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GEOMORPHOLOGY

OF THE

SOUTHERN APPALACHIANS

BY

C. WILLARD HAYES AND MARIUS R. CAMPBELL

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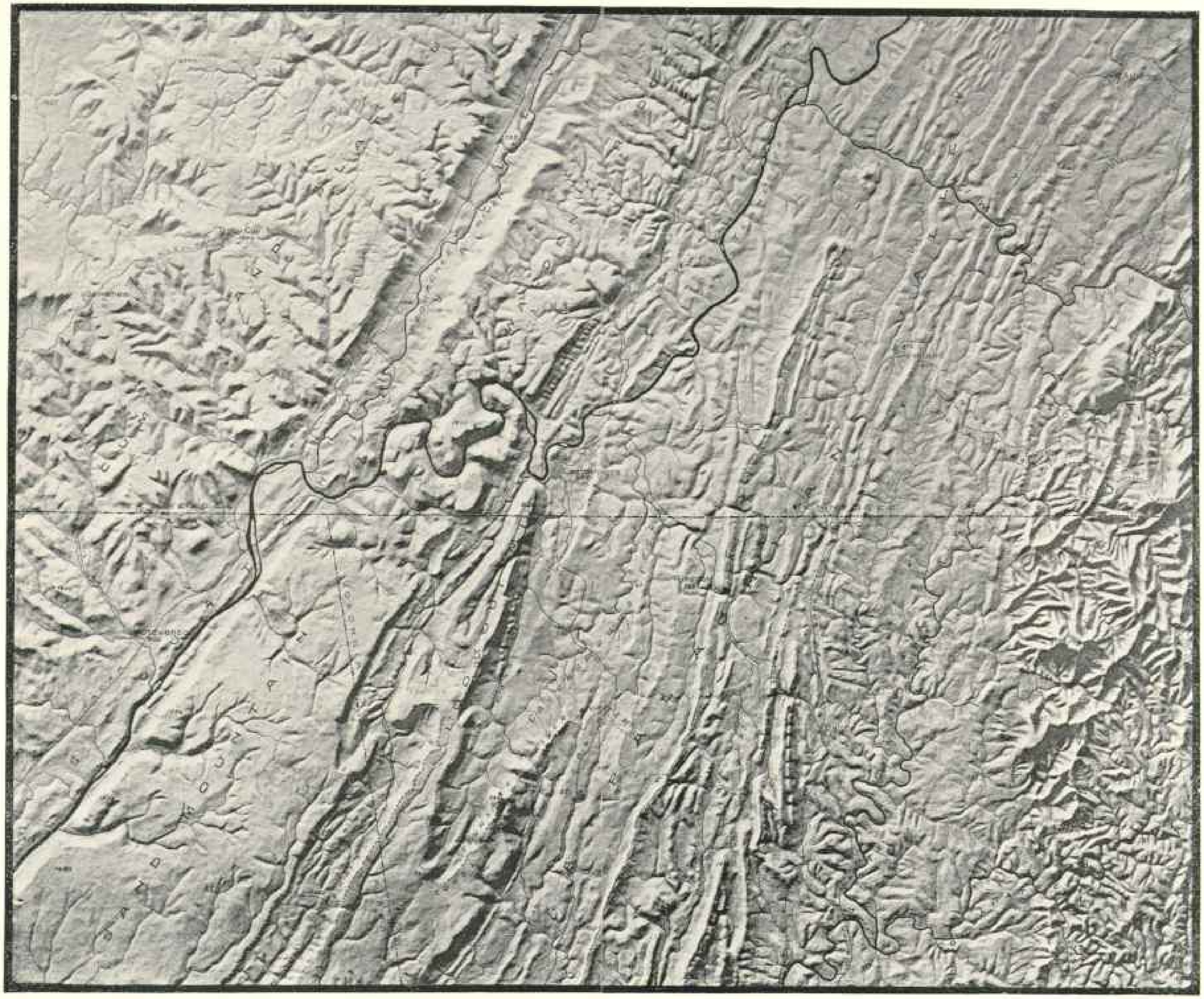

Modelled by E. E. Howell,
Washington, D. C.

RELIEF MAP OF THE CHATTANOOGA DISTRICT.

Horizontal scale 16 miles = 1 inch.

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CHARLES WILLARD HAYES AND MARIUS R CAMPBELL

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Introduction.

Review of previous work.

The post-Paleozoic history of the Appalachian province has, until recent years, been known only in the most general terms. That the region has been a land area since the close of Carboniferous time was known, and it was assumed that, in common with other land areas, it had been repeatedly elevated and depressed, yet the extent and character of these movements, in the interior at least, were not only unknown, but no data were supposed to exist by which they could be measured. Along the

margin of the province the subsidences are recorded in the sediments deposited as the sea transgressed upon the land, and in some cases the amount of subsequent uplift is indicated by the recession of overlying deposits. In so far as these oscillations have been determined from sedimentary deposits, each transgression of the sea was regarded as marking a continental depression, and each recession a continental uplift. Within the past few years, however, a complete revolution has been effected in the interpretation of the post-Paleozoic history of this region. Through the work of a few pioneers in this field the number and character of the principal oscillations and their position in geologic time are now fairly well known.

The first systematic application of the new methods of research was made by McGee in the middle Atlantic slope. In 1885, in a paper on the geology of Chesapeake bay,* he pointed out the methods pursued and the importance of utilizing topographic forms resulting from degradation, as well as the complementary sedimentary deposits in interpreting geologic history. In 1888† he more definitely correlated the principal oscillations with the sedimentary deposits, thus fixing their position in geologic time, and in a subsequent paper‡ he made the very important generalizations that all elevations have been accompanied by seaward tilting of the land, and that along certain axes the oscillations have reached a maximum amount, while along others both elevation and depression have been at a minimum.

Davis§ published the results of his studies on the geomorphology of the middle and north Atlantic slope shortly after the

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* The Geology of the Head of Chesapeake Bay, by W J McGee: Seventh Annual Report U. S. Geological Survey, 1888, pp. 545–646.

† Three Formations of the middle Atlantic Slope, by W J McGee: Am. Jour. Sci., vol. xxxv, 1888.

‡ The Lafayette Formation, by W J McGee: Twelfth Annual Report U. S. Geological Survey, 1891, pp. 353–528.

Geology of Washington and Vicinity, by W J McGee: Compte Rendu de la Congrès Géologique International, 5th Session, Washington, 1891, pp. 219–251.

§ The Rivers and Valleys of Pennsylvania, by W. M. Davis: Nat. Geog. Mag., vol. i, 1889, pp. 183–253.

The geographic Development of northern New Jersey, by W. M. Davis and J. W. Wood: Proc. Boston. Soc. Nat. Hist., vol. xxiv, 1889, pp. 365–423.

The Rivers of northern New Jersey, by W. M. Davis: Nat. Geog. Mag., vol. ii, 1890, pp. 81–110.

appearance of the first two papers above cited. He has carried his observations somewhat further toward the interior and describes two well marked baselevel peneplains in eastern Pennsylvania, New Jersey and portions of New England, the formation of which, he ascribes to long continued erosion in Cretaceous and Tertiary time. A general seaward tilting of the peneplain is described, but no attempt is made to locate the axes of their deformations. In 1890 Davis published a more comprehensive paper,† bringing in review all previous publications on the baselevels of the Atlantic slope and discussing the probable continuation of the peneplains, found in the northern portion southward over the whole of the Appalachian province.

Thus the broad outlines and to some extent the details of post-Paleozoic history of the Atlantic slope and Mississippi embayment have been determined, but for most of the interior the details are still wanting. The present paper is an attempt to supply in some measure this deficiency.

THE PROVINCE DEFINED.

For present purposes the southern Appalachian province is regarded as embracing the region south of the Ohio and Potomac rivers and limited toward the east, south, and west by the Cretaceous and the later formations of the coastal plain and Mississippi embayment. One or both of the present writers are personally familiar with the greater part of this region, and many observations made in connection with the work of the Appalachian division of the United States Geological Survey are here for the first time brought together. The location of the region is exceptionally favorable for the study of its geomorphology. Surrounded on three sides by Mesozoic and later deposits, the relations of land and water which prevailed during post-Paleozoic time are fairly well determined. The character of the sediments serves to establish correlations between them and their corresponding erosion features. The intersection of erosion planes with deposits of known age serves to fix the date of each erosion period within narrow limits. Finally, the absence of glaciation and glacial deposits renders the interpretation of topographic forms and of drainage systems much easier than in regions

† The geologic Dates of Origin of certain topographic Forms on the Atlantic Slope of the United States, by W. M. Davis: Bull. Geol. Soc. Am., vol. ii, 1890, pp. 545–586.

where glaciation has interfered with their normal development or masked their completed form.

THE PROBLEMS AND THE DATA.

Since the southern Appalachian province, as above defined, has stood above sealevel throughout the whole of the period whose history is under consideration, that history must be read in the topographic forms developed during the process of subaerial degradation and in the adjustments of drainage to changing conditions.

The fundamental conception, in the interpretation of the history of a region from its topographic forms, is the *baselevel of erosion.* The formation of a general baselevel peneplain implies the long continuance of certain well defined conditions, so that wherever the presence of such a peneplain can be established the former existence of these conditions may be safely inferred; also it can be formed only near sealevel; hence by contouring the present remnants of a baselevel peneplain the contour at any point represents very nearly the algebraic sum of all changes in altitude which that portion of the plain has suffered.

In the southern Appalachian province the more or less perfectly preserved remnants of two baselevel peneplains have been mapped and their deformations represented by contours; the conditions implied by these baselevels have been inferred; their probable correlations with the contemporaneous sedimentary deposits indicated; and finally the development of the drainage has been traced through a complex series of adjustments upon the repeatedly deformed surface to its present mature location.

Part I—Physiographic Development.

CLASSIFICATION OF TOPOGRAPHIC FEATURES IN THE PROVINCE.

The southern Appalachian province has certain topographic features common throughout its entire extent. They are so modified by local conditions that their identity in different portions of the province would scarcely be recognized by the casual observer, but to the student of geomorphology they stand out as the most prominent feature of the landscape and he reads from them many chapters in the history of the province during post-Paleozoic time. With our present information we are able to classify these topographic forms and to trace with considerable

certainty the more prominent features over the greater portion of the province. In some portions lack of data prevents the identification and correlation of these forms, but it is probable that further study will show the same features there as in the better known regions. The identity and practical continuity of certain topographic forms have been clearly proven through the major portion of the southern Appalachian province, and by other writers across Pennsylvania, New Jersey and the greater portion of New England, so that the conditions and agencies which produced them must have prevailed uniformly over wide areas.

In addition to these principal topographic forms, there are many minor features which doubtless record brief and local conditions, but in most cases the data at hand are not sufficient for their determination.

Inferences from the observed topographic forms back to the conditions under which they were produced necessarily involve elements of uncertainty, and the writers are fully aware that some of their conclusions are open to question and may be modified by further study.

The classification of the main topographic features of the province is as follows:

1. Elevations standing above the Cretaceous peneplain.
2. Deformed Cretaceous peneplain.
3. Intermediate erosion slopes.
4. Deformed Tertiary peneplain.
5. Post-Tertiary erosion slopes.

Of these five classes the two baselevel peneplains are most important to the student of geomorphology, for they render it possible to interpret the meaning of the other topographic features and to fix the dates of their origin in geologic time.

ELEVATIONS STANDING ABOVE THE CRETACEOUS PENEPLAIN.

The oldest topographic forms found in the southern Appalachian province are those portions of the land which were not reduced to baselevel during the long period of Cretaceous erosion. These summits may possibly mark the position of a still earlier baselevel peneplain; but if so, the remnants are so few that we are unable to reconstruct the ancient plain. Protected by a favorable location with reference to drainage lines or composed of exceptionally durable rocks, they stood during the formation of the Cretaceous peneplain in low relief above the

level surface and still remain as isolated peaks, ridges or mountain groups above the remnants of that plain. The distribution and relations of these remnants will be more easily understood after the Cretaceous peneplain has been described in detail; hence their consideration will be deferred and included under the physiography of the Cretaceous peneplain.

DEFORMED CRETACEOUS PENEPLAIN.

The oldest topographic feature that can be identified with certainty in this region, one which forms the basis upon which all later history has been recorded, is a more or less perfectly preserved baselevel peneplain. The reasons for ascribing its formation to Cretaceous time are given in a subsequent part of this paper and its Cretaceous age may be assumed for the present. Doubtless, at earlier periods the surface of the province had been baseleveled again and again, but subsequent erosion has so modified these earlier forms as to leave them unrecognizable.

Conditions of Development.—The condition under which a plain of erosion will be formed is long-continued stability of baselevel, and as baselevel is usually determined by sealevel, the essential condition is that the relative position of land and sea shall remain unchanged for a period long enough to allow the agents of erosion to carry their work toward completion and reduce the surface of the land to drainage-level, the baselevel of erosion.

During Cretaceous time the condition of stability prevailed in this region for the longest period of which we have any record in its history; for, while it is a popular belief that the normal condition of the earth's crust is one of stability, the reverse is shown to be true of this region. Its history in post-Paleozoic time is a record of almost continuous orogenic movement—extremely slow, it is true, but with sufficient time allowed, capable of producing the greatest deformations with which we are acquainted.

Throughout this period of exceptional quiet, erosion was in progress, reducing the surface toward baselevel—rapidly at first, as the land was high and the slopes steep, but at a rate growing gradually less and less as the gradient of the streams decreased and with it their ability to carry off the waste of the land. As the gradient approached its lowest limit the mineral matter removed from the land was almost wholly in solution. This process continued, reducing to baselevel first the soft and soluble

rocks, and then, less perfectly, the harder rocks; the degree to which it was carried depending largely upon their location with reference to the margin of the sea or the larger streams. In this manner the greater portion of the province was reduced to an almost featureless plain. The surface over hard and soft beds alike was smoothed until gentle slopes and low relief replaced the sharp declivities and high elevations which marked the early stages of the process.

Following the period of quiescence above described came one of epeirogenic activity, and the process of baseleveling was brought to an end. The land was elevated and the streams began anew the rapid trenching of its surface; but the land was elevated unequally, and as it arose the surface was warped and twisted. Where the elevation was greatest the erosion was most active and quickly destroyed the symmetry of the surface, in some places producing a deeply cut mountain region, the summits alone marking the position of the former peneplain; where the elevation was slight the surface remained practically unchanged; and all gradations exist between these extremes—on the one hand, where the peneplain is wholly destroyed, and on the other, where it is perfectly preserved.

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

Western marginal Type.—In general around the margin of the province this peneplain has been almost entirely obliterated by later erosion. Especially is this true in central Tennessee and Kentucky, where limestone occupied the baseleveled surface or lay beneath a thin capping of sandstone. When erosion was revived upon the peneplain by its elevation the streams quickly

sank their channels to the second baselevel and almost completely removed the intervening portions. Hence there are only a few widely separated outliers of the Cumberland plateau whose summits still mark the surface of the peneplain. One of the most typical of these outliers is Short mountain, in central Tennessee, which rises 1,000 feet above the surrounding level plain. It has about the same altitude and is capped by the same hard sandstone as the Cumberland plateau, 20 miles distant. The intervening low plain is underlain by limestone, which, on the removal of the sandstone cap, offered comparatively little resistance to degradation, so that only a combination of favorable accidents has preserved this remnant of the old peneplain once continuous over the whole region.

Plateau Type.—This is very different from the foregoing, chiefly in the degree and manner of its preservation. In the great Appalachian coal basin, south of Cumberland gap, the rocks are comparatively undisturbed. Along certain lines narrow anticlinal folds have developed, leaving broad basins between. The anticlines have been eroded, and the synclinal basins, with their flat lying strata, constitute the mountains or more properly the plateaus of this region. The form of the level topped plateaus has been attributed to the attitude of the strata, especially where the surface is formed by the great Carboniferous conglomerate, as is the case over most of the region; but close study shows that this uniform surface does not always correspond to the geologic structure, but is a more or less perfect plain, regardless of the attitude of the strata. The few low knobs and ridges which rise above this common level are truly monadnocks,* standing out in striking contrast to the uniform surface below. They generally bear no definite relation to the outcrop of the harder beds, but appear to be due rather to the accidents of erosion and remoteness from main drainage lines. These features prevail throughout the coal basin from central Alabama to Kentucky. The plain is well preserved in the southern portion, but becomes more deeply dissected toward the north, until near Cumberland gap there remain only a few narrow remnants of the once continuous surface. The conditions for the study of this plain are nearly ideal in the plateau region, where it was so perfectly

*A term lately used by W. M. Davis to designate those isolated elevations standing above a baseleveled plain as mount Monadnock stands above the surrounding plain.

formed and so excellently preserved. It can be traced continuously from an altitude of 600 feet in central Alabama to 2,000 feet at the Tennessee-Alabama line, and thence holding about the same altitude, with slight irregularities, to Cumberland gap. North of the Kentucky-Tennessee line the identification of this peneplain becomes a much more difficult matter, for elevation has been greater and erosion more rapid. The rocks are generally soft and have been unable to preserve any extent of level surface; hence the plain is almost wholly destroyed. Nevertheless, upon careful study of a wide area, it is seen that along northeast-southwest lines there is a marked uniformity in the altitude of the summits, and on transverse lines an extremely regular increase in their elevation toward the interior. This gentle but regular slope bears apparently no relation to the structure, and there seems no other explanation but to regard this as an almost completely dissected peneplain whose surface is represented approximately by the summits of the isolated knobs. The altitudes of these remnants of the plain vary from 1,300 or 1,400 feet near the mouth of the Big Sandy river to 4,000 feet near the central portion of the Virginia-West Virginia line. Above this inclined peneplain no summits rise until well toward the interior of the region, where their occurrence seems to be due to the same causes which produced monadnocks further southward, viz., unfavorable location with reference to the main drainage lines. This is well exemplified in the Big Black mountain on the state line between Kentucky and Virginia. This irregular mountain mass near Big Stone gap is composed of upper Coal Measures, and has an altitude of 4,100 feet, while Pine mountain, but a few miles northwestward, is finely baseleveled at about 2,500 feet. True, there is a great difference in attitude of the strata in these two mountains, for in Pine mountain the dip is about 30° southeastward, while in Big Black mountain the rocks are horizontal; but the former is made up of 1,200 to 1,400 feet of hard conglomerate, interbedded with shales and sandstones, while the latter is composed of the ordinary shales and sandstones of the upper Coal Measures. Apparently Big Black mountain owes its preservation to the presence of Pine mountain on its northwestern side, which acted as a barrier against erosion from that direction.

Valley Ridge Type.—In the Appalachian valley the type is more uniform throughout the whole extent of the province and con-

sists of the even crested ridges similar to those of Pennsylvania which have been so well described by Davis.* As a rule the ridges of the southern Appalachian valley are remarkably even crested and are unquestionably the remnants of a plain. In many cases, however, more or less wide variations from the type are found. In some instances a continuous but irregular ridge seems to rise quite above the peneplain, while in others the wind gaps have a constant altitude and probably represent the old baselevel, while the intervening portions of the ridge rising 100 to 300 feet higher stand, now as then, as a series of knobs above the general level. On the other hand, some ridges composed of less resistant rocks or occupying more exposed positions have been so reduced by subsequent erosion that no points along their crests reach the altitude of the peneplain. In reconstructing the peneplain from the valley ridges, careful study is required to determine its true position, and in some regions considerable uncertainty attaches to the determination. On the whole, however, the results obtained from the ridges are surprisingly concordant with those obtained in adjacent regions where the plain is better preserved.

Smoky Mountain Type.—This type differs altogether from those previously described and consists almost wholly of baseleveled valleys. They prevail from the vicinity of Roanoke, Virginia, to Cartersville, Georgia, giving rise to some prairie-like country in the heart of the Smoky mountains. It was in these valleys that this peneplain was first recognized. In a paper read before this Society in 1889 Willis described the baseleveled valley of the French Broad river as follows:†

> A broad amphitheater lies in the heart of the North Carolina mountains which form its encircling walls; its length is forty miles from north to south and its width ten to twenty miles. At its southern gate the French Broad river enters; through the northern gate the same river flows out, augmented by the many streams of its extensive watershed.
>
> From these water-courses the even arena once arose with gentle slope to the surrounding heights. . . . But that level floor exists no longer. In it the rivers first sunk their channels, their tributaries followed, the gullies by which the waters gathered deepened, and the old plain was thus dissected. It is now only visible from those points of view from

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* The Rivers and Valleys of Pennsylvania, by W. M. Davis: Nat. Geog. Mag., vol. i, pp. 183–253.

† Round about Asheville, by Bailey Willis: Nat. Geog. Mag., vol. i, pp. 291–300.

which remnants of its surface fall into a common plane of vision. This is the case whenever the observer stands upon the level of the old arena. He may then sweep with a glance the profile of a geographic condition which has long since passed away.

Again, in speaking of its altitude and probable origin, he says:*

We have recognized that dissected plain, the level of the Asheville amphitheater, now 2,400 feet above the sea. It was a surface produced by subaërial erosion, and as such it is evidence of the fact that the French Broad river and such of its tributaries as drain this area at one time completed their work upon it, reached a baselevel.

This baseleveled condition, as described by Willis on the French Broad, has been found to characterize nearly all the river valleys of the Great Smoky mountains and has been observed by the present writers on the Little Tennessee, Hiwassee and Ocoee rivers of the Tennessee system and on the Coosawattee and Etowah rivers of the Alabama system. The altitudes of the baseleveled valleys vary considerably, but on the whole show a gradual descent southwestward. Thus the altitude of the peneplain is 2,400 feet at Asheville, 2,200 feet on the Little Tennessee, 2,000 feet on the Hiwassee, 1,900 on the Ocoee and 1,600 feet on the Coosawattee. The proportion of the surface which was reduced to baselevel also increases southwestward and in northern Georgia, in place of the baseleveled mountain valleys, most of the surface was reduced and adjacent river basins merge with low divides. Thus the upper basin of the Coosawattee and Etowah present to the eye the characteristic form of broad undulating plains partly enclosed by mountains and from which rise the gentle slopes of island-like monadnocks. In detail these plains are found to be deeply etched by the present streams, which flow in narrow recently-cut gorges several hundred feet below their general level. On the Etowah river and southward this enclosed valley type disappears and the peneplain assumes a different form, which will be described later.

Blue Ridge Type.—The writers are less familiar with the region northward from the French Broad river and the data for reconstructing the Cretaceous peneplain are less abundant. The topographic maps, however, show quite strong evidence of the existence of this peneplain in the region in question, though it

*Op. cit., p. 297.

is not so well marked as about Asheville. Considerable study has been given to the region just north of this province by Davis, who suggests in the paper above cited* the probability of the extension of the Cretaceous peneplain over the entire southern Appalachians. Though he makes no definite statements as to its elevation and attitude, yet he concludes that the summits of the Blue ridge, south of the Pennsylvania line, probably represent this baselevel. The present writers have searched quite carefully for definite evidence as to the existence of the peneplain in this region and so far have been unable to find anything entirely satisfactory. That the region in question was baseleveled is conceded by all who are familiar with its topography, but the present elevation and attitude of the peneplain are less certain. Southeast of the Blue ridge there are a few outliers or isolated knobs standing above the Tertiary plain, and these show a uniform altitude of about 1,000 feet. It seems scarcely possible that these outliers should have been reduced to so nearly a common level unless that level were the baselevel of erosion. Immediately north of the Blue ridge, the Massanutten mountain shows traces of baseleveling at altitudes varying from 2,400 to 2,500 feet, and the valley ridges to the northward probably show traces at still greater altitudes. The Blue ridge varies greatly in altitude; its crest rises toward the south from 1,200 feet at Harpers Ferry to 4,000 feet at the Peakes of Otter, in central Virginia, and toward the north to 2,300 feet on the Maryland-Pennsylvania line. If there were a corresponding gradient in the peneplain it would necessitate a deformation along a cross-axis, of which there is no trace further westward; also the crest line of the Blue ridge between the points mentioned is extremely irregular and bears no resemblance to the remnant of a baseleveled plain. The varying elevations of the plain, determined on either side of the Blue ridge, agree with certain features of the ridge itself and make it decidedly probable that the peneplain here is highly tilted eastward; the strike of the plain—i. e., the direction of the contours representing the restored surface—crosses the ridge at a low angle instead of being parallel with it. The result of these complex conditions is that no two remnants of the old plain are found along the trend of the ridge at the same altitude, and consequently they are extremely difficult to recognize. Assuming this attitude of the peneplain

* Bull. Geol. Soc. Am., vol. ii, 1891, p. 502.

as a working hypothesis, traces of a baselevel can be found in places that otherwise afford no evidence of its existence; a terrace cut here and a wind-gap there serve to locate the plain so that it can be restored and contoured with considerable confidence. The restored surface corresponds with the summits of the ridges at Harpers Ferry, where proximity to the Potomac insured complete reduction to baselevel and afforded opportunity for subsequent erosion to almost completely dissect the plain. On either side, away from the river, the crests become more irregular, and evidently stand above the peneplain, while the present wind-gaps show traces of baseleveling, and probably correspond in altitude very nearly with the plain. On the eastern side of the Blue ridge throughout North Carolina there is but little data available for reconstructing the Cretaceous peneplain. The present writers are personally unacquainted with the region and a large part of it has never been mapped with contours. At only one point has the phenomenon of baseleveling been recognized. Kerr has described certain topographic features observed in the vicinity of Morganton, North Carolina,* and likened them to the Asheville baselevel. His theory as to their glacial origin cannot be accepted, but from his description it may be inferred that the valley of the Catawba river has been baseleveled to about the same extent as the French Broad at Asheville, and that the plain has been nearly as well preserved. Its altitude here is 1,400 feet, so that it must have a very rapid ascent toward the west in order to reach an altitude of 2,400 or 2,500 feet at Asheville, which is only fifty miles distant. This sharp ascent of the Cretaceous peneplain on the eastern slope of the Blue ridge dies out rapidly southward, partly through the flattening out of the fold in that direction and partly through the influence of a cross-axis of depression in the vicinity of Atlanta.

Southern marginal Type.—In the region southwest from Atlanta as far as the Coosa river the present attitude of the peneplain differs from that in any other portion of the province. In this region the baseleveled plain has suffered but little uplift from the position in which it was formed, and this slight elevation has taken place in very recent geologic time. Hence the peneplain is well preserved and many of the present streams, as the

*Origin of new Points in the Topography of North Carolina, by W. C. Kerr: Am. Jour. Sci., 3d series, vol. xxi, 1881, pp. 216–220.

Tallapoosa and its tributaries, are flowing partly on this old surface and partly in channels which they have been able to sink but a short distance below it, although it now stands from 1,000 to 1,400 feet above sealevel. In northern Georgia it merges into the Smoky mountain type, differing from the latter in the greater perfection to which the baseleveling process was carried and in the more perfect preservation from subsequent erosion. This peneplain is well preserved in Dug Down mountain, south of Rockmart, Georgia, and it is from this plain that the historic knobs of Kennesaw and Stone mountain stand up so prominently.

When the peneplain was formed it must have extended to the margin of the Cretaceous sea which at that time bounded the province on three sides; but it is this marginal portion which was subjected to the greatest erosion, so that wherever any considerable elevation took place the peneplain has been wholly destroyed. Hence there is a narrow belt within which no data are available for reconstructing the peneplain, except by interpolation from the approximately known position of the sea margin and the remnants of the surface still to be found at greater or less distances therefrom. These distances are not usually so great as to cause much uncertainty in determining the position of the peneplain at any point.

PHYSIOGRAPHY OF THE CRETACEOUS PENEPLAIN.

The existing remnants of the Cretaceous peneplain having been described in some detail, a fairly complete view may be gained of its physiography at the close of the long period of quiescence during which it was formed. Although this is the most perfectly baseleveled plain ever developed in the province, and although it was exceptional for its extent and regularity, it did not have a perfectly horizontal surface; in fact, it was level only where erosion acted under the most favorable conditions, either near sea margin and along the largest streams or where the rocks were easily removed by solution. Where soft and hard rocks alternated, the former were quickly reduced, while the latter remained above baselevel for longer or shorter periods, according as they were more or less remote from the main drainage lines. Where the location was most favorable for erosion, hard and soft rocks alike were perfectly reduced, and the rivers wandered in sinuous courses and with sluggish currents, uninfluenced by the

character or attitude of the underlying strata. That this was rather the exceptional case, however, is inferred from the infrequence of superimposed drainage which can be attributed directly to baselevel wanderings. Probably the outcrops of many if not most of the hard beds appeared embossed in low relief upon the baseleveled plain. The distribution of the unreduced areas, so far as they can be determined at the present time, is shown in plate 5. It will be seen that these areas coincide in position with the present mountain regions. Doubtless many points which then stood slightly above the peneplain have been so reduced by subsequent erosion that their summits no longer rise above its general level. Western North Carolina as early as Cretaceous time was the culminating point of the Appalachian highlands, a position which it has held uninterruptedly from that time to the present. At the close of the period of baseleveling the mountains here stood at altitudes varying from 3,000 to 3,600 feet above sealevel, and in some portions of the region they have changed in appearance but little from that time to this. Thus, in the Asheville region there was then a broad, level valley, over whose surface the streams meandered in winding courses. Encircling the valley were the same mountains as today with almost the same contours. The chief difference is in the altitude of the baseleveled valley, which then stood near sealevel, but now has an elevation of 2,400 feet, and in the deep gorges which the present streams have etched below its surface. The present line of the Blue ridge in Virginia was marked by a series of monadnocks, isolated or in groups, but not comparable in extent with the mountain mass toward the southwest.

In the region of the Cumberland mountains, across the Appalachian valley from the Great Smokies, the map shows some areas not reduced to baselevel. These formed a group of monadnocks the highest of which, the Big Black mountains, did not much exceed 1,500 feet in altitude. They are composed of rocks not specially obdurate and, as suggested above, probably owe their preservation from erosion to the surrounding barrier formed by the great Carboniferous conglomerate, and also to their position in the interior, away from the main drainage lines.

In the valley region where the rocks are highly tilted and present sharp contrasts in capacity for resisting erosion, many short ridges or linear monadnocks stood from 100 to 1,000 feet above the baselevel. These form the higher portions of many

of the present valley ridges, while the present wind-gaps represent the former baseleveled intervals between the monadnocks. In the plateau region south of the Crab Orchard mountains no areas of sufficient extent to be represented on the map remained unreduced. The peneplain in this portion of the province was less perfect than in some others and occasional slight elevations remain clearly above its general level. These are sometimes due to the attitude of unusually resistant beds, but more often to the accidents of erosion acting on tolerably homogeneous material.

DEFORMATION OF THE CRETACEOUS PENEPLAIN.

One of the most important conclusions contained in the present paper, in its bearings upon geomorphology, is the recognition of the nature of the deformation found recorded in the present attitude of the baselevel peneplains. It is that these deformations have been mainly produced by true orogenic movements affecting comparatively narrow areas along certain well defined axes; that they were not epeirogenic or continental uplifts such as would preserve a peneplain in approximately its original horizontal position; nor even, as suggested by Willis,* uplifts which broadly arched the surface across the whole expanse of the province; also that orogenic activity has not been continuous along any one axis nor always in the same direction, though the total effect of the intermittent motion has been to elevate the whole province.

Deformations of the baselevel peneplains have been recognized in this and adjacent regions by other writers, especially Davis and McGee. Thus Davis has shown that the Cretaceous peneplain in Pennsylvania, New Jersey and portions of New England is tilted seaward, but he has not located its axis of elevation; also McGee has shown that in the southern Appalachians every subsidence has been greatest at the sea margin and every elevation greatest in the interior, which implies a cumulative seaward tilting. The class of facts from which he derived his evidence did not enable him to locate the main axes of uplift, though he clearly recognized the transverse Memphis-Charleston axis, which will be more fully described on a subsequent page.

*Topography and Structure of the Rays Mountains, Tennessee, by Bailey Willis: School of Mines Quarterly, vol. viii, 1887, p. 252.

In order to represent in as graphic a manner as possible the present form of this Cretaceous peneplain a contoured map of the deformed surface has been constructed. Upon this map are assembled all available data derived from a careful comparison of the various known remnants of the plain within the province. The result appears as plate 5, and although regarded by the writers as preliminary, it embodies all the information at present attainable. Although imperfect, the map is highly suggestive, and it is hoped that it may lead to the construction of similar maps of other regions in which equally important results would undoubtedly be obtained. Different portions of the map represent widely different proportions of fact and hypothesis, and hence differ in value. Thus in the southern part of the province the peneplain, as already described, is well preserved; also the map of this portion is based upon a large number of personal observations and may be considered fairly accurate. In some regions in the northern portion of the province only scanty remains of the peneplain can be found, and the evidence of its existence is so indefinite that while the present map is unsatisfactory it is doubtful if anything better can be constructed even with fuller field observations. Other portions are based upon a study of imperfect topographic maps or railroad profiles and verbal descriptions of topography, so that the results are correspondingly unsatisfactory.

As already indicated, the deformations of the Cretaceous peneplain represented by the contour map (plate 5) are not the result of a single elevation or a single system of orogenic movements, but the algebraic sum of all movements both of elevation and depression which have affected the region since the peneplain was formed. Not only have the movements been in opposite directions and at different periods, but the axes of maximum motion have not always been the same nor even parallel; they have intersected at various angles, and the surface has been warped accordingly. The data are not sufficient for mapping all the details and a description of the principal axes only will be attempted.

Longitudinal Axes of Elevation.—There are three principal longitudinal axes, and so far as known, these are axes of elevation alone, though depression of which no record is left may have taken place along them also. They are indicated by broken lines on plate 5 and marked by the letters *C D*, *E F* and *G H*.

These are lines of maximum elevation and they have had a predominant influence in producing the present topography of the province. They coincide with the present mountains and in a general way parallel the great structural features of the Appalachian valley.

Transverse Axes of Oscillation.—In addition to the predominating longitudinal axes a number of interesting transverse axes are brought out by the contours representing the deformed Cretaceous peneplain. In the central portion of the map the contours swell out on either side, giving a broader and more regular profile to the elevation than elsewhere. This is suggestive of a transverse line of uplift intersecting the longitudinal axes nearly at right angles. If this line be prolonged in both directions it is found to connect Cincinnati and cape Hatteras, both of which have been recognized as occupying regions of recent elevation. As early as 1871 Shaler* described a transverse uplift which he concluded had produced the great projection of the coast line at cape Hatteras; also McGee has shown that this axis has been an important factor in determining the form of the coast line during the time represented by the deposition of the coastal plain sediments. He describes it† as "an axis of interruption or change in epeirogenic movement during every geologic period since the Cretaceous." If this line from cape Hatteras to Cincinnati be continued across the Ohio river its direction will be found to coincide with that of the main or northwestward branch of the Cincinnati arch which crosses Indiana to Chicago. Although, with the information at present available, it cannot be asserted that motion has taken place along the southeastern portion of the line except in post-Cretaceous time, still the coincidence of the two axes suggests the probability that there was orogenic movement in the Appalachian region during the uplift of the Cincinnati arch in Ohio and Indiana, and, conversely, that north of the Ohio river may yet be found traces of post-Paleozoic movements corresponding to the later uplifts in the vicinity of cape Hatteras. The probability of such contemporaneous movement is increased by the fact that in the southern portion of the province evidence was found by the writers proving that certain

*On the Causes which have led to the Production of cape Hatteras, by Professor N. S. Shaler: Proc. Bost. Soc. Nat. Hist., vol. xiv, pp. 110–121.

†The Lafayette Formation, by W J McGee: 12th Annual Report U. S. Geological Survey, 1891, p. 403.

axes of post-Cretaceous oscillation have also been lines of Paleozoic movement.

A second and more clearly defined axis of elevation, *O P*, is found crossing the provinces in the vicinity of Chattanooga. Its trend is nearly due north and south, and it has been traced nearly as far north as Cincinnati. If the axis be continued across the Ohio river it falls in line with the eastern branch of the Cincinnati arch passing through Findlay and Toledo, Ohio. This also may be only a coincidence, but it strongly suggests genetic connection between the portions of the axis north and south of Cincinnati.

The third and most prominent of the transverse axes crosses the southern portion of the province, passing near Atlanta and forming a tangent to the great northwestward bend of the Tennessee river. It was first recognized by McGee in studying the sediments of the southern Atlantic coastal plain and Mississippi embayment. He describes this "Charleston-Memphis axis"* as an axis of maximum subsidence during both low level periods (represented by the Lafayette and Columbia formations) and an axis of maximum uplift during both high level periods. It is represented on the map by the broken line *A B*, having a nearly east-and-west direction; it intersects the last described north-and-south transverse axis as well as the longitudinal axes, and since, as shown by the contours, it is at present a line of depression the effect of the elevation along the other axes is wholly or partially neutralized at their intersections. The oscillations on this axis *A B* have been an important factor in determining the drainage of this region and will be again referred to in the second part of this paper.

The probability of orogenic forces having been active upon the transverse axes during Paleozoic time was mentioned above. In case of the axis *A B*, there is proof of such activity at two or more distinct epochs. In mapping the Paleozoic formations of northern Georgia and Alabama it was found that two terranes which present strong indications of having been deposited under shore conditions terminate abruptly against this line. These shore formations are the Birmingham breccia at the top of the Knox dolomite and the Oxmoor sandstone occurring in the lower Carboniferous. Other stratigraphic changes scarcely less

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* The Gulf of Mexico as a Measure of Isostacy (abstract), by W J McGee; Bull. Geol. Soc. Am., vol. iii, p. 503.

striking mark this as a line of instability during the whole of Paleozoic time and the physiographic evidence shows that the instability has continued down almost to the present. Hence it seems at least probable that orogenic activity has been persistent on the other axes in pre-Cretaceous or Paleozoic time, and that the forces which produced the Cincinnati arch are the same as those which have deformed the Cretaceous peneplain.

Considerable evidence has been collected bearing upon the relative age of the oscillations recorded in the deformed peneplain, but since it is closely connected with topographic features to be described later its consideration is postponed to a subsequent page.

DEFORMED TERTIARY PENEPLAIN.

The long period of quiescence, during which the Cretaceous peneplain was produced, was terminated by a general elevation of the larger part of the province. Like most of the oscillations that have occurred since, it was compound in character, combining epeirogenic and orogenic movements; the former affected the entire province, carried the coast line considerably beyond its previous location and stimulated the streams to increased activity; but the energies culminated along certain axial lines and resulted in pronounced orogenic uplifts that warped and twisted the surface as it arose.

The immediate effect of this elevation was to stimulate erosion, and the streams which for a long period had been carrying only the finest sediments began the rapid corrasion of their channels and quickly trenched the rising land. The process was carried on differently in different parts of the province; where the elevation was slow, erosion was very moderate in its effects, but where elevation was rapid the streams were greatly stimulated and rapidly dissected the peneplain.

The movements which inaugurated this cycle still continued to affect the province, not continuously along any one axis, but by intermittent and gradually decreasing elevations and depressions. These oscillations were terminated by a second period of quiescence, during which the surface was again reduced to a base-level peneplain.

The extent of the movements occurring between these two periods of baseleveling can be roughly measured by the vertical

distance between the two peneplains. The uplift attained its maximum of about 2,000 feet in northern Virginia and West Virginia, and was apparently continuous from the close of one period of baseleveling to the inauguration of the other. As a direct consequence of this steady uprising of the land we find in this portion of the province the Cretaceous peneplain almost completely dissected, and it is extremely doubtful if any of the level surface is still preserved. From this maximum the elevation decreased in an irregular manner toward the margin of the province, where the earlier and later baselevels coincide.

The period of Cretaceous baseleveling was a very long one—so long that over much of the province the rocks, hard and soft alike, were reduced nearly or quite to the same level. The period of Tertiary baseleveling, on the other hand, was comparatively short when measured by geologic standards. It sufficed for the complete removal of the previous peneplain only about the margin of the province, where conditions of erosion were exceptionally favorable, and for the cutting of broad valleys upon the soft rocks of the interior. Since only the softer rocks were reduced to baselevel, there is less diversity in the Tertiary than in the Cretaceous peneplain, but when the surrounding erosion slopes are considered in connection with the plain, as they must necessarily be, there is found a great variety of topographic forms, depending jointly on the kind of rocks, location with reference to the margin of the sea or large drainage channels, and amount of pre-Tertiary elevation. This peneplain, like the Cretaceous, has been greatly modified by late erosion, but even in this the three elements named above are the controlling ones and mainly responsible for the forms produced.

Marginal Types.—In the western portion of the province conditions were favorable for the production of an extensive baselevel peneplain during this period. The very perfect Cretaceous plain was elevated from a few feet at the margin of the Tertiary sea to about 1,000 feet at the western line of the Cumberland escarpment. The greater part of the rocks thus raised above baselevel were limestones, in which the streams quickly lowered their channels and by lateral corrasion entirely removed the intermediate highlands, with the exception of a few isolated monadnocks, of which Short mountain, already described, is the type. Owing to the coincidence throughout central Tennessee

of the Carboniferous limestone and the Tertiary baselevel, this peneplain was formed up to the base of the steep plateau escarpment and far within the narrow limestone coves which indent its border. In the time that has elapsed since the formation of this peneplain the streams have not been able to cut their gorges back to the escarpment, so their head-waters are still flowing upon that old plain, though at an altitude of from 1,000 to 1,100 feet. Thus in a belt of country bordering the plateau on the west and extending northeastward from Huntsville, Alabama, to the Kentucky-Tennessee line the conditions were favorable for the production and have since been favorable for the perservation of this peneplain.

Across Kentucky the conditions were similar to those of Tennessee, except that the hard Coal Measure sandstones were less elevated and formed no plateau, and subsequent erosion, as the Ohio river is approached, has been more and more active, until in the immediate vicinity of the river the peneplain is recognized with difficulty. The conditions north of the Ohio river are at present entirely unknown, and the only suggestion the present writers can offer is that probably the two peneplains gradually approach each other in that direction until they practically coincide.

About the southern margin of the province the elevation between the two periods of baseleveling was so slight that the rocks have been practically exposed to baselevel conditions from nearly the beginning of Cretaceous to Neocene time, and as a result are deeply decayed and but poorly preserve the records of the past. In the Coosa valley the Tertiary peneplain is generally distinguishable, although subsequent erosion has cut deeply into its surface and, owing to the decay of the rocks, has reduced the least resistant members to a still lower baselevel—that at which the present streams of the region are flowing. Continuing eastward, the vertical interval between the Cretaceous and Tertiary baselevels decreases and in the vicinity of Atlanta they practically coincide, so that the recognition of the two peneplains is almost impossible. The streams have not cut below the old peneplains in their upper courses and the tributaries of the Chattahoochee and Tallapoosa rivers still flow upon the surface of the Cretaceous peneplain.

On the southeastern margin of the province, throughout the

piedmont plain, the Tertiary peneplain is well developed and only occasional monadnocks show the position of the Cretaceous plain. Although crystalline rocks are generally regarded as offering great resistance to erosion, they are, under baseleveling conditions, subject to very deep decay and probably at the close of the Cretaceous cycle were softened to a far greater depth than at the present time. As the elevation succeeding the Cretaceous period of baseleveling was not great, the streams quickly swept away this mantle of residual material down to baselevel. Under such conditions the Tertiary peneplain was very perfectly developed throughout the whole of the piedmont plain. The subsequent erosion of this peneplain has been comparatively slight and in many parts, especially in the vicinity of the James and Potomac rivers, it is almost perfectly preserved.

Interior Valley Type.—As stated above, this period was not sufficiently long for hard rocks to be reduced except under peculiarly favorable conditions. In the interior of the province only areas of limestone and shale were lowered to the newly established baselevel. These rocks formed the surface chiefly in the zone of folded rocks known as the Appalachian valley. Upon the elevation of the region the streams sank their channels mainly within these belts of easily erodible rocks, although in some cases their wanderings during the preceding period of baseleveling had led them across hard rocks upon which they thus became superimposed. The greatly stimulated erosion rapidly reduced the soft rocks to baselevel in the immediate vicinity of the large streams; the valleys were broadened until checked by hard rocks which remained at the level of the old peneplain, either as the valley ridges, the plateaus upon the west, or the present mountain valleys upon the east. This removal of the soft rocks progressed well toward the head branches of most of the rivers within the Appalachian valley. In many cases the divides between adjacent river basins were almost perfectly baseleveled, though in some cases (explained in Part II of this paper) the present divides were then crossed by large streams whose courses were subsequently changed. The Shenandoah valley may be taken as the type of this portion of the Tertiary peneplain. Its level floor, cut in the soft limestone and shale, is abruptly terminated on either side by steep slopes, composed of more resistant strata. The divide between the

Shenandoah and James is but little higher or narrower than the valleys themselves. The same is true of the divides between the James and Roanoke and the Roanoke and New rivers, and their valleys are almost as perfectly baseleveled as that of the Shenandoah. In the southern portion of the Appalachian valley the great Cambro-Silurian limestone becomes very siliceous and its surface was less perfectly reduced than in Virginia. Many rounded ridges of residual chert reach slightly above the level of the Tertiary peneplain, even in the vicinity of the larger streams. The amount of the erosion, however, was even greater than on the Shenandoah and James, for the valley in eastern Tennessee and northwestern Georgia is considerably wider than in northern Virginia. In the New-Kanawha basin the Tertiary peneplain was extensively developed; conditions of erosion appear to have been exceptionally favorable, for not only limestones but considerable areas of sandstone and shales were very completely reduced. Owing to subsequent elevation this Tertiary plain now forms a plateau 2,500 feet above sealevel and the present streams have cut their channels 1,500 feet or more below its surface. The altitude of the peneplain decreases rapidly westward and in the valley of the Ohio corresponds with the highest bluffs, below which the river has sunk its bed from 400 to 700 feet.

Plate 6 shows the portions of the surface not reduced to the Tertiary baselevel, and from it more easily than from descriptions may be obtained a general idea of the physiography of the Tertiary peneplain at the end of this baseleveling process. These areas are seen to be very extensive on both sides of the Appalachian valley, while only the narrow ridges remain within the latter. The area unreduced to baselevel during this period is in round numbers 45,000 square miles, and the ratio of this area to that of the entire province then above sealevel is 1:4.7. During the Cretaceous baseleveling, on the other hand, the unreduced portion is only 8,700 square miles and its ratio to the then existing province 1:22.

A comparison of these ratios affords some idea of the relative duration of the two periods. The reduction of a surface to baselevel, however, does not vary directly as the time, but rather as some highly complex function of the time, being a process which decreases in its rate as it approaches completion. Hence the comparative duration of the two periods cannot be determined without considering other factors whose values are at present

unknown. Nevertheless, it seems probable that the earlier period was at least eight or ten times as long as the later one.

DEFORMATION OF THE TERTIARY PENEPLAIN.

Although the second peneplain was less perfectly developed than the first, it has been more perfectly preserved, and so can be reconstructed with even greater certainty. The same plan of representation has been pursued as in the case of the Cretaceous peneplain, and the deformed surface is represented by contour lines with an interval of 200 feet; also similar qualifications should be made here as in the case of the map representing the Cretaceous peneplain. Not all parts are equally reliable by reason of differences both in degree of baseleveling and also in the quality of maps and other data upon which it is based.

The deformation is somewhat exaggerated, especially in the interior of the province, for the gradient of the baseleveled valleys has not been taken into account. This gradient varies with the size of the stream, but present knowledge of baselevel conditions is not sufficient to warrant definite statements as to the altitude of the baselevel in the interior. Probably the error in determining the altitude of the peneplain at any point is greater than the error introduced by neglecting its gradient.

The contours in plate 5 represent the algebraic sum of all movements which have affected the province since the completion of the Cretaceous peneplain, while the contours in plate 6 represent movements which have occurred since the close of the Tertiary period of baseleveling; hence the contours of plate 5 represent all the deformation expressed in plate 6 plus the deformation occurring between the two periods of quiescence. The amount of this intermediate deformation or the vertical distance between the two baselevels at any point may be found by subtracting altitudes indicated by the contours on plate 6 from those on plate 5.

The character of the orogenic activity which followed the comparatively long period of Tertiary quiet is much better known than that which followed the longer Cretaceous period. It is much nearer the present than the latter, and the evidence for deciphering its history has not yet been obliterated. Part of this evidence consists of modified physiographic forms, but the larger portion is found in the sediments deposited around the seaward margin of the province. We are largely indebted to

McGee for their interpretation and the determination of their bearing on Appalachian history. The conclusions will be stated briefly without attempting to give the evidence on which they are based, although some of it is contained a subsequent page.

The series of oscillations occurring since the close of the Tertiary period of baseleveling consists, first, of a depression which allowed the waters of the ocean and the Mississippi embayment to advance inward far beyond their previous margin.* Following this came an elevation of the entire province that again started the streams in a career of great activity, and the sea retreated probably beyond the present shoreline. These broad movements may properly be termed epeirogenic, as they affected the entire province, but in every case the movements culminated along certain axial lines and produced decided local or orogenic warping. In the subsidence the greatest depression was along the cross-axis *A B*, but in the subsequent elevation the greatest movement was along the main longitudinal axes. A period of comparative quiescence followed, during which the land stood somewhat higher than at present and much higher than during the Tertiary baseleveling period. It was during this interval that the rivers of the eastern coast carved their broad outer valleys, now almost completely submerged beneath the waters of the Atlantic, and the Mississippi corraded its broad valley from Cairo to the Gulf.

In very recent geologic time these oscillations have been repeated in the same order and with a similar effect. The land first subsided and the Columbia sediments were laid down; then it arose to its present position and the modern gorges mark the duration of the present high level attitude of the land.

INTERRELATIONS OF THE TWO PENEPLAINS.

The greatest divergence in altitude between the two deformed peneplains is in the northern portion of the province. This great pre-Tertiary elevation is somewhat dome-shaped and attains its maximum elevation of 2,400 feet about 30 miles northwest of Harrisonburg, Virginia; from this point it descends quite rapidly in all directions, but shows a partial agreement with the axes *C D* and *E F* (plate 5). Toward the west the actual coincidence of the two plains cannot be determined, but they appear

*The Lafayette Formation, by W J McGee: 12th Ann. Rep. U. S. Geol. Survey, 1890–'91, pp. 568, 569.

to be within 200 feet of each other in the vicinity of West Union, forty miles east of Parkersburg, West Virginia. On the eastern margin of the province the upper peneplain is completely obliterated, but the two probably coincide in the vicinity of Richmond, Virginia. Along the axes the descent was much less rapid. On the Pennsylvania line the uplift probably did not exceed 1,200 feet, while toward the southwest, along the axis *E F* (plate 5), it extended certainly as far as the Tennessee line. South of this line the uplifts were much more irregular and distributed over a broader area, so that their general effect has been to produce a broad fold extending from Greenville, South Carolina, to Nashville, Tennessee, and with an altitude not exceeding 1,000 feet. In this broad uplift can be traced several local orogenic disturbances, of which the uplift along the axis *O P* is quite prominent, but the greatest elevation occurred along the axis *G H* (plate 5). Many minor folds both of elevation and depression can be distinguished in this region, but their meaning is as yet obscure and we only know that they are intimately associated with the general warping of the surface of the province. In the vicinity of Atlanta the two baselevels are so near the same altitude that their peneplains cannot be discriminated, and the same is true along a line toward the northeast as far as Asheville. In the upper portion of the French Broad basin only one peneplain can be detected and it is ascribed to Cretaceous time. The streams have, however, barely sunk their channels through the mantle of disintegrated rock, although the present altitude of the region renders them extremely active. Westward from Asheville the two baselevels diverge under the influence of an uplift along the axis *G H* and indications of the two corresponding peneplains are found along the lower course of the French Broad river.

DISSECTION OF THE TERTIARY PENEPLAIN.

By far the larger part of the erosion of the Tertiary peneplain was accomplished during the period of high level which preceded the Columbia depression. The streams were greatly stimulated, and where the elevation was considerable they carved deep gorges along their lower courses, giving rise to the numerous bays and broad-mouthed rivers now indenting the Atlantic coast. The distance these gorges were cut toward the interior varies greatly, depending upon the elevation of the land and the char-

acter of the rocks. Where the uplift was considerable the streams cut narrow gorges in their rocky floors, but where the elevation was slight the valleys were widened and present more the appearance of corrasion under baseleveling conditions.

This broad dissection of the Tertiary peneplain is greatest in the southern portion of the province, for there the elevation was only sufficient for the streams to work upon the decayed rock and residual mantle which had accumulated during the preceding period. The streams were almost entirely occupied in broadening their valleys, so that in the Coosa-Alabama basin probably a third of the surface was removed during this period. After the Columbia depression this region was once more elevated and the streams have deeply trenched their broad valleys. In the vicinity of Chattanooga the Tennessee river has lowered its channel but 250 feet below the Tertiary peneplain, and this has been accomplished gradually, for the contours are generally flowing and well rounded, except where the river cuts some unusually hard stratum. Throughout the basin of the Tennessee river northeast of Chattanooga the amount of cutting is variable, depending upon the amount of deformation of the peneplain. Streams located upon the axes of maximum elevation were stimulated to a high degree of activity, while those located between such axes in areas of minimum uplift received only a moderate acceleration. The Clinch and Holston rivers show in a striking manner the effect of the warping on the erosion of the peneplain. The upper Clinch is located upon the axis *K L*, plate 6, and has cut a canyon from 500 to 700 feet deep through the limestones and calcareous shales, with slopes as steep as such material will stand. In striking contrast with this is the broad open valley of the Holston, located in an area of minimum elevation between the axes *K L* and *M N* and about twenty miles southeastward of the Clinch river.

The great gorges cut in the Tertiary peneplain in the New-Kanawha basin have been referred to. They indicate clearly that the conditions which prevailed here in post-Tertiary time have been different from those in any other portion of the province. The uplift which elevated the Tertiary peneplain to an altitude of 2,500 feet, as shown in plate 6, was confined almost entirely to the axis *K L*. This axis crosses the river in its lower course, but the river had sufficient volume to hold its antecedent position across the rising fold. In doing so it has cut a narrow,

rugged gorge 1,500 feet deep, and is still actively corroding its channel. The movement along the axis must have been practically continuous from the completion of the Tertiary peneplain down to the present.

The region northeast of New river, in which rise branches of the Potomac, the James, the Kanawha and the Monongahela, has probably been an area of continuous uplift during every period of orogenic activity affecting the province. The Cretaceous peneplain, of which only a few doubtful remnants exist, was elevated at least 2,400 feet and Tertiary erosion was proportionally stimulated. It succeeded, however, only in reducing to baselevel and slightly broadening the valleys of the larger streams. A post-Tertiary elevation of 1,500 feet has renewed their activity, so that it has been continued with scarcely a pause from the close of the Cretaceous period down to the present.

The result of this almost continuous downward stream cutting has been to produce the most sharply cut region in the Appalachian province. The slopes are steep and generally uniform from the highest points, which may represent the surface of the earlier peneplain, down to the present streams, with only an occasional trace of terracing to mark the Tertiary baselevel.

The elevation of the Tertiary peneplain along the eastern border of the province has been only moderate, and the streams have accomplished correspondingly little erosion upon its surface. The Roanoke, the James and the Potomac have cut rather narrow and shallow valleys across the piedmont plain. These become shallow gorges in the broad baseleveled valleys west of the Blue ridge.

RELATIVE DATES OF THE OROGENIC MOVEMENTS.

Before closing this portion of the paper it is perhaps advisable to review hastily, as far as the evidence will admit, the succession of oscillations in post-Paleozoic time. As already stated, the determination of the character of these movements is one of the most important results derived from this study, since the entire physiography of the region, including the arrangement of its drainage systems, has been modified to a great extent by them.

Movements in the Tertiary Cycle.—It is not advisable at present to go farther back in geologic time than to the close of the Cretaceous period of baseleveling, although there are traces of simsimilar movements in the preceding ages of post-Paleozoic time.

In one portion of the province only has the elevation since then been practically continuous. This is in northern Virginia and West Virginia and, as shown in plate 5, exhibits an aggregate uplift since the completion of the Cretaceous peneplain of 4,000 feet. During the Tertiary baseleveling this region was necessarily free from movement, but at no other time does there seem to have been a complete cessation of the uplift. The axes along which it culminated in pre-Tertiary time are *C D* and *E F* (plate 5). While the movement along these axes occurred synchronously and at their maximum reached the same elevation, the deformation on the two was quite different. Along the axis *C D* it extended but little south of the Kanawha river, while in the opposite direction it passed into Pennsylvania, extending probably half way across that state. Along the axis *E F* the elevation reached only a little north of the Potomac, but continued in the other direction as far as Tennessee. These axes are arranged *en echelon* and the maximum elevation occurred at the point of overlap. Some time during this period the uplift extended southwestward along the axis *E F*, but only sufficient to raise a low swell a few hundred feet in altitude. This is quite intimately connected with a later uplift along the same line and probably occurred late in the interval between the two periods of baseleveling.

It seems probable that an uplift took place in the Smoky mountain region quite early in this epoch, its axis coinciding approximately with the state line between Tennessee and North Carolina. The reason for assigning this movement to the early part of the epoch is that there are traces of an uplift along this same line in pre-Cretaceous time, and probably the later uplift was but the continuation of the earlier, following immediately the Cretaceous period of quiescence. This late uplift increased toward the northeast, reaching 1,200 feet on the southern line of Virginia.

Some movement occurred along the Hatteras axis during this epoch, reaching its maximum elevation on the northwestern side of the province near the Ohio river. The longitudinal uplift of the Great Smoky mountain region terminated at this transverse line, and their combined forces caused a pronounced dome-shaped elevation in the Cretaceous peneplain.

An uplift occurred at the beginning of this epoch along the axis *O P*, reaching a maximum near Chattanooga, from which it

descended rapidly toward the south and gradually toward the north. The continuation of the axis *O P* beyond the Ohio river is quite uncertain, but it probably extended far into Ohio and there may have been within that state a development of the fold similar to the one near Chattanooga.

Besides these axes of elevation there are several along which depression occurred during this interval. These depressions were not pronounced, but sufficient to vary the altitude of the Cretaceous peneplain from 100 to 400 feet. One of these is located between and parallel with the axes *E F* and *G H* (plate 5); another is the axis *A B*, along which some movement occurred at this time; and the third probably connected these, lying east of and parallel with the axis *O P*. There is no evidence in the physiography of the region to show when these were active, but a careful study of the coetal-plain sediments will probably determine the question.

Movements in the present Cycle.—One of the most pronounced movements connected with the close of the Tertiary baseleveling was subsidence along the axis *A B* (plate 6). This, as described later, occurred during the deposition of the Lafayette formation. After this depression there came a period of apparent quiescence, during which no movement is recorded along this line. In the time of the Columbia depression this axis was affected in a manner similar to the Lafayette depression.

Uplift along the axis *K L* (plate 6) occurred soon after the general elevation of the land following the Lafayette depression. The uplift increased from the Tennessee river in Alabama, reaching a maximum of 2,000 feet at the Virginia-West Virginia line south of New river. From this point it gradually decreased northward, passing into Pennsylvania with a probable altitude of 1,500 feet. As before stated, the northern portion of this uplift has been practically continuous, but the southern portion has probably been intermittent in its activity.

Early in the present cycle an uplift occurred along the northern end of the axis *M N*, and this seems to have been connected with movement along the eastern portion of the Hatteras axis. According to McGee, the Hatteras axis, from Roanoke to the coast, has been the seat of activity since Eocene time. Its influence is shown on plate 6, in the eastward trend of the axis *M N* at its northern extremity and the outward swelling of the contour lines. About the middle of the present cycle the uplift

extended southwestward along the axis *M N*, so that in very recent geologic time the Tertiary peneplain from Asheville to Atlanta and southwestward has been elevated to its present position.

Movements have occurred along some minor axes chiefly of subsidence, but their exact date cannot be fixed.

The latest movements which can be detected in the province are along the axes *K L* and *O P*. That along *K L* has resulted in a slight ponding of the Tennessee river in the vicinity of Huntsville, Alabama, while the uplift along *O P* has affected the Cumberland river above point Burnside, Kentucky, in a similar manner.

Part II.—Drainage Development.

SUBDIVISIONS OF THE PROVINCE.

Geologically, and topographically as well, the southern Appalachian province falls into four well-marked divisions. These are (1) an eastern piedmont plain, sloping gently seaward and composed of metamorphic and crystalline rocks; (2) a montanic tract, embracing the Blue ridge and the Great Smoky range with its many outliers and containing chiefly crystalline rocks with sediments which have undergone various degrees of metamorphism; (3) a central broad valley with numerous parallel ridges of Paleozoic sediments; (4) a western dissected plateau of upper Silurian and Carboniferous rocks.

OUTLINE OF THE PRESENT DRAINAGE.

In the northern portion of the province the water parting between the Atlantic and Gulf drainage is westward of the Appalachian valley. The Potomac heads upon the edge of the plateau and flows eastward across the Appalachian valley, the montanic tract and the piedmont plain. From the western point of Maryland the divide passes nearly due southward, crossing the Appalachian valley diagonally, so that the James and Roanoke drain only the eastern part of the valley, but, like the Potomac, flow eastward across the montanic tract and the piedmont plain. South of these streams the divide follows near the eastern margin of the montanic tract to its southern extremity, only the eastern slope being drained by streams crossing the piedmont plain to-

ward the southeast. The westward-flowing streams in the northern portion of the province drain only the plateau region. Farther southward New river heads well toward the eastern side of the montanic tract and flows northwestward across the Appalachian valley and the plateau to the Ohio. Between New river and the Tennessee-Georgia line most of the montanic tract and the Appalachian valley are in the drainage basin of the Tennessee, whose many branches flow northwestward across the former region and southwestward within the latter to Chattanooga, where the river turns abruptly and enters the plateau region. It crosses first the Walden plateau through a deep canyon, and after flowing seventy miles in Browns valley, parallel to its former course, again enters the plateau and flows northwestward to the northeastern corner of Mississippi, the margin of the former Mississippi embayment. Here it makes another abrupt change in its course, flowing directly northward to the Ohio. South of the Tennessee-Georgia line the Appalachian valley, with the adjacent portions of the montanic tract, are drained by the Coosa-Alabama river, which flows directly to the Gulf. The greater part of the plateau region lying between the New-Kanawha and Tennessee rivers is drained toward the northwest by streams flowing into the Ohio. The most important of these are the Kentucky and Cumberland.

CLASSIFICATION OF DRAINAGE.

Applying to the streams of the southern Appalachian province the accepted principles of classification, representatives of all the main divisions are found.

A few show indications of following, in part at least, antecedent courses in which they have persisted through all the vicissitudes the region has suffered. The most striking example of this class is perhaps the New-Kanawha, which seems to hold the course occupied antecedent to the development of the present structure of the region. To the same class belong probably the eastern tributaries of the Tennessee and Alabama systems which cross the montanic tract from its eastern border northwestward to the Appalachian valley; also the streams of the plateau flowing into the Ohio river may be placed in this, although there are some grounds for placing them in the next class.

A few of the streams are directly consequent upon the structure of the region, flowing in synclines where their position has been

determined by the flexures of the strata. To this class belong portions of the Tennessee and Coosa tributaries, generally rather small streams which in the process of drainage adjustment have been robbed of the greater part of their original basins by others more favorably situated.

Many of the stream courses are directly dependent upon the structure, but occupy positions which they have acquired by a process of adjustment subsequent to the deformation of the surface. This class of maturely adjusted subsequent streams includes most of those within the area of folded rocks of the Appalachian valley. Their courses are on or near the axes of anticlines, positions manifestly impossible in early stages of the folding or before a long process of adjustment had taken place.

A few streams show superimposition, probably not from a superjacent horizontal terrane, but by wandering during the later stages of a very complete baseleveling period. Examples of this are seen in the course of the Clinch river where it crosses Lone mountain, and of the Coosa where it crosses the point of Beans mountain.

Finally some streams appear to have become adjusted to certain past conditions of slope and baselevel, so that their courses are not such as they would seek under the influence of conditions now existing. A most striking example of such an anomalous course is that of the Tennessee river. Portions of it may be regarded as inherited from conditions to which they were adjusted in the past, but which have wholly or in part disappeared.

By a study of the drainage, especially streams of the latter class, a tolerably definite idea of these conditions may be reached. The present river courses indicate the changes in altitude and attitude which have taken place within recent geologic epochs. The history of the same period, interpreted from the topographic features of the province, has been presented in Part I. Evidence was found of an almost continuous succession of orogenic oscillations, separated by well marked epochs of tranquility. These periods, both of tranquility and orogenic activity, have left an unmistakable impression upon the topography, and it seems reasonable to suppose that they should have produced an equally marked effect upon the drainage. There is a third method of interpreting this history, which until recent years has been considered the only one available; this consists of a study

of the sediments derived from the waste of the land during the interval and deposited as a fringe around its margin.

That the conclusions reached by these three methods of investigation should agree is manifest, and our confidence in them may be in proportion to their concordance. It remains to be seen whether the conclusions already reached can be verified by the study of the drainage and by the sediments deposited in the surrounding seas.

CYCLES OF DRAINAGE DEVELOPMENT.

The evolution of the drainage of this region began with the earliest emergence of Paleozoic sediments from the sea and the consequent increase of the eastern continental area toward the west. This process of emergence is believed to have begun in Cambrian time and to have continued at intervals to the close of the Carboniferous. The character of the drainage is much better known since the final emergence of the entire province than during Paleozoic time. Its modifications can be traced much more definitely because the surrounding conditions are better understood, and hence the history of the drainage development which can be read with any degree of certainty may be considered as beginning with the close of Paleozoic time. This development has not been a continuous process, but has been at times rapid, and then again for long periods almost stationary. This recurrence of similar conditions in the life history of a river may be termed cycles of drainage development. First comes a general elevation of its drainage basin, by which the stream is rejuvenated. The elevation ceasing, the stream in the course of long ages accomplishes its life-work and sinks into the sluggish inactivity of old age. This is followed by an uplift and the cycle of events is repeated.

Two such cycles are represented on the accompanying diagram, figure 1. The heavy line represents the position of the surface with reference to present sealevel, and hence its changes in altitude, by the slow process of degradation and the more rapid process of orogenic movement. The horizontal spaces are roughly proportional to the duration of the periods which constitute a cycle. The first of these cycles was extremely long, reaching from the final emergence of the western half of the province to near the close of the Cretaceous period. It includes the most extensive period of baseleveling known to have affected this

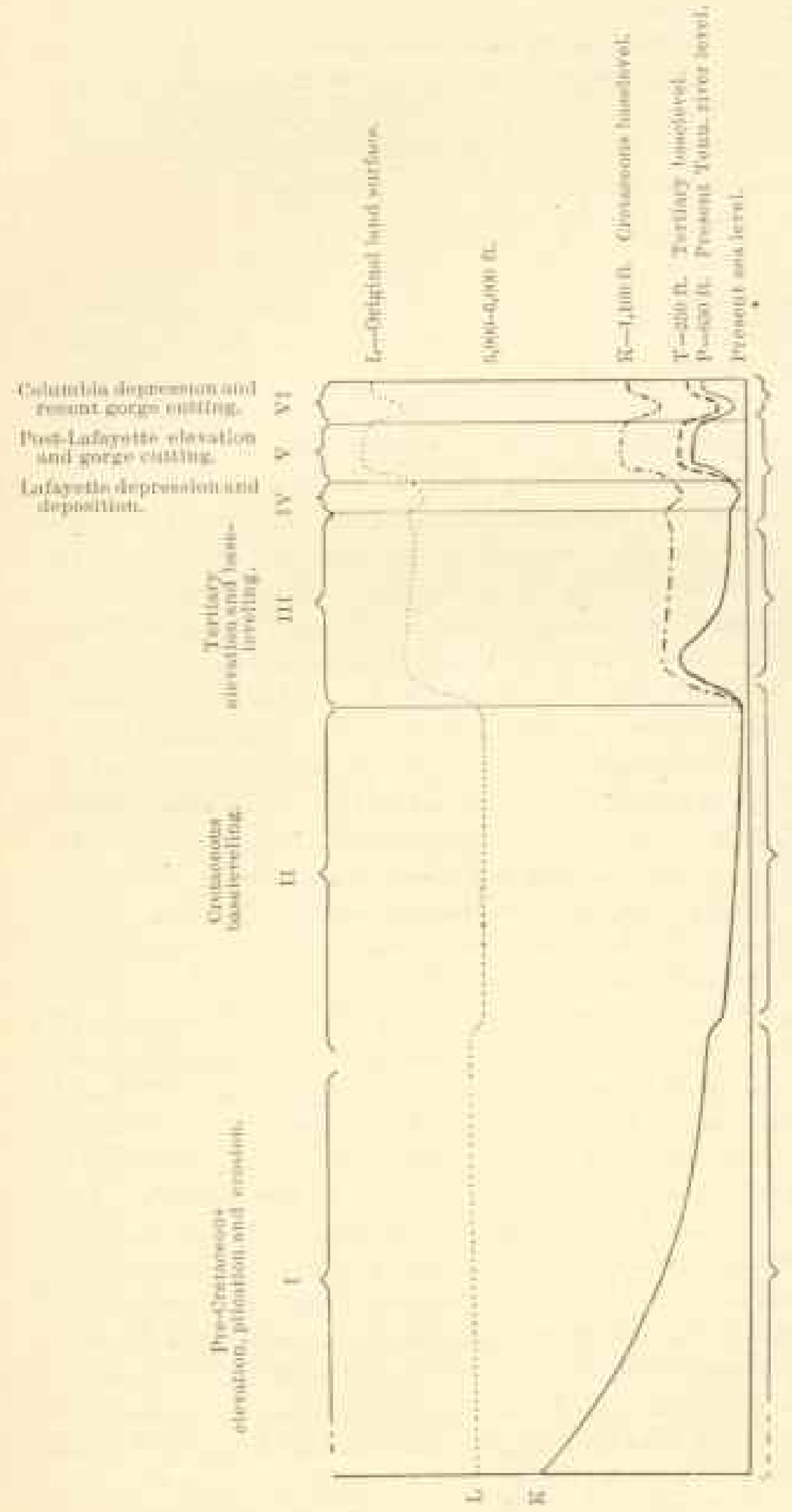


FIGURE 1.—*Diagram showing the Oscillations of the Land Surface at Chattanooga, Tennessee, and Cycles of drainage Development.*

region. The second cycle was much shorter, but the time was sufficient for the warping of the Cretaceous peneplain and the reduction of considerable portions of its surface to a second baselevel. The region has barely entered upon its third cycle, which has thus far been a period of elevation and active erosion, and a peneplain is again in process of formation.

CONDITIONS PRECEDING CYCLE 1.

Present knowledge of the physiography of the Appalachian province prior to the beginning of this cycle is extremely vague; but the conditions which then prevailed are so intimately connected with the subsequent drainage, having determined the location of the ancestors of the present streams, that they should briefly be considered. As far back as the history of the province can be traced, from near the beginning of Paleozoic time, a continental land area existed to the eastward of the present Appalachian valley. How far this land extended eastward is not known with any certainty, but it probably reached somewhat beyond the present Atlantic coast line. The process is not well understood by which the land included in the present Appalachian valley was added to this old continent. It has been generally supposed that the folding of the region and its elevation above sealevel occurred wholly in post-Carboniferous time. Recent investigations, however, afford ground for the theory that folding occurred at various epochs in the Paleozoic, and that during many of these periods of folding the land area was materially increased and the coast line of the interior sea was pushed further and further westward.

Streams flowing westward from the portion of the continent now included in the southern Appalachian province bore down the materials eroded from the land and spread them out over the bottom of the Paleozoic sea. These rivers were certainly the early representatives of the present streams and a few may have persisted in their original courses to the present. The effect upon these streams of the additions to the land area was probably less marked in the northern than in the southern portion of the province. Thus in northern Virginia the drainage was westward, though by what stream or streams is not known, from the time of the first emergence of Paleozoic sediments until the entire province was raised above sealevel; in central Virginia the New-Kanawha occupied much the same position as at

present; while farther southward some axial drainage may have been developed before the beginning of cycle I, as defined above. This axial drainage was at first consequent upon the folded surface and afterward became subsequent by the process of stream adjustment, but how far the process had gone previous to the beginning of cycle I is not known.

1.—CRETACEOUS CYCLE.

In the post-Paleozoic history of stream development the first cycle was long and complex—probably very much longer than all the time which has elapsed since its conclusion. It began with the final emergence of the western part of the Appalachian region above sealevel, near the close of the Carboniferous, and ended with the production of the Cretaceous baselevel peneplain which has already been described in Part I. It covered a period of elevation, deformation and erosion, but the products of this erosion were carried far beyond the margin of the sea as located in succeeding epochs and deeply buried beneath the later sediments; hence we are deprived of the evidence which might be afforded by the character of the material, as to the relative elevation and slope of the land. It is not known how many partial peneplains may have been formed during this time, but it is inferred that it was in general a period of rapid degradation and correspondingly rapid sedimentation.

As stated above, little is known of the process by which the Appalachian valley and the western portion of the province was added to the Paleozoic continent—whether the folding and emergence took place at the same or at different periods. If the corrugation was extremely slow the larger streams may have been and probably were able to cut their channels through the rising folds and for a long time hold their original or antecedent courses toward the northwest. On the other hand, if the folds rose rapidly the streams must have been ponded and most of them diverted to entirely new courses in the synclines; but by the process of river adjustment the final result would be the same in either case. The difference would be that if the folding were very slow the drainage would be first *antecedent* and then subsequent, while if it were rapid it would be first *consequent* and then subsequent. Since there is no evidence in this region, so far as known, that lakes formed by corrugation ever existed, only the first hypothesis—that of slow and long-continued folding—need

be considered. Local diversion of small streams may very likely have taken place by folding, but the drainage at the close of the Cretaceous cycle was essentially the result of spontaneous adjustment of the streams to the structure surface revealed by erosion. The chief difficulty in deciphering the record of this drainage development is to determine how much of the adjustment took place within this cycle and how much before its beginning.

Drainage of northern Virginia.—In the northern portion of the province the main streams held their westward courses across the rising folds and found an outlet in the shrinking mediterranean sea. At some time during the early part of the cycle a depression occurred in the present piedmont plain, in which the Newark sediments were subsequently deposited. This depression was different from the purely Appalachian type of synclinal fold, more nearly resembling those uplifts described in Part I—slight orogenic movements by which the surface was somewhat broadly arched or depressed, but unaccompanied by any perceptible folding of the rocks. This eastward tilting produced a decided effect upon the drainage of the northern portion of the province. The headwaters of the former streams were soon reversed by the pronounced eastward slope and the divides were forced back some distance from the margin of the Newark sea. Thus the Potomac, the James and the Roanoke had their birth in the subsidence which preceded the deposition of the Newark formation, and presumably in the very earliest stages of this cycle. The influence of this eastward tilting evidently diminished toward the south, for the Potomac drains more of the Appalachian valley than the James, and the James more than the Roanoke, while the New-Kanawha holds its original westward course, unaffected by any tilting which may have occurred about its headwaters.

Drainage of the southern Appalachian Valley.—South of the New-Kanawha basin the main streams also doubtless persisted across the rising folds for a short time after the beginning of the cycle, although in this region the chances of diversion to synclinal troughs were much greater than farther northward, even with extremely slow folding. As soon as the folds had risen sufficiently high so that erosion upon their flanks and summits became active and beds of varying hardness were exposed, southward flowing axial streams, aided by the general southward pitch of the axes,

began a career of conquest and the original streams were successively diverted to southern courses. There are indications in the extreme southern portion of the province that the drainage was more immediately turned to and longer held in consequent courses by the folding than elsewhere. This may have been due to the occurrence of broad synclinal troughs whose axes have a decided southward pitch. There are at present a few synclinal streams in this region and during the Cretaceous cycle the number and size of such must have been considerably greater; but even here the drainage had probably become so far adjusted that the main streams had subsequent courses upon the anticlinal axes. In the central portion of the province the Cumberland river probably drained a portion of the Appalachian valley in southwestern Virginia, holding its antecedent course through Cumberland gap and flowing into the extreme end of the Mississippi embayment.

The conquest of axial over transverse streams progressed at a diminishing rate toward the northeast as far as the New-Kanawha, which had sunk its antecedent channel sufficiently deep for its own protection.

Thus at the close of the cycle nearly the whole of the Appalachian valley southward from the New-Kanawha constituted a single drainage system whose main trunk was a large river flowing southwestward into the Cretaceous sea and occupying very nearly the present position of the Coosa river. The present writers propose the name Appalachian river for this Mesozoic stream, since it was almost entirely limited to the Appalachian valley and drained more than half the area of the valley within this province.

Drainage of central Kentucky and Tennessee.—In most of the region west of the Appalachian river basin the strata are so nearly horizontal that stream adjustment produced but little modification in the original drainage. The rivers of central Kentucky and Tennessee have shifted their channels under the influence of more recent surface warping, but at the close of the Cretaceous cycle they probably flowed directly down a gently sloping surface toward the Mississippi embayment. Many of them were the beheaded lower courses of those streams which originally flowed from the highlands on the east, but had been robbed of their upper drainage basins by the subsequent Appalachian river.

Drainage of the Sequatchie Anticline.—The Walden plateau syncline must originally have been occupied by a consequent southward flowing stream, since the axis pitches in that direction and the fold reached the margin of the Cretaceous sea. The lower portion of this stream still holds its original position and is now the Black Warrior river.

West of Walden plateau the Sequatchie anticlinal fold brought soft limestones above the Cretaceous baselevel and so afforded ample opportunity for stream adjustment to act. That the Walden synclinal stream did not migrate westward to the anticlinal axis was probably due to the southward pitch of the latter in northern Alabama by which the hard Carboniferous conglomerate was brought down to baselevel around the point of the anticline; but a stream flowing northwestward in nearly the position of the present Tennessee appears to have been able to capture the drainage of the Sequatchie anticline at some time during the Cretaceous cycle. It is quite possible that the southern portion of the anticline now forming Browns valley was for a time in the Black Warrior drainage; but that the westward diversion occurred rather early in the cycle is apparent from the imperfect development of the Cretaceous peneplain about its southwestern end, where a subsequent stream flowing into the Black Warrior must have escaped from the anticline, while, on the other hand, the country was very perfectly reduced to baselevel in the vicinity of the present westward outlet. It was shown in Part I that the axis *A B*, plate 5, has been the locus of oscillations from very remote geologic time down nearly to the present, and it appears probable that the location of the diverting stream was determined by this axis. The altitude of the Cretaceous peneplain relative to the geologic structure shows that this was a zone of relative elevation during a portion at least of the cycle, and consequently was a line of weakness which erosion would most readily follow, since the soft limestone was there brought nearest the surface.

At the close of the first cycle, then, the whole province, except the few residual areas shown on plate 5, was reduced to an almost featureless plain, over which the streams, as sketched above, flowed with sluggish currents in meandering courses. Their transporting power was greatly diminished, so that the land was being degraded almost wholly by solution and the surface was covered by a heavy mantle of residual material,

resulting from a long period of subaerial rock decay. The divides were low, slopes gentle, and the drainage systems delicately adjusted among themselves.

2.—TERTIARY CYCLE

The first cycle was brought to a close and the second cycle inaugurated by an uplift of the province. As explained in Part I, the maximum uplift was along certain axial lines which produced a warping of the previously formed peneplain. The first effect of elevation was to revive the streams, so that they began active erosion of their channels. If the uplift had been uniform over the province the streams would simply have persisted in their old courses, but the warping gave some streams a decided advantage over others and the process of adjustment to new conditions produced some decided changes in the drainage. Owing to the delicate interadjustment which the streams had reached during the preceding long period of baseleveling, they were peculiarly susceptible to change, and the first slight warping, after the baseleveling, was productive of greater changes than that which occurred later.

Effects of Uplift on the Axis O P.—The first decided movement at the beginning of this second cycle appears to have taken place along the axis *O P*, shown on plate 5. The effect which it produced upon the drainage had so direct a bearing on the subsequent diversion of the Appalachian river to the present course of the Tennessee that a somewhat detailed account of its effects will be given.

It must be borne in mind that at the beginning of this cycle the most of the Appalachian valley was occupied by southward flowing streams, which discharged their waters directly into the Cretaceous sea; that the Sand mountain syncline south of the Tennessee gorge was occupied by a consequent stream also flowing southwestward to the Cretaceous sea, and that the Sequatchie anticline was held by a subsequent stream flowing, in its lower course, northwestward to the Mississippi embayment. The Cumberland river was at the same time a vigorous stream, probably flowing nearly due westward along the present Kentucky-Tennessee line to the upper end of the Mississippi embayment. The plateau region was almost completely reduced to baselevel and the streams nicely balanced against each other. Under such conditions the slight uplift occurring along the line *O P* checked

some streams and started others upon careers of conquest. Only the larger streams continued across the axis, and the courses of these were shifted by the uplift. Thus the axis became a well marked divide between eastward and westward flowing streams. It crossed the present Tennessee gorge about midway from Chattanooga to the Sequatchie valley and determined the position of the divide against which streams of the Appalachian and Sequatchie systems worked during the whole of the second cycle. Northward from the Tennessee gorge it diagonally crossed Walden plateau, the Sequatchie anticline and the Cumberland plateau to the western escarpment of the latter, diverting to the eastward Appalachian system the heads of many streams which had previously flowed westward. The uplift on this axis was greatest in the vicinity of Chattanooga, from which it decreased in either direction. Toward the north the pitch of the axis was quite rapid, producing a marked effect upon the course of the Cumberland river.

That stream, as stated above, probably flowed due westward near the present Kentucky-Tennessee line. It was too large to be diverted eastward to the Appalachian system, but it was so checked by the rising fold that a tributary crossing the axis 50 miles further northward, where the uplift was less, had sufficient advantage over the main stream to carry off its headwaters to the more favorable position.

As indicated above and shown upon plate 4, the streams of Sand mountain south of the Tennessee gorge flow westward from the extreme eastern edge of the plateau and have cut deep notches in its western side, in some cases even beyond the center of the basin. In Walden ridge, a continuation of the same plateau north of the Tennessee gorge, all the streams flow eastward, heading in some cases only a few hundred yards from the western escarpment. These have cut deep notches in the eastern side of the plateau. This peculiar drainage is due chiefly to the axis of uplift *O P*, described above, but also in part to local conditions which continued from the preceding cycle. In the first place, the anticlinal valley west of the plateau was formed by a southward flowing stream, so that its southern portion was first excavated and erosion progressed toward the north; hence the streams flowing from the plateau into the southern part of the valley had lower outlets, and so cut more rapidly than those toward the north. East of this southern part of the plateau is

an anticlinal and synclinal fold—Lookout valley and mountain—of which the latter was probably not reduced entirely to the Cretaceous baselevel, and hence afforded a protecting bulwark against erosion upon the eastern side of Sand mountain. North of the present Tennessee gorge the conditions were exactly reversed. The western side of the plateau was protected from erosion by the Sequatchie anticline, the eastern limb of which, composed of heavy conglomerate, had probably remained somewhat above the Cretaceous baselevel, turning the drainage eastward to the Appalachian rivers, whose valleys were rapidly lowered upon soft rocks early in the Tertiary cycle. These streams cut deep notches in the eastern side of the plateau as far south as Chattanooga, beyond which the eastern side was protected by the Lookout mountain syncline of hard sandstone, as already explained. As a result of these peculiar conditions the plateau was attacked by streams on both its eastern and western sides only within a strip a few miles broad, where the Tennessee river now crosses. Here deep notches were cut on opposite sides of the plateau and the capping sandstone removed on several lines entirely across. So long as the uplift on the axis *O P* continued the divide was held stationary and neither set of streams encroached upon the territory of the other, but the cols were reduced nearly to the valley level on either side, and the way thus prepared for the diversion of the Appalachian river, later in the cycle. The uplift along this axis probably continued with diminishing force through the first half of the Tertiary cycle or possibly longer. During the same period variable amounts of uplift occurred in other portions of the province, which was thus brought to an altitude from 100 to 1,000 feet higher than that held at the close of the Cretaceous cycle. Probably other stream adjustments similar to those described in the Chattanooga district were brought about by this unequal uplift; but in general the streams simply sank their channels below the surface of the peneplain, following the same courses as in the preceding cycle. Wherever these courses were located upon soft rocks the rivers were quickly lowered to the newly established baselevel and began to widen their channels, forming a second peneplain.

Condition of Drainage prior to the Lafayette Depression.—Thus toward the close of the Tertiary cycle the streams flowing west-

ward had cut broad baselevel valleys, described in Part I, in the soft horizontal limestone of the plateau region and in some of the folded rocks immediately eastward. The greater part of the Sequatchie anticline had thus been reduced to a peneplain continuous with the more extensive one through the plateau to the westward. Cumberland river had cut deeply into the old Cretaceous peneplain and again baseleveled its valley in the soft limestones of the plateau region. It also probably baseleveled a small area of folded rocks in the Appalachian valley—the present basin of Powell river which then flowed westward through Cumberland gap. The New-Kanawha had cut an extensive peneplain in the Carboniferous limestone on the eastern side of the West Virginia coal field, and also in the folded Cambro-Silurian limestone of the valley region. The latter limestone is less soluble and homogeneous than the former, so that its outcrops were less perfectly reduced, forming a rolling surface instead of a level plain.

In the southeastern portion of the province the uplift of the Cretaceous peneplain was so slight that the streams were scarcely at all accelerated, and in the vicinity of Atlanta deepened their channels not more than 100 feet throughout the whole Tertiary cycle.

From the New-Kanawha southwestward to the margin of the Tertiary sea the Appalachian river and its tributaries had cut deeply into the Cretaceous peneplain and reduced all areas of soft rocks, more or less completely, to the new baselevel. The physiography of this Tertiary peneplain has already been described in some detail. The plain was very perfectly developed over areas of pure limestone, while siliceous limestones, shales and sandstones formed a rolling surface or ridges of varying heights, in proportion to their induration or capacity for resisting erosion.

It seems probable that the great Appalachian river was formed by two main branches which flowed in nearly parallel courses to their junction west of Rome, Georgia. The western branch followed the present course of the Clinch and Tennessee to Chattanooga, and thence of the Chickamauga and Chattooga to the junction of the latter with the Coosa; the eastern branch followed the course of the Holston and continued southward from Knoxville along the base of the Great Smoky mountains

to the Coosa at Rome, and thence to its junction with the western branch.

DIVERSION OF THE APPALACHIAN RIVER.

It is stated above that the drainage of the Appalachian valley was southwestward, from the New-Kanawha basin to the sea margin, until the close of the Tertiary baseleveling period. Since the date of diversion of this drainage is an extremely important point in the history of the region and since the above statement is liable to be questioned, the grounds on which it is based will be given in some detail. The evidence is derived from (1) the perfectly baseleveled divide between the Tennessee and Coosa river basins; (2) a comparison of the volume of material eroded from the Appalachian valley with that of the Tertiary sediments in central Alabama; and (3) the immaturity of the Tennessee gorge through the plateau below Chattanooga.

Evidence from the Coosa-Tennessee Divide.—As already stated, a peneplain, extending from the Cumberland plateau on the northwest to the Great Smoky mountains on the southeast, stretches from the head of the Holston and Clinch rivers to the edge of the Tertiary sediments in central Alabama. This peneplain is well shown in the photograph of the relief map of this region reproduced as plate 4. It is as perfectly developed across the Coosa-Tennessee divide as elsewhere, and shows no perceptible variation in the two basins except the gradual southward descent shown in plate 6 and due to subsequent differential elevation. It extends across the Appalachian valley from Pigeon mountain to the base of the Cohutta mountains, a distance of 40 miles, interrupted only by the valley ridges of hard sandstone or by low knobs of siliceous Knox dolomite. Since the peneplain is developed only on soft rocks, it is possible that the divides might have been cut down to their present altitudes by backward erosion of headwaters while the streams occupied their present courses; but while the altitude of the divides is not conclusive evidence that the main streams have flowed across them, the breadth of the valley upon the divide materially strengthens the evidence. By the backward cutting of streams at their headwaters a characteristic dendritic, inosculating drainage is developed, and it seems improbable that the divides should have been maintained in their present position throughout the Tertiary cycle without producing this characteristic surface, which is conspicuously absent.

It should be remarked that while the writers formerly regarded the character of the divides between these drainage basins as conclusive evidence that large streams flowed across them until the close of the Tertiary period of baseleveling, they have recently found reasons for modifying this conclusion. A study of the divides between drainage basins throughout the Appalachian valley from Pennsylvania southward shows that most of them are quite perfectly reduced to the altitude of the Tertiary peneplain in adjacent basins, although not generally so broadly cut as the one in question. There is no reason, so far as known, for supposing that the divides between the Potomac and James or the James and Roanoke basins have shifted during the Tertiary cycle, yet they are nearly as inconspicuous as those between the Tennessee and Coosa. On the other hand, the divide between the New and Holston basins has the form of a narrow col, such as would be expected to characterize all long-maintained divides.

Evidence from the Volume of Material eroded and deposited.—The second line of evidence bearing on the date at which the Appalachian drainage was diverted to its present westward course is derived from a comparison of the volumes of Tertiary erosion and Tertiary sediments. It is comparatively easy to compute the volume of the material which was removed by the rivers during the Tertiary cycle, when the vertical distance between the previously existing peneplain and the one developed during the Tertiary cycle is known, together with their lateral extent; also a tolerably safe estimate may be made of the volume of sediments deposited by each of the rivers during the Tertiary cycle. If the drainage during the whole of the cycle was essentially as it is at present, then the volume of sediments which would naturally be deposited by the present streams and the volume of the material eroded by those streams should show a practical agreement. The formations laid down during the Tertiary cycle are regarded as including (1) the Ripley—sands and sandy clays overlying the Rotten limestone and marking the uplift which terminated the preceding cycle; (2) Lignitic; (3) Buhrstone; (4) Claiborne; (5) White limestone*—a series decreasing in coarseness and increasing in amount of calcareous

* The Tertiary and Cretaceous Strata of the Tuscaloosa, Tombigbee and Alabama Rivers, by Eugene A. Smith and Lawrence C. Johnson: U. S. Geological Survey, Washington, Bull. 43, 1887, 150 pp., 21 pls.

matter contained. The sediments brought down by a Tertiary stream, corresponding in location to the present Alabama river, were spread over the adjacent sea bottom, mingling on the east with the sediments brought down by the Chattahoochee and on the west with those brought down by the Tombigbee. It is probable that more sediment was brought down by the Alabama than by the streams on either side, since it occupies the axis of uplift where the greatest erosion took place. Hence if a line be drawn midway between the Alabama and Chattahoochee on the east and between the Alabama and Tombigbee on the west the area included would certainly not be wider than the deposition area of the axial river. The area included by these lines and by the limits of the Ripley and White limestone formations is about 6,500 square miles. The thickness of the sediments in this area, down to the bottom of the Ripley, varies from 0 at the northern edge to 1,300 feet at the southern edge, and their volume is about 1,470 cubic miles; but these formations extend under the covering of later deposits, thinning out seaward, and while it is impossible to determine their extent or thickness in that direction, it seems a conservative estimate to regard the volume of the sediments in the seaward extension of the formations as equal to that of the actual outcrops. This estimate would make the volume of the sediments which may be attributed to the stream whose lower course occupied the present position of Alabama river during the Tertiary cycle about 2,340 cubic miles.

Turning now to the volume of material eroded from the Cretaceous peneplain during the Tertiary cycle by the Alabama and its tributaries, the basis for an estimate is somewhat better than in the case of the sediments. The greater part of the erosion has been in the valley of the Coosa and comparatively little in that of the Tallapoosa—first, because the vertical distance between the baselevels is greater in the former than the latter river basin, and, second, because the rocks are softer and hence have been more perfectly reduced. Throughout most of the Coosa basin the two peneplains are sufficiently well preserved so that a definite estimate can be made of the material removed during the Tertiary cycle. The amount of elevation and distortion which the Cretaceous peneplain suffered at the close of the Cretaceous cycle may be determined from a comparison of plates 5 and 6. It varies from 300 or 1,000 feet at the

Tennessee-Georgia line to 0 where the two plains coincide in southern Alabama. A careful estimate shows that the volume of material removed by the Alabama and all its tributaries during the Tertiary cycle is about 622 cubic miles. The great disparity between this and the volume of sediments laid down during this cycle by a river occupying the position of the Alabama leads us to seek farther for the source of the great mass of material. Manifestly this source is in the Appalachian valley north of the Coosa basin and at present drained by the Tennessee toward the northwest. The volume of material removed from the Tennessee basin above Chattanooga during the Tertiary cycle combined with that removed from the Alabama basin is about 2,500 cubic miles. Comparing this with the 2,340 cubic miles of sediments deposited during the Tertiary cycle by the Alabama river, the agreement is so close that the conclusion seems to be inevitable that the drainage of the Appalachian valley was southward until near the end of the Tertiary cycle.

Evidence from the Character of the Gorge below Chattanooga.—A third line of evidence bearing on the date at which the Appalachian drainage was diverted to its present westward course is derived from an examination of the Tennessee gorge below Chattanooga and a comparison of this gorge with other portions of the Tennessee valley formed under analogous conditions.

The winding course of the Tennessee river through Walden plateau has been considered as evidence that this portion of its course was determined during a period of baseleveling when the present summit of the plateau stood near sealevel; that with subsequent uplift the river continued to flow in its sinuous course, acquired under baselevel conditions, cutting its present gorge below the surface of the old peneplain. If this explanation of its winding course is correct, it follows either that the Tennessee is here flowing in an antecedent course or that it was diverted some time before the close of the Cretaceous cycle; but this conclusion is at variance with that reached by the two lines of evidence given above, as well as by a consideration of the gorge itself. The character of the gorge is shown on plate 4. Its sides are extremely steep from the cliffs at the plateau summit to the water's edge. In most places there is scarcely room for a wagon road between the abrupt slope and the river, and only a few narrow strips of flood-plain occur throughout its entire length. On the hypothesis of diversion in the Cretaceous cycle, the river

has occupied this narrow gorge throughout the entire period during which the enormous erosion of the Appalachian valley was accomplished. That a peneplain should have been developed from 20 to 40 miles in breadth and from central Virginia to northern Georgia by the same river in the same time that the insignificant strips of flood-plain in the gorge were being cut is quite improbable. It is true, the conditions of erosion in the two cases were not the same. The Tertiary peneplain in the Appalachian valley is developed only on areas of soft rocks which are generally steeply inclined; but, even allowing the greatest possible weight to the different conditions of erosion, the discrepancy in amount of erosion requires some further explanation, if the time were the same in both cases.

While a direct comparison cannot be made between the Walden gorge and the upper Tennessee valley on account of difference in conditions, such a comparison can be made between the gorge and a valley in northern Alabama, extending from Scottsboro southwestward to the mouth of Flint river. A portion of it is shown on plate 4. It is nowhere less than six miles broad, and its floor is very regular, forming a portion of the Tertiary peneplain. The age of this valley is easily determined; it is carved in the Cretaceous peneplain; therefore it is more recent than the Cretaceous; it is continuous with the Tertiary peneplain, and hence was completed at the close of the Tertiary base-leveling period; and at the close of that period it was deserted by the stream which carved it. The conditions under which this valley was cut are practically the same as those now prevailing in the gorge through Walden plateau. In both cases the rocks are nearly horizontal, heavy sandstones capping the plateau, with easily erodible Carboniferous limestones beneath. Such conditions are highly favorable for rapid corrasion of a river channel. The sandstone cap is undermined and its débris rolls down and forms a talus on the lower slopes. The rate at which the cliffs recede depends largely on the rate at which the sandstone talus is removed from the slopes and the limestone is exposed to erosion. No conditions could be more favorable for this rapid removal of the protecting débris than those now present in the Walden gorge, where the base of the slope is washed by a stream competent to remove all talus from the cliffs above, the coarsest as well as the finest. Certainly the conditions in the gorge are fully as favorable as they were in the valley west of

Scottsboro when that was being cut, and the stream which flowed in that valley was probably smaller than the present Tennessee; therefore, if under the same conditions a smaller stream than the present Tennessee could cut so broad a valley as it did in northern Alabama during the Tertiary cycle, the conclusion seems inevitable that the present gorge through Walden plateau has been occupied a very much shorter time, and hence the Appalachian drainage was not diverted to its present westward course till after a part or the whole of the Tertiary cycle. The explanation of the manner in which the writers believe the present winding course of the Tennessee through the plateau was acquired will be given in describing the process by which the diversion was accomplished.

Conditions immediately preceding the Diversion.—During the rapid elevation which inaugurated the Tertiary cycle and the much slower uplift which occurred near the close of the base-leveling period, the land area was enlarged by the addition of successive narrow belts of newly emerged sediments. In most cases the streams pushed their way across these belts by the shortest line to tidewater. The stream draining the Sequatchie anticline flowed westward through the plateau of northern Alabama by the broad valley already described; from the mouth of Flint river its course coincided with that of the present Tennessee to the Mississippi line. From this point it flowed southwestward to the Mississippi embayment very nearly in the present position of Black river, crossing the Cretaceous sediments as they were exposed at the close of the Cretaceous cycle and the successive belts of Tertiary sediments as they slowly emerged during the latter part of the Tertiary cycle.

The Tertiary cycle was marked near its close by a depression which effectually stopped the baseleveling process. This depression was not uniform, but like the preceding elevation was accompanied by warping of the surface. As indicated by the contemporaneous sedimentation, the depression was very slight at the present Gulf coast, 25 feet more or less at Mobile, increasing northward to 650 feet or more on the Memphis-Charleston axis (*A B*, plate 6). Northward from this axis the depression decreased, passing into a pronounced uplift in the northern portion of the province. In other words, the southern portion of the province was tilted northward, decreasing its seaward gradient, while a portion at least of the interior was tilted south-

ward, increasing its slope. There was also some warping on the lateral axis, so that the depression on *A B* was less in the Appalachian valley than on either side. As the first result of this depression, the sea, which had retreated beyond the present Gulf coast during the Tertiary, advanced past the inner limits of Tertiary and Cretaceous sediments, while the Mississippi embayment became a broad, shallow gulf and a portion of the Sequatchie valley a narrow tidal estuary. During this depression the Lafayette formation was deposited. The previously baseleveled streams, by the warping of the land, were accelerated in the interior and brought down vast quantities of detrital material which had accumulated during a long period of subaerial rock decay. This was spread out mantle-wise over the submerged border of the province and along the lower courses of the streams where their currents were checked. These gravels are found on the remnants of the Tertiary peneplain about Chattanooga, 250 feet above the present river; they are also found on the Tertiary peneplain in Sequatchie valley, 150 feet above the river, but so far as known they are entirely absent from the divide between the Tennessee and Coosa rivers. These gravels have the same character on both sides of Walden plateau, being composed of quartzite and vein quartz, of which the latter at least must have been brought from far to the eastward; therefore it appears certain that the Appalachian drainage was diverted from the present Tennessee-Coosa divide westward to its present course through the Walden gorge very early in the period of Lafayette depression. Following this period of depression came one of uplift, when the streams of the province were stimulated to renewed activity and began cutting the present river channels. That the Appalachian drainage was diverted to its present course before this uplift is quite certain, for no channels are cut in the Tertiary peneplain across the Coosa-Tennessee divide.

Manner in which the Diversion was accomplished.—Having fixed its date in geologic time with a fair degree of certainty, the process by which the diversion was effected may now be described in detail. The conditions which prevailed in the region between Chattanooga and Sequatchie valley during the Tertiary cycle have been already described. With the uplift at the beginning of that cycle the main southward flowing streams rapidly sank their channels on the soft limestone, while their tributaries began an active contest for the intervening territory. The axial uplift

on the line *O P* determined the location of the divide between the contending streams and held it stationary for a long time, neutralizing the advantage which local conditions would have given one or the other system and preventing consequent encroachment.

Figure 2 represents a restoration of the drainage as it probably existed when the Tertiary cycle was well advanced. The present course of the Tennessee river is represented by broken lines and the present relief by dotted contours. A rather large tributary, *M M*, joined the Sequatchie where that river now joins the Tennessee. It had numerous branches on the east heading against the divide along the axis *O P*. Flowing into the Clinch-Appalachian river on the east, the principal stream was *L L*, with the branches *F*, *G*, *H* and *K*, also heading against the divide *O P*. At the points *a* and *b* streams were cutting backward toward the same part of the divide from opposite directions, and as the process continued the heavy sandstone capping the plateau was removed and deep cols formed on the limestone. Under such conditions the divides may have been cut very low at these points

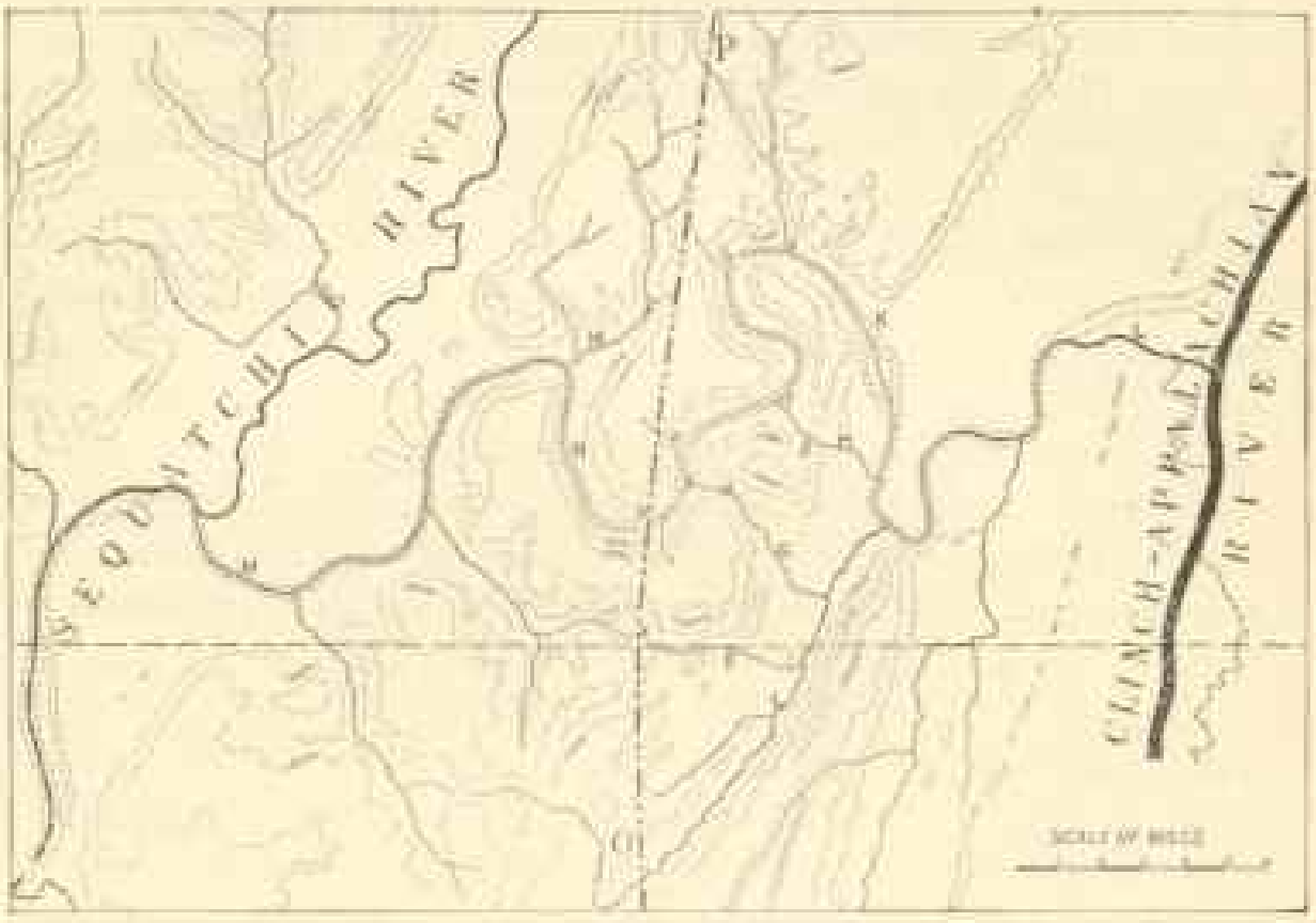


FIGURE 2.—*Sketch Map of the Tennessee Gorge, showing the present Course of the Tennessee River through Walden Ridge and the probable Arrangement of the Drainage immediately preceding the westward Diversion of the Appalachian River.*

without appreciable shifting. That the col at *a* was reduced nearly to its present altitude by erosion during the Tertiary cycle appears from a comparison of the amount of cutting which has since taken place in the most favored localities along the rivers and in the least favored localities on the divides. In the former the post-Tertiary erosion has been from 150 to 300 feet, and 100 feet seems a liberal estimate of the erosion in the same period upon the divides; but 100 feet added to the present altitude of the col at *a* would still leave the divide in soft shale or limestone. Since the divide at *b* is the one through which the contending streams finally forced a passage, it is not unreasonable to suppose that it offered some advantage which the divide at *a* did not possess. This was doubtless its altitude, which was in all probability considerably less than that of the divide at *a*. At the same time the divides *c* and *b*, between the streams *G*, *H* and *K*, had been similarly reduced, although the streams belong to a single drainage basin. On the above hypothesis it appears that the conditions were quite favorable for diversion of drainage, since the heavy conglomerate had been removed not alone from the main divide at *b*, but also from a series of connecting channels occupied by the streams *G*, *H* and *K*.

A careful study of the Tertiary peneplain in this region shows it to be higher on the eastern than on the western side of Walden plateau. In the vicinity of Chattanooga its altitude is nearly 900 feet, while in Sequatchie valley it is somewhat less than 800 feet; hence there appears to be a difference of at least 100 feet in the altitude of these two neighboring peneplains formed during the same period of baseleveling. A corresponding difference in the altitude of the Lafayette gravels was noted above. The probable explanation of this difference in altitude is found in the fact that the Sequatchie river had during the Tertiary cycle a more direct outlet to the sea than the Appalachian river, and also was flowing on softer and more homogeneous rocks; hence its valley was more perfectly baseleveled, and indeed it seems probable that under the exceptionally favorable conditions there prevailing the Sequatchie river may have reduced its gradient southward from the Tennessee line almost to zero. If the Appalachian river on the opposite side of Walden plateau were 100 feet higher than the Sequatchie it would have a descent of 100 feet in about 400 miles, or a fall of 3 inches per mile. Consider-

ing the nature of the rocks over which it was flowing, this rate would seem quite consistent with the formation of an extensive peneplain.

This difference in altitude of the drainage on opposite sides of Walden plateau gave the streams flowing westward a very decided advantage over those flowing eastward. So long as the uplift continued on the line *O P* this advantage was not sufficient to push the divide eastward beyond that line. Before the close of the Tertiary baseleveling, however, this uplift probably ceased and the westward streams then began a career of conquest which resulted in changing the course of the entire drainage of eastern Tennessee.

The process by which this conquest was accomplished is probably somewhat as follows: The advantage which the westward drainage possessed by reason of its more rapid descent enabled the stream *N* to push the divide from *b* to *c*, capturing a portion of the drainage area of the eastward flowing stream *G*. The contest was thus transferred to the divides *c* and *e*. The large volume of water coming from the plateau northward apparently determined the location of most rapid cutting at *e*, for while the divide *c* was pushed back only a short distance to its present position at *d*, the stream *e f* was reversed and the headwaters of *H* diverted westward, *f* and *h* thus becoming the actively contested divides. As in the previous case, cutting was most rapid at *h*, and while the divide *f* was pushed back to its present position at *g*, the branch *h i* was reversed and the headwaters of *K* diverted to the westward drainage. How far this process had gone before the end of the Tertiary baseleveling it is impossible to say, but it was probably well under way. The warping which accompanied the Lafayette depression gave the westward streams a still further advantage, and early in that depression the divide *i* was pushed eastward, reversing the flow, first, of the stream *K*, and then *L* to the junction of the latter with the Clinch-Appalachian river. Although the latter was a comparatively large river, the advantages possessed by the westward stream were sufficient to overbalance the advantage of size, and the Clinch-Appalachian river was captured and led off westward through the newly cut gorge. The capture of the western fork of the Appalachian river was probably followed shortly after by that of the eastern fork. This was accomplished by a tributary of the former working backward from Kingston to Loudon. Thus

the drainage of the Appalachian valley assumed practically the form which it has today.

As indicated in the above discussion of drainage adjustment, the present writers have reached the conclusion that an extremely important factor in the process is the slow and gentle warping of the surface which has accompanied every epeirogenic movement of which there is any record. We believe this factor is only less important than the great structural features of a region, and in some cases, of which the Tennessee is a notable example, the structure of the region has played a secondary part in determining the drainage courses. This gentle warping of the surface has hitherto been recognized only in a general way and few attempts have been made to locate axes; consequently the manner in which it influences drainage has not yet been discussed. The writers have in preparation a paper in which an attempt will be made to formulate the laws of this action and to show much more fully than the limits of the present paper will permit to what extent it has determined the courses of the Appalachian streams.

3.—PRESENT CYCLE.

Northward diversion of the Tennessee River.—The Lafayette depression, with its accompanying deposition of coarse sediments about the border of the province, occupied the closing epoch of the Tertiary cycle. The next, which may properly be termed the Present cycle, was inaugurated, like the two preceding, by uplift, and the uplift was accompanied by warping of the surface. The southern portion of the province was tilted northward, probably somewhat beyond the Memphis-Charleston axis. The rivers whose lower courses had been rendered sluggish or even submerged by the preceding depression were stimulated to renewed activity and began a rapid trenching of the lately deposited Lafayette formation. The land area was extended considerably beyond its present limits, and the rivers throughout their lower courses cut deep gorges, forming notches in the present submerged continental shelf. The uplift along the southern border of the province was so rapid that only the larger streams or those favorably located upon soft rocks were able to keep their channels down near baselevel. The Alabama river, although only the shrunken representative of the once powerful Appalachian river, had its lower course located on soft Tertiary

limestones, sands and clays, so that it was able to keep pace with this uplift and retain its southward course unchanged to the Gulf. The Mississippi, by reason of its greater volume, was also able to keep near baselevel, and as the land rose cut a deep gorge through the Lafayette and well into or through the underlying Tertiary and Cretaceous formations.

The westward flowing stream which had diverted the Appalachian drainage occupied in its lower course about the position of Black river, and it probably continued in this course a short time after the post-Lafayette elevation began—long enough, at least, to cut through the mantle of Lafayette gravel down to the Grand gulf, which is the most indurated of all the Mississippi embayment formations. While the lower course of this river was thus held in check by the elevation of the indurated beds, northward flowing streams were greatly stimulated by the tilting of the surface in that direction. Small streams flowing northward to the Ohio along the strike of the easily erodible Cretaceous beds therefore had a double advantage over those flowing westward or southwestward, and by cutting backward were able to capture and divert the Tennessee river to a northward course.

After a comparatively short period of elevation the province was again depressed, though not so much as during the Lafayette epoch, and this depression was in turn followed by elevation to the present altitude. The record of these oscillations is found chiefly in the deposits and erosion forms of the region bordering the Appalachian province, and hence is somewhat beyond the scope of this paper. The time was too short for permanent records to be inscribed on the land surface in the interior. Minor stream adjustments doubtless occurred, and the rivers sank their channels within the surface of the Tertiary peneplain, in some regions deeply dissecting that surface, as already described in Part I.

SUMMARY OF THE DRAINAGE DEVELOPMENT AND LAND OSCILLATIONS.

It is seen from the foregoing that the present course of the Tennessee river is extremely complex, and that a history of its development is practically a history of the province in post-Paleozoic time. Different portions of the river course furnish a record of the various vicissitudes through which the province has passed, or at least confirm the record found in other physio-

graphic features. We have seen that most of the eastern tributaries are very old, having occupied approximately their present positions while the western portion of the province was still covered by the great inland sea. From the eastern highlands they brought down the vast Paleozoic sediments and built the floor of the future continent. As successive belts of these sediments were lifted to form dry land and the sea margin migrated westward, the streams extended their lower courses to the shrinking sea. Then during the long period of Appalachian folding and the longer period of degradation these westward-flowing streams were diverted to southward courses and collected in a single great stream, the Appalachian river. In the early part of this long cycle the southern portion of the province stood relatively higher, so that until the close of the Jurassic the materials carried down by the Appalachian river were swept to unknown distances and deeply buried beneath the later Mesozoic sediments. Early in the Cretaceous the land was tilted seaward and the water advanced to the present inner margin of the Cretaceous sediments. At the close of the cycle the Appalachian river wandered over a broad and nearly featureless plain. The second cycle began with uplift of the land, and broad valleys were cut by the streams nearly to their headwaters. Then came the Lafayette depression, accompanied by warping, which gave so great advantage to the streams flowing westward along the axis *A B* that the upper Appalachian drainage was captured and led off to the Mississippi embayment. The great river was scarcely adjusted to its new position before the tilting of the surface again changed it northward to its present course into the Ohio. Thus the lower portion of the Tennessee river dates from the present cycle. The portion in northern Alabama and across Walden plateau was occupied at the close of the Tertiary cycle; that in the Appalachian valley was adjusted during the long Cretaceous cycle; and, finally, the tributaries flowing from the present Smoky mountains have inherited their courses from the early Paleozoic continent.

In conclusion, a graphic representation of this history will be given, in order to bring together the conclusions contained in the preceding portions of this paper. The oscillations of the surface have been so variable, accompanied by such diverse warping, that the relations of the surface of the whole region to sealevel cannot be represented diagrammatically; but if a single

point on the surface be taken its relations to sealevel may be so represented. A point on the present site of Chattanooga has been selected as fairly representative and where the various altitudes can be well determined. These relations are represented in the diagram, figure 1, page 99. The vertical lines divide the space into five time divisions. These divisions are only approximately proportional to the time, the late divisions being much too large and the earlier divisions too small. Taking the horizontal line at the base of the diagram as sealevel, the full line represents the altitude of the main stream channels and the dotted lines their altitudes at former periods marked by the remnants of baselevel peneplains still existing. The upper dotted line *L* in the diagram indicates the position of the original land surface with reference to sealevel. Its distance above the present land surface at the right of the diagram corresponds with the thickness of strata removed by erosion from the point taken, which is on an anticlinal fold and hence upon rocks low in the series. The thickness of the rocks eroded is only represented approximately, since the original thickness of the Carboniferous is not known. The line *K* represents the altitude of the land surface slowly approaching sealevel by degradation during the long cycle of Cretaceous baseleveling. It is scarcely probable that the land remained stationary during this long period. There were doubtless minor oscillations, but these have left no record upon the surface and hence cannot be represented. At the close of the Cretaceous cycle came the elevation of the surface shown by the rise in the line *K* at the beginning of the second time division. With the elevation, the line *K* ceases to represent the stream level which is indicated by the heavy line *T*, diverging from *K* at first rapidly and then slowly, the peneplain being developed during the Tertiary cycle. Since this cycle was not so long as the preceding and the baseleveling not so complete, the line *T* does not approach so near sealevel as the line *K*. During the third period, which was one of depression, the lines *K* and *T* remain parallel, since little, if any, erosion was taking place at Chattanooga at that time. With the elevation at the end of the Lafayette depression the line *T* in turn ceases to represent the stream level which is indicated by the line *P*, and this diverges continually to the present except during the Columbia depression. Thus the various lines at the right of the diagram indicate the position of various plains of erosion with reference

to each other and to present sealevel, but not to sealevel in past time. The lowest line, *P*, the present flood plain of the Tennessee river, is 650 feet above sealevel; the second, *T*, the Tertiary peneplain, is 250 feet above the present river; the third, *K*, the Cretaceous peneplain, is about 1,100 feet above the Tertiary; and, last, the original land surface is about 5,000 or 6,000 feet above the Cretaceous baselevel.

Part III—Sedimentary Record.

The variation in character of sediments deposited on the southern border of the Appalachian province during Cretaceous and later time has been briefly referred to, and also the correlation between kind of sediment and attitude of land. The conclusions reached by other lines of evidence are so fully borne out by a consideration of the sediments that the subject merits a somewhat fuller treatment. The character of sedimentary rocks is usually regarded as indicative of the depth of water in which they were formed, and while this is in a measure true, a more important element is probably the character and attitude of the adjacent land from which the sediments were derived.

High land is subjected to active degradation, especially if it has been recently elevated and is covered by a heavy mantle of residual material. Its streams have rapid fall and are supplied with an abundant load of coarse mechanical sediment which they carry in great volume to the sea. Under such conditions of rapid erosion the deposits formed are gravels, sands and clays, generally highly colored from the complete oxidation of the residual mantle before transportation. Solution is at the same time going on, but the volume of material removed by that means is small in comparison with the mechanical sediment, and the proportion of calcareous matter is correspondingly small in the deposits formed. As the cycle advances the gradients of the streams decrease, and with it their carrying capacity. Hence the proportion of matter in solution is increased by the diminution in the absolute amount of mechanical sediment and the deposits become correspondingly more calcareous. In the final stages of baseleveling, chemical agents are more active than mechanical; the sluggish streams are able to transport only the finest silt in suspension and the resulting deposit is a more or less pure limestone. The character of the sediments derived from the

southern Appalachian region during the long period of degradation which it has suffered ought to show gradations from arenaceous to calcareous, corresponding with the stage of development of the cycle in which deposition occurred, coarse sands and clays when a surface subjected to a long period of subaerial decay and rock disintegration was elevated so as to stimulate stream transportation, and calcareous shales and limestones when the surface had been so far reduced to baselevel that only fine sediment in suspension or matter held in solution was carried by the streams. Since the geomorphy of the interior proves the existence of several of these cycles of continental development, one should expect to find cycles of sedimentation corresponding in geologic age and degree of completeness.

The record of sedimentation in the Gulf region from the Tuscaloosa (probably late Jurassic or early Cretaceous) to the close of the Vicksburg or White limestone (late Eocene) is fairly continuous and complete. Arranging the formations intervening between these limits in their proper order and assigning to each a space, not in proportion to its thickness, but to the probable time occupied by its formation, the curve shown in figure 3 is derived, in which the horizontal coordinates represent relative time, and the vertical coordinates relative coarseness or fineness of the sediments. Thus the curve expresses immediately the variation in character of the sediments carried into the sea by the southern Appalachian rivers during Cretaceous and Tertiary time and, by inference, the altitude of the land over which the rivers flowed. The character and amount of material carried off by these streams during the long period of degradation preceding the Cretaceous can only be inferred from the known character and amount of rocks removed, for the sediments were carried to an unknown distance seaward and concealed by overlap beneath the subsequent formations. The accessible record begins with the Tuscaloosa, a thick deposit of sands and clays marking rapid erosion and great carrying power of the streams, and hence a considerable altitude of the land surface. Through the Eutaw and into the Rotten limestone the sediments show a decrease in coarseness and an increase in calcareous matter, and the curve approaches the horizontal axis, continuing approximately parallel with it throughout nearly the whole of the Rotten limestone. This marks a long period dur-

ing which the transporting power of the streams was gradually diminishing and the surface approaching baselevel at a constantly decreasing rate. This great mass of calcareous sediment, part of which is a mechanical deposit, points to erosion of extensive limestone areas which must have been in the Appalachian valley; hence the character of the formation supports the conclusion reached from other evidence, that the drainage of that region was southward during the whole of the Cretaceous cycle. Passing the Rotton limestone, the curve leaves the horizontal axis, and in the Lignitic reaches its farthest distance therefrom, marking a period of high land or steep slopes and rapidly cutting streams. From this point it rapidly descends through the Buhrstone and Claiborne to the Vicksburg

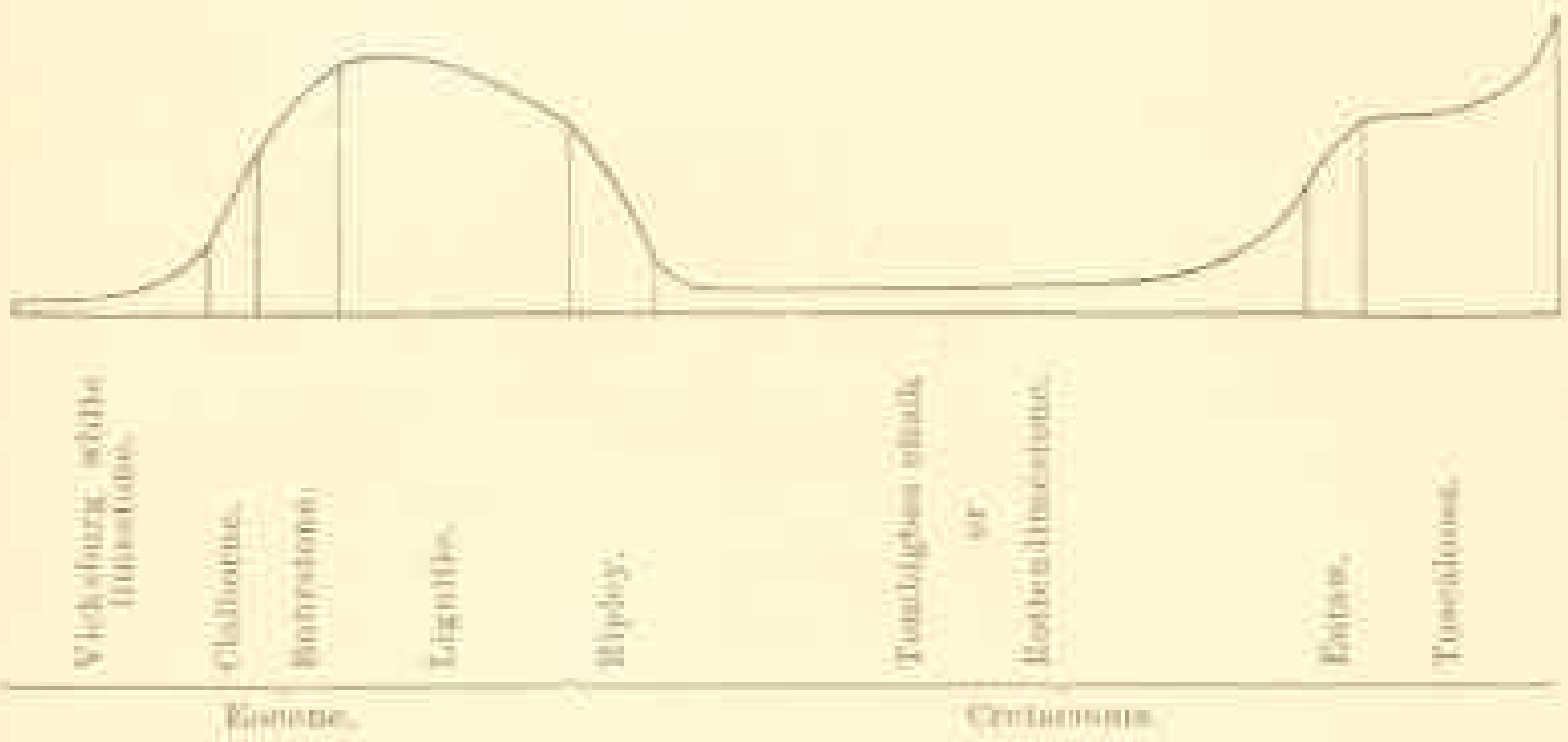


Figure 3.—Diagram showing variation in Character of Cretaceous and Tertiary Sediments in Alabama.

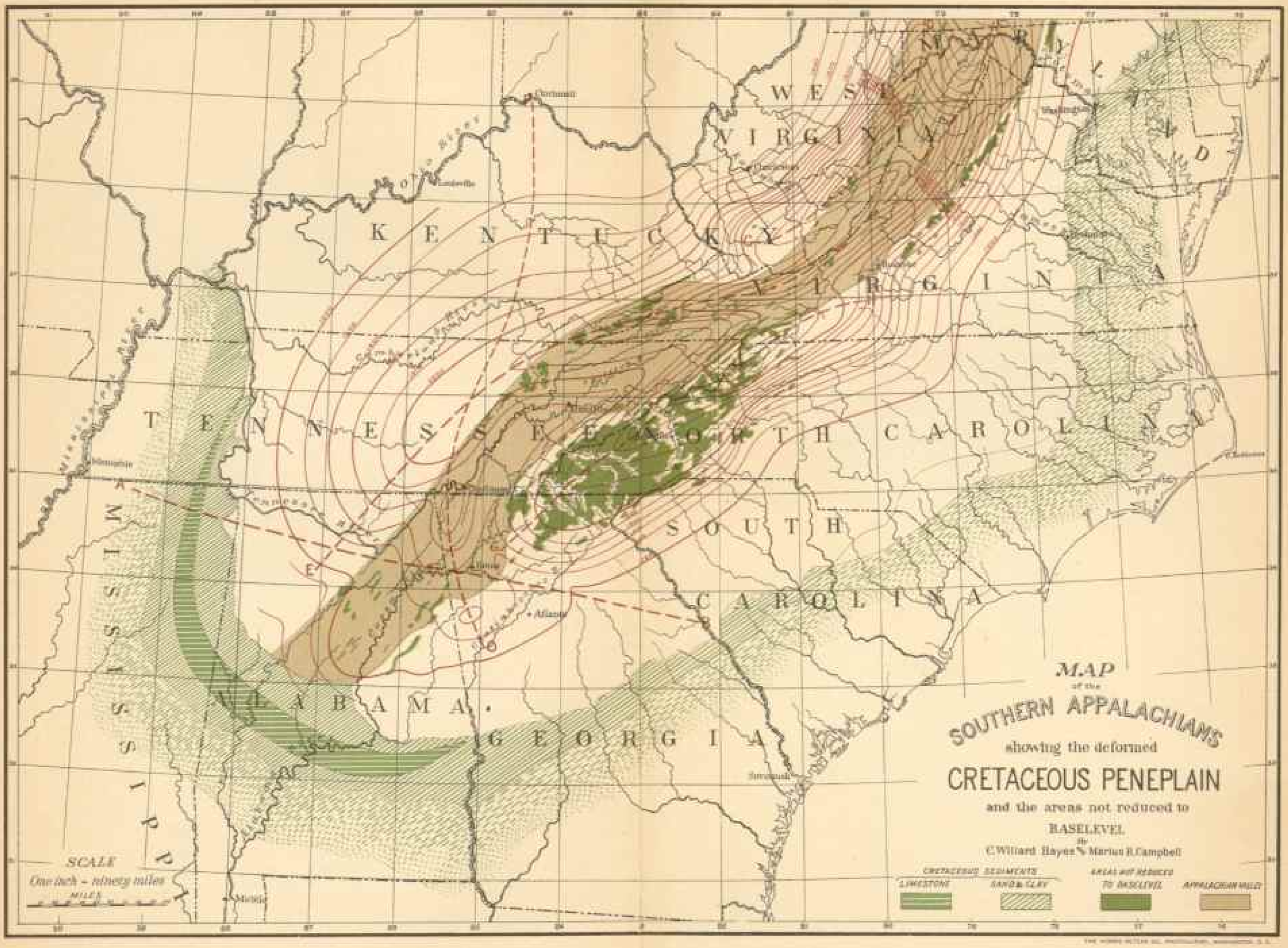
limestone, showing a rapid decrease in carrying power of the streams and a near approach to baselevel in the valleys.

It is thus seen that during the time covered by the sedimentary record in southern Alabama there were two periods in which the land stood high and the streams were rapidly degrading the surface, and that these alternated with two periods in which the land was low, approximately at baselevel, and the streams carried little sediment, but were degrading the surface by solution. Hence two baselevel peneplains separated by a considerable uplift are to be sought in the region from which the sediments were derived. The two already described fulfill all the theoretical conditions, and the correlation of these peneplains, from other considerations, with Cretaceous and Tertiary time is

greatly strengthened. On the Atlantic slope the data are not so complete. Almost all of the sediments were derived directly from the granitic rocks of the piedmont plain, and hence show less differentiation in character than the rocks of the Gulf coast. So far as known there is nothing in the character of the Atlantic coastal plain sediments which will conflict with the conclusions given above, but exact correlations cannot at present be made.

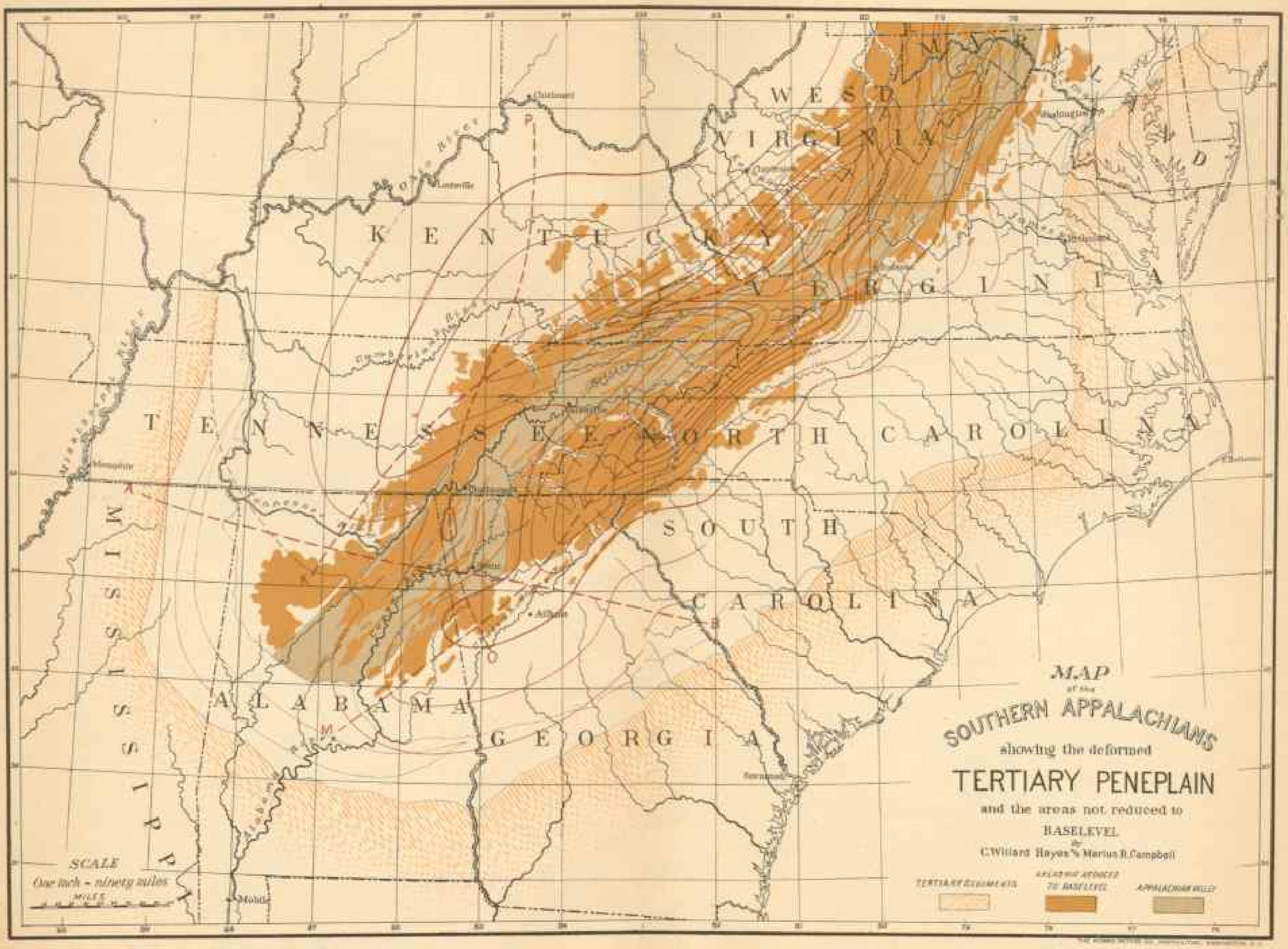
Thus the same history of the province which was read in the forms of the land surface and in the location of the streams is also found recorded in the sediments derived from its erosion. The three lines of investigation outlined at the beginning of this paper are found to lead to harmonious results and each to supplement the others. While many details remain to be worked out, the main features of post-Paleozoic history of the southern Appalachians as given above seem fairly well determined.

United States Geological Survey,
Washington, D. C.



MAP
of the
SOUTHERN APPALACHIANS
showing the deformed
CRETACEOUS PENEPLAIN
and the areas not reduced to
BASELEVEL
By
C. Willard Hayes & Marius R. Campbell

CRETACEOUS SEDIMENTS: LIMESTONE; SAND & CLAY
AREAS NOT REDUCED TO BASELEVEL
APPALACHIAN FIELD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A L A B A M A
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M I S S I S S I P P I
Louisville
Chattanooga
Atlanta
Mobile
SCALE
One inch = ninety miles
MAP
of the
SOUTHERN APPALACHIANS
showing the deformed
TERTIARY PENEPLAIN
and the areas not reduced to
BASELEVEL
by
C. Willard Hayes & Marius R. Campbell
TERTIARY SEDIMENTS
APPALACHIAN VALLEY