idea of the size of the depressions.



(B) Natural Chimneys near Mt. Solon, Virginia,—erosion columns in limestone.

The relation between James River and Mud Run just north of Gala on the Eagle Rock quadrangle attracted attention. The ridge between the two streams is only about 25 feet high at its lowest point, showing how nearly the James came to capturing Mud Run by intercision. The valley wall is here very steep, indicating that the James has recently been cutting at its base. At present the river is cutting well in against the end of Big Hill about a mile upstream, and it is possible that this has deflected the current to the middle of the floodplain farther down the valley, thus serving to prevent the capture of Mud Run.

A more striking instance of imminent capture could scarcely be found than in the case of Shavers Fork of Cheat River in the northwestern corner of the Monterey quadrangle. This stream flows leisurely on the surface of the plateau, while Leather Bark Run, a tributary of Greenbrier River is gnawing back into the plateau scarp. The fall of Leather Bark Run is more than 1,000 feet in less than a mile and a half. It is within three-fourths of a mile of Shavers Fork, and not more than 400 yards from one of its tributaries. In the near future, geographically speaking, the upper two miles of Shavers Fork will become part of the Greenbrier drainage, descending over falls due to the forthcoming capture, into the picturesque gorge which will mark the sharp elbow of capture.

MINOR TOPOGRAPHIC FEATURES.

Limestone sinks and caverns.

Limestone sinks are extremely common in the Valley region. (Plate XII, A). They also occur in the narrow limestone belts exposed in the cores of anticlines in the Ridges sub-province. So widely are they distributed that one may expect to find them in any portion of the Valley. Some members of the Shenandoah group of limestones are more favorable to their formation than others. Their origin is in some cases due to the sudden collapse of the roofs of underground caverns formed by solution. Instances are known where the roofs have fallen in during historic times, as for example, the collapse in the city of Staunton in August, 1910, which caused considerable damage to property.[1] In some localities a score or more sinks may be counted in a square mile, while in other districts they are absent entirely. They are especially abundant just west of Lexington. In size they vary from shallow depressions a few feet in diameter to those whose bottoms occupy an acre or more of ground with a depth of 100 feet. The walls are usually steep, and in some, the solid rock outcrops. An unusually deep sink with precipitious walls is found at Mt. Solon on the Staunton quadrangle. The openings which connect the bottoms of the sinks with underground channels occasionally become clogged so that the water cannot escape. For this reason ponds are of frequent occurrence.

No really important cave has been discovered within the limits of the region under discussion, but the famous Weyers Cave (The Grottoes) is just off the Staunton quadrangle. Very small caverns are rather common. Sinking Creek disappears underground at a point about two miles north of Burnsville, in the central-eastern portion of the Monterey quadrangle, and other examples of subterranean drainage are common.

Natural Chimneys.

There are five limestone columns standing in the face of a hill near Mt. Solon which are called the "Natural Chimneys." (Plate XII, B). The rocks in this vicinity are strongly affected by several sets of joints, the vertical ones being the most prominent. Underground waters were con-

[1] Kindle, E. M., The collapse of recent beds at Staunton, Virginia. Proc. Wash. Acad. Sci. Vol. XIII, No. 2 pp. 35-49, May 15, 1911.

centrated along the principal planes of weakness, causing extensive solution and other weathering effects, especially along the vertical joints. The group stands in the face of the valley wall of North River, against which the stream has recently been cutting. It is easy, therefore, to understand how the weathered material was readily removed, leaving the more resistant, less jointed masses standing as columns or chimneys.

Natural Bridge.

"Natural Bridge," about 12 miles southwest of Lexington, has been known since the early days of Virginia history, and it was a favorite theme of discussion for early scientists. Many descriptions and explanations have been published. Gilmer in 1818 was the first to explain it on the basis of solution.[1] Walcott's explanation is probably the best that has been proposed.[2] "Cedar Creek was engaged for a considerable period in excavating the gorge from James River to a point not far below the present site of the bridge, when a fall appears to have existed, the summit of which was not far if at all below the present level of the top of the bridge. About this time the water found a subterranean passage in the limestone further up the stream than the present site of the bridge, and through this it flowed and discharged beneath the brink of the falls. The passage gradually enlarged until all the waters of the Creek passed through it and the bridge began its existence. All of the rock has disappeared except the narrow span of the bridge." A more recent article by Cleland deals with the origin of this and other natural bridges in North America.[3] A near view of the Bridge is shown in Plate XIII.

Pyramid Hill.

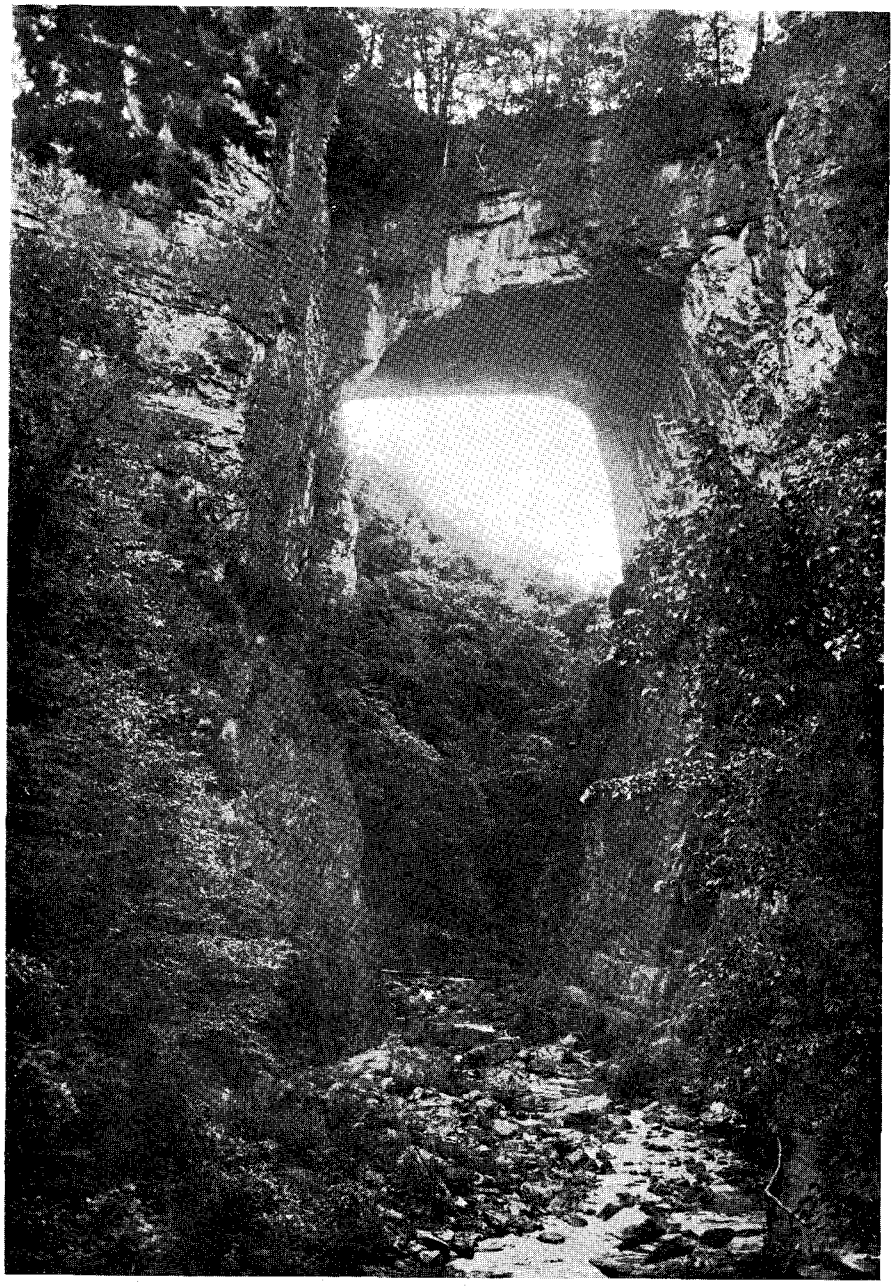
About one half mile south of Monterey, in the synclinal valley of Jackson River, there is a very sharp conical knoll named Pyramid Hill. Its chief point of interest lies in the fact that it possesses a basaltic core. Fragments of this rock occur abundantly on the summit and slopes of the hill. According to Darton[4] the rock occurs in the form of dykes or slender

[1] Gilmer, F. W., On the geological formation of the Natural Bridge of Virginia. Am. Phil. Soc. Trans. Vol. 1 new ser., pp. 187-192, 1818.

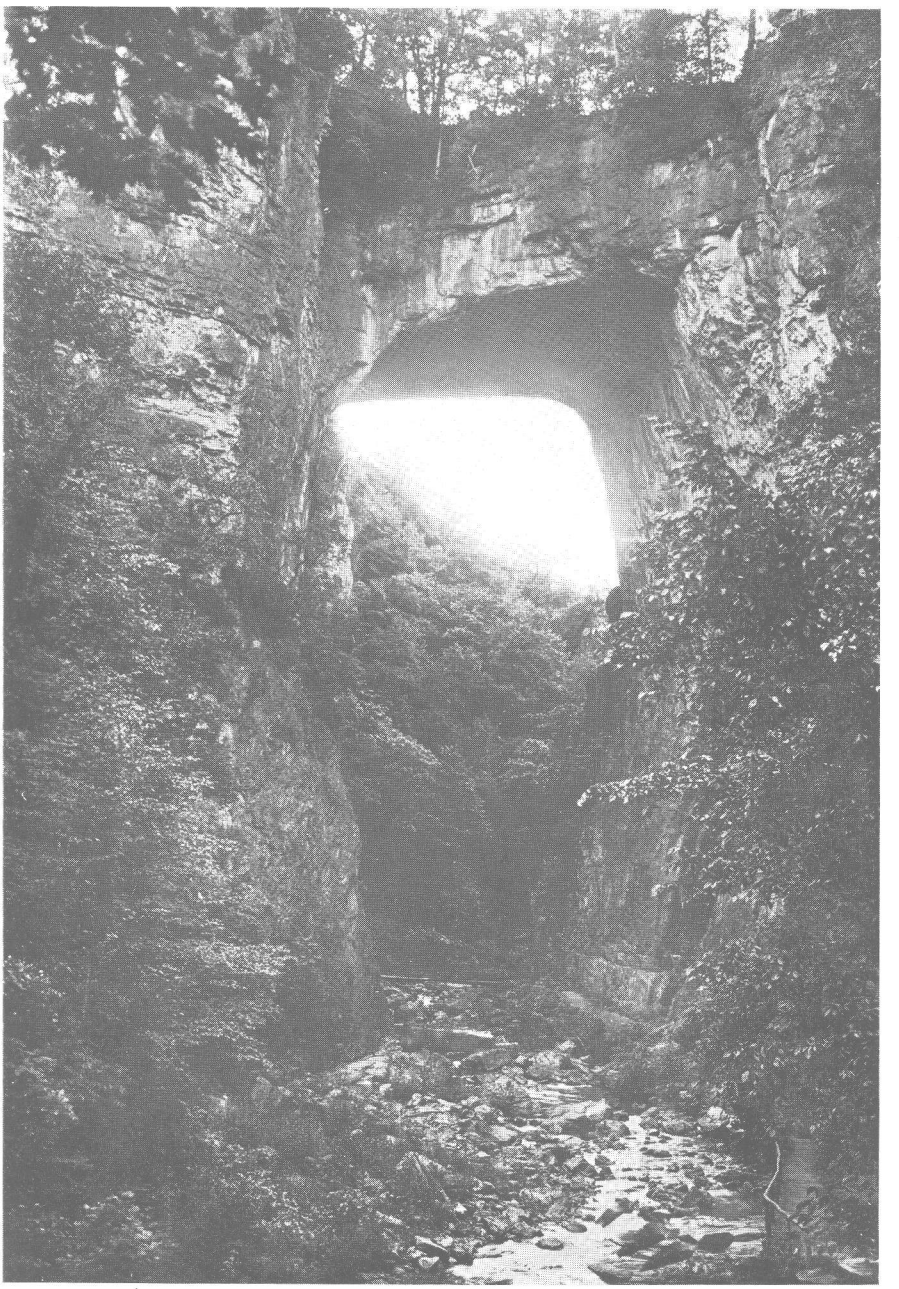
[2] Walcott, C. D., The Natural Bridge of Virginia. Nat. Geog. Soc. Mag. Vol. V, pp. 59-62, 1893.

[3] Cleland, H. F., The formation of North American Bridges. Popular Science Monthly, Vol. LXXVIII, No. 5, May, 1911.

[4] Monterey Folio, No. 61, U. S. Geol. Survey.



Natural Bridge from the east.



Natural Bridge from the east.

necks. He further states that "at Pyramid Hill the basalt is in the Romney shales, but it is flanked on one side by a breccia of a variety of quartzite and calcareous rocks brought up from below." It is a very striking local feature and owes its prominence to the greater resistance which the basalt offered to the agents of denudation.

BIBLIOGRAPHY.

BARRELL, JOSEPH, The Piedmont terraces of the Northern Appalachians. Amer. Jour. Sci., Fourth Series, Vol. XLIX, pp. 227-258, 327-362, 407-428, 1920.

BASCOM, F., Cycles of erosion in the Piedmont Province of Pennsylvania. Jour. of Geol., Vol. 29, pp. 540-559, 1921.

CAMPBELL, J. L., Geology of Virginia: continuation of section across the Appalachian chain. Amer. Jour. Sci., Third Series, Vol. 18, pp. 119-128, 239, 1879.

————, Geology of Virginia: Balcony Falls. The Blue Ridge and its geological connections; some theoretical considerations. Amer. Jour. Sci., Third Series, Vol. 18, pp. 435-445, 1879.

————, Mineral resources of the James River Valley, Virginia, with map and sections, 119 pages, New York, 1883.

COBB, COLLIER, A recapture from a river pirate. Science, Vol. XXII, p. 195, 1893.

DARTON, N. H., Staunton folio, Virginia-West Virginia. U. S. Geol. Surv., Geol. Atlas of U. S., Folio No. 14, 1894.

————, Monterey folio, Virginia-West Virginia. U. S. Geol. Surv., Geol. Atlas of U. S., Folio No. 61, 1899.

DAVIS, WILLIAM M., The rivers and valleys of Pennsylvania. Nat. Geog. Mag., Vol. 1, pp. 183-253, 1889. Also "Geographical Essays," edited by D. W. Johnson. Ginn and Company, pp. 413-484, 1909.

————, The geological dates of origin of certain topographic forms on the Atlantic Slope of the United States. Geol. Soc. Am. Bull., Vol. 2, pp. 541-542, 545-586, 1891.

HAYES, C. WILLARD, The Southern Appalachians. Nat. Geog. Soc., Mon. Vol. 1, No. 10, pp. 305-336 and map, 1895.

HAYES, C. WILLARD and CAMPBELL, M. R., Geomorphology of the Southern Appalachians. Nat. Geog. Mag. Vol. VI, pp. 63-126, 1894.

KEITH, ARTHUR, Geology of the Catoctin Belt. U. S. Geol. Surv., 14th An. Rept., pt. 2, pp. 285-395, 1894.

————, Some stages of Appalachian erosion. Geol. Soc. Am., Bull., Vol. VII, pp. 519-525, 1896.

KNOPF, ELEANORA BLISS, Relation of former drainage channels to the topography of eastern Pennsylvania and Maryland. Bull. Geol. Soc. Amer. Vol. 35, p. 77, 1924.

ROGERS, WILLIAM B., A Reprint of annual reports and other papers on the geology of the Virginias. 832 pages, plates, maps, New York, 1884.

SPENCER, A. C., The geology of Massanutten Mountain in Virginia. Published by the author, Washington, D. C., 54 pp., 1897.

SURFACE, G. T., Geography of Virginia. Bull., Geog. Soc. Philadelphia, Vol. 5, No. 4, pp. 1-60, October, 1907.

STOSE, G. W., MISER, H. D., KATZ, F. J., HEWETT, D. F., Manganese deposits of the west foot of the Blue Ridge, Virginia. Va. Geol Surv. Bull. No. XVII, 1919.

VIRGINIAS, THE, Staunton Virginia, 1880-1886. A journal edited by Jed Hotchkiss.

WALCOTT, CHARLES D., The Natural Bridge of Virginia. Nat. Geog. Mag., Vol. V, pp. 59-62, 1893.

WATSON, THOS. L., A geological map of Virginia. Va. Geol. Surv. 1914, slightly revised in 1916.

————, Mineral resources of Virginia. J. P. Bell Co., Lynchburg, Va., 1907.

WATSON, THOS. L. and CLINE, J. H., Drainage changes in the Shenandoah Valley region of Virginia. Univ. of Va. Pub., Philos. Soc., Bull., Scientific Series, Vol. 1, No. 17, pp. 349-363, July, 1913.

WILLIS, BAILEY, The Northern Appalachians. Nat. Geog. Soc., Mon., Vol. 1, No. 6, pp. 169-202, 1895.

INDEX

Acknowledgments, 6.
Age of Paleozoic rocks, Newer Appalachians region, 1-2.
Alleghany Mountains, 45.
Ridges, classification of terraces, 41.
domes in, 16-17.
sub-province, characteristics of terraces in valleys of, 38-40.
"Alleghany, Top of," 13-14.
Anticlinal ridges, 23-24.
drainage of, 47.
Anticlinal valleys and synclinal ridges, origin of, 46-47.
drainage of, 48.
Appalachian Plateau, 2.
Valley province, 2.
Asymmetrical topography, 49-50.

Back Creek, 45, 50, 51, 52.
anticline, 25.
valley of, 49.
Bald Dome, 15.
Knob, 12.
Barrell, Joseph, cited, 5.
Betsy Bell, 30.
Beveling of folded mass by Upland Peneplane, 47.
Bibliography, 61-62.
Big and Little House Mountains, 29.
Hill, 32.
Black Lick, 53.
Blackwater, 2.
Blue Ridge Dome, possible, 17.
Bolar anticlinal valley, 47.
valley, 48.
Buchanan region, 31.
Buffalo Creek, 44, 54.
Bullpasture River, Valley of, 49.

Calf Pasture River, 50.
Campbell, Hayes and, cited, 31.
Campbell, J. L., on geology and mineral resources of James River Valley, 3.
Canaan formation, 2.
Capture at Spring Gap, of Cedar Creek on summit of Short Hills, immediate danger of, 54.
Capture, cases of imminent, 54-55.
river, classical example of, 51.
Catoctin belt, Keith on geology of, 4.
Caverns, 57.
Cedar Creek, 48.
evidence in favor of piracy affecting, 54.
Ridge, 31.
Characteristics, terraces in valleys of Alleghany Ridges sub-province, 38-40.
Cheat Mountain, 13.
Chimneys, natural, 57-58.
Classification, terraces of Alleghany Ridges, 41.
Cleland, H. F., cited, 58.
Cline, Justus H., Watson and, cited 5, 27, 51.
Cobb, Collier, cited, 51.
on piracy affecting waters of Back Creek and Jackson River, 3.
Contour map of warped Upland Peneplane, methods employed in securing data for, 30-31.
Covington region, 32-33.
Cow Pasture River, 45, 50.
location of valley of, 46.
upper portion of valley of, 49.
Craig Creek, entrenched meanders of, 52.
Cretaceous peneplane in southern Appalachians, W. M. Davis on, 3.

Darton on Pyramid Hill, 58-59.
source of water at Hot Springs and Warm Springs, Va., 49.
Davis, W. M., cited, 6, 7, 35, 37, 47.
on Cretaceous peneplane in southern Appalachians 3.
Degree of dissection, 33.
Development, Valley Peneplane, 27-28.
Dissection, degree of, 33.
Upland Peneplane, 11.
Dome, Bald, 15.
Blue Ridge, possible, 17.
Fisher, 16.
High, 16-17.
Job, 16.
Pots Mountain, 17.
Spruce, 16.
Strouds, 16.
Domes, 15-22.
drainage of, 19-21.
in Alleghany Ridges, 16-17.

Plateau, 15-16.
origin of, 18-19.
relations between, 17.
Drainage, 43-55.
anticlinal ridges, 47.
anticlinal valleys, 48.
Drainage changes, minor, 51-52.
Shenandoah Valley, Watson and Cline on, 5.
development, 43-50.
on Upland Peneplane surface, 19.
developments in southern Appalachians, Hayes and Campbell on, 4.
modifications, 50-55.
of domes, 19-21.
monoclinal valleys, 49.
relations between Jackson River and Back Creek in the southwestern part of Monterey quadrangle, 51-52.
relations northwest of Eagle Rock, 53.
subsequent, importance of, 43-45.
synclinal ridges, 48.
valleys, 49.
Driscol, levels at, 40.
Duncan Knob, 47.
Dutchman Branch, 53.
Dutton, C. E., cited, 37.

Eagle Rock, drainage relations northwest of, 53.
Earliest restored surface, 9-10.
Elevations, Balcony Falls, 40.
between Natural Bridge and Lexington, 30.
Churchville, 30.
Fairfield, 30.
Frost, four miles north of, 40.
one mile south of, 40.
Gala region, 32.
Middlebrook, 30, 31.
Millboro Springs on Cow Pasture River, ten miles south of, 40.
Mt. Solon, 30.
Natural Bridge, 30.
peneplane surface going northeastward from Balcony Falls to the divide between James and Potomac rivers, 30-31.
Staunton, 30.
terraces, variation in, 39.
Valley Peneplane, Middlebrook, 31.
Elliott Knob, 12.
Entrenchment of stream in its floodplain, causes of, 35.
Erosion, differential, rock terraces due to, 36-37.
Keith on Appalachian, 4.
Esplanade of Grand Canyon of the Colorado as example of rock terrace due to differential erosion, 36.

Fincastle region, 32.
Fisher Dome, 16.
Floodplain gravels, 39.
terraces, 35-36.

Gala region, 32.
Geography of Virginia, Surface on, 5.
Geomorphology of Southern Appalachians, Hayes and Campbell on, 3.
Giles, Albert W., coöperation of, 6.
Gilmer's explanation of "Natural Bridge," 58.
Glen Wilton, levels at, 40.
Gorge of James River, 44.
Gravels, floodplain, 39.
Great Valley, 46.
Greenbrier limestone, 2.
River, 45.
Grottoes, The, 57.

Hampshire formation, 2, 45, 46.
Hayes and Campbell, cited, 31.
on "Geomorphology of the Southern Appalachians," 3.
Hayes on peneplanes in southern Appalachians, 4.
Healing Springs, 49.
High Dome, 16-17.
Holt, S. P., coöperation of, 6.
Hotchkiss, Jed, editor of "The Virginias," 3.
Hot Springs, 48-49.

Initial surface, 7-10.
Introduction, 1-6.
Iron Gate gorge, 23-24.

Jack Mountain, 45, 47.
Jackson River, 45, 50, 51, 52.
location of valley of, 46.
valley of, 49.
Jackson River and Back Creek, drainage relations between, 51-52.

James River, course of, 43-44.
gorge of, 44.
James River and Mud Run just north of Gala on Eagle Rock quadrangle, relation between, 55.
Jennings formation, 1-2, 45, 46.
Job Dome, 16.
Johnson, Douglas W., coöperation of, 6.

Keith on Appalachian erosion, 4.
geology of Catoctin belt, 4.
Kindle, E. M., cited, 57.

Leather Bark Run, 55.
Levels at Driscol, 40.
Glen Wilton, 40.
represented in Upper James River Basin, 11.
terrace, on Jackson River three miles north of Covington, 39.
Lewistown limestone, 1.
as a valley maker, 46.
Limestone sinks and caverns, 57.
Literature, review of, 2-6.
Little Mountain, 25.
Little Timber Ridge, 31.

Marlin Mountain-Sandy Ridge range, 45.
Martinsburg shale, 1, 46.
Mary Gray, 30.
Massanutten formation, 46.
Mountain, 45. 47.
Spencer on geology of, 4.
sandstone, 1, 45.
Meadow Fork, 52.
Meanders of Craig Creek, 52.
Jackson River three miles north of Covington, 40.
Methods of reconstructing the initial surface of the folded Appalachians, 7-9.
Middlebrook region, 31.
Minor topographic features, 57-59.
Modifications, drainage, 50-55.
Mole Hill, 30.
Monadnocks in Valley, 29-30.
on Upland Peneplane, 12-13.
Valley Peneplane, 23-26.
other, 12-13.
Monoclinal ridge bordering Warm Springs Valley on west, 25.
ridges, 24-26.
valleys, drainage of, 49.
Monterey Folio, reference to, 45, 58.
Mountain, 25.
sandstone, 1.

Natural Bridge, 58.
chimneys, 57-58.
Newer Appalachian region, age of Paleozoic rocks of, 1-2.
Northeast Peak, 12.
North River, 44.

Origin, anticlinal valleys and synclinal ridges, 46-47.
domes, 18-19.
terraces in general, 35-38.

Peneplane, Upland, 11-22.
Valley, 27-33.
valley of Craig Creek, 32-33.
Peneplanes, 5.
northern Appalachians, Barrell on, 5-6.
Willis on, 4.
southern Appalachians, Hayes on, 4.
Perfection, degree of, Valley Peneplane, 28-29.
Physiographic Forms, G. W. Stose on, 5.
Piracy affecting Cedar Creek, evidence in favor of, 54.
waters of Back Creek and Jackson River, Collier Cobb on, 3.
Back Creek and Jackson River, 3.
evidence of, affecting Cedar Creek, 54.
Plateau, domes in, 15-16.
Pocono sandstone, 2.
Potts Mountain Dome, 17.
Principal ridge and valley makers, 45-46.
Purgatory Mountain, 29.
Pyramid Hill, 58-59.

Relations between the domes, 17.
Remnants, local, Upland Peneplane, 14.
Restoration of Upland Peneplane, method employed in, 9-10.
Rich Patch Mountain anticline, 23.
, topography of, 24.
Ridge and valley makers, 45-46.
formers in Newer Appalachians region, 2.
makers, 45-46.
Ridges, anticlinal, 23-24.
monoclinal, 24-26.
synclinal, 24.
River capture, classical example of, 51.

Robinson, H. H., cited, 5.
Rock-defended rock terraces, 37-38.
Rock terraces due to differential erosion, 36-37.
successive uplifts, 37.
Rockwood formation, 1.
Rogers, William Barton, 2-3.
Romney shale, 1, 38, 46.

Sallings Mountain, windgap in, 53-54.
Sandstone layers, 38-39.
Saville Branch, 53.
Shale prevailing rock type in terraces in valleys of Alleghany Ridges sub-province, 38-39.
Shavers Fork of Cheat River in northwestern corner of Monterey quadrangle, striking instance of imminent capture, 55.
Shenandoah limestone, 1, 46.
Mountains, 14, 45.
Valley, drainage changes in, Watson and Cline on, 5.
Shirky Mill Branch, 53.
Short Hills, 24, 29, 45, 47.
Sinking Creek, 57.
Sinks, limestone, 57.
Slash School Marsh, 52.
Sounding Knob, 12, 47.
South River, 45.
Spencer, cited, 4, 27.
Spruce Dome, 16.
Stose, G. W., cited, 5.
Strouds Dome, 16.
Subsequent drainage, importance of, 43-45.
streams, 50-51.
Sugar Loaf, conical monadnock, 30.
Surface, earliest restored, 9-10.
Surface on geography of Virginia, 5.
Synclinal ridges, 24.
drainage of, 48.
valleys, drainage of, 49.

Terrace levels on Jackson River three miles north of Covington, 39.
Terraces, 35-41.
Alleghany Ridges, classification of, 41.
floodplain, 35-36.
in valleys of Alleghany Ridges sub-province, characteristics of, 38-40.
origin and characteristics of, 35-40.
rock-defended rock, 37-38.
rock, due to differential erosion, 36-37.
rock, due to successive uplifts, 37.
variation in number of, 39.
"Tertiary Peneplane," 27.
Timber Ridge, 31.
"Top of Alleghany," 13-14.
Topographic features, minor, 57-59.
Topography, assymetrical, 49-50.
Upland Peneplane, 11.
Trend of provinces, 2.
Tributaries of James River on north, 50.
Typical areas, Valley Peneplane, 31-33.

Upland Peneplane, 11-22.
and its monadnocks, earliest restored surface, 9-10.
beveling of folded mass by, 47.
dissection of, 11.
local remnants of, 13.
monadnocks on, 12-13.
surface, drainage development on, 19.
warping, 21.
surface, general character of, 14-15.
Uplift, axes of, 15.
zone of maximum, 15.

Valley, Back Creek, 49.
Bullpasture River, 49.
Cow Pasture River, 49.
Jackson River, 49.
monadnocks in, 29-30.
Valley maker, Lewistown limestone as, 46.
Shenandoah limestone as, 46.
Valley makers, 46.
ridge and, 45-46.
Valley Peneplane, 11, 27-33.
degree of perfection of, 28-29.
equivalent of "Tertiary Peneplane," 27.
extent of development, 27-28.
typical areas of, 31-33.
warping, 30-31.
Variation in number of terraces, 39.
"Virginias, The," reference to, 3.

Walcott, Charles D., cited, 54.
Walcott's explanation of "Natural Bridge," 58.
Walker's Mountain, 23, 45.
Warm Springs, 48-49.
anticlinal valley, 48-49.
Valley, monoclinal ridge bordering, on west, 25.
Warped Upland surface, general character of, 14-15.
Warping, 30-31.
earlier versus later, 21.
Upland Peneplane, 21.
, Valley Peneplane, 21.
Water gaps, Warm Springs and Bolar valleys, 50.
Watson, Thomas L. and Cline, Justus H., cited, 5, 27, 51.
coöperation of, 6.
Weyers Cave, 57.
Willis, Bailey, cited, 51.
on peneplanes in northern Appalachians, 4.
Windgap in Sallings Mountain, 53-54.
Windgaps, 50.

Contour map of the restored Upland (Cretaceous) Peneplane showing its strongly warped character.

Note the presence of what appear to be local domes in addition to zones of greater upwarping.

Present surface contour interval, 500 feet ; peneplane contour interval, 200 feet.

(Base: U. S. Geological Survey Topographic Maps)

SCALE $\frac{1}{500,000}$

0 10 20 30 40 50 kilometers

0 5 10 15 20 25 miles

1924