THE GEOGRAPHIC DEVELOPMENT OF NORTHERN NEW JERSEY.

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Preface.

1. The following essay had its beginning in work by the authors as teacher and student in a second course in physical geography at Harvard College in 1887–88. The home of the student being in New Jersey, the physical geography of that state was taken as our theme; and with the reports and admirable contoured maps published by the State Geological Survey in hand, the subject was investigated with such methods as could be devised. An excursion across northern New Jersey in the spring of 1888 gave us a brief view of the typical areas described below. At about the same time the publication of the first number of Mr. McGee's essay on "Three Formations of the Middle Atlantic Slope" gave us the results of his observations over an extended area, with which we were already in substantial accord as far as the topography of New Jersey is concerned. The investigation proved instructive and entertaining beyond our expectations, and foreshadowed the impulse that will be given to geographical study when all our states shall be well surveyed.

The completion of our manuscript having been much delayed, it has been extended from time to time by the senior author beyond its original form. Use has thus been made of the five-mile relief map of New Jersey, published in the summer of 1888; of the later articles by Mr. McGee; of his account of the fall-line displacement,

as presented in the "Geology of the Head of Chesapeake Bay" in the Seventh Annual Report of the U. S. Geological Survey; and of the account of the Topography of New Jersey by C. C. Vermeule lately published in the first volume of the Final Report of the State Geologist, Prof. George H. Cook. In the untimely death of Professor Cook we have lost the leader under whose direction nearly all of the published data on which our work rested was prepared.

Introduction.

2. *General scheme of geographic classification.* The surface of the land may be regarded as composed of a number of individual forms, whose general character depends on the rock-structure which the processes of land-sculpture have worked upon, and whose more particular expression depends on the degree of advance in the degradation of the surface from its initial, constructional form to the smooth, low, baselevel plain to which it is finally reduced. Thus regarded, any geographic individual may be associated with certain others, to which it is related by similarity of structure, and the whole group of similar individuals, thus related, may be idealized in a type, which presents all the essential, but none of the accidental features of the group that it represents. The type is therefore an elastic conception, not limited in the way of size, nor in the number of its features, nor in any variable element; but always holding fast to those characteristics that distinguish it from the types of other groups. Moreover, in order that individuals of different age may be properly represented by a single type, every type must be conceived to vary systematically in passing through the cycle of changes that its individuals suffer from the time when the first attack is made upon them by the destructive forces of the weather, to the time when they are worn down to baselevel, the level of the standing water into which their drainage flows, below which land erosion cannot reduce them; and, if they front on the sea, their type will include a coast-line with its varying expression from the early time when the waves make their first attack upon it to the distant end when the whole is planed down to a flat submarine platform at an undetermined depth. Individuals under a type may then be regarded in natural relationship; they are not final results of processes, but are stages in a cycle of systematic change, and are therefore to be regarded not only

as related by similarity of structure, but also as comparable in regard to age. Moreover, some individuals raised to a considerable elevation in their youth, attain an intense development of all their features in maturity, and weaken only in old age; others that have never gained much elevation have but a mild expression even at the strongest.

3. *Conception of systematic geography and geographic development.* This conception of geography differs from that generally adopted in giving more attention than is commonly allowed to the development of geographic form, and in basing a classification on the sequence of forms assumed in the successive stages of the development of the type, as well as on the different structures of the types of various groups. It seems to be a rational extension of the study; for nothing is better established than that the surface of the earth was not made in a final form as we see it, but has come to its present form through the action of natural processes, still in operation, such as are discussed in geology; that the form resulting from these natural processes depends on the structure that the processes work upon, on the time that the processes have been at work, and on the rate and opportunity for work as determined by altitude, climate, and other factors. It is certainly advisable to extend our conception of geography as fast as the various branches of knowledge applicable to it are extended; meteorology has advanced into a field of mathematical physics; zoölogy turns on embryology; chemistry follows physics in utilizing atomic and molecular hypothesis to an extraordinary degree; and if geography is to advance beyond narration and numeration, it must take all that it can gather from geology, and search for natural and genetic systems of classification and description. Geography comprehends a description of the surface of the earth; and in order to carry the study out to its fullest use, it must draw on any source of information that aids and completes its descriptions. Physical geography includes discussion and explanation besides description, and must employ every method that increases the rational understanding of its data.

When one attempts the physical description of a political area, such as one of our states, it is like the work of a botanist in describing the flora of a limited region. Plants of many kinds will be found there naturally associated in an order quite unlike that given to them in a treatise on systematic botany; but if good work

is to be done, the systematic order embodying the concentrated experience of earlier students must be familiar before an examination of the order in the state of nature is undertaken. Otherwise the observer will fail to apprehend the significant features discovered by previous investigators, and will be too much influenced by individual and temporary characteristics. Trees might be classified according to their height; growing trees would be separated from dead and leafless trunks of the same kind; small plants would be overlooked.

In the same way there should be some general scheme of geographical classification in mind before attempting to describe the topographical features of any given region: we shall therefore follow the scheme based on structure and age, outlined above[1]. Besides this, there is need of some systematic order of arrangement of the members of the scheme, but geographers are not yet agreed about the order that shall be followed; it has therefore been our purpose not only to present a systematic description of New Jersey, but also to illustrate one—the historic—of the many possible systems of arrangement that might be followed, in the hope that by trial of various systems, a satisfactory one may be at last adopted for general use.

4. *The geographic divisions of New Jersey.* New Jersey may be conveniently divided into three main districts, according to the broader features of its structure and topography roughly outlined in fig. 1. The crystalline Highlands lie in the north, a region of rugged uplands, broken by deep and steep-sided valleys; associated with Kittatinny valley and mountain on the northwest. The sandy Lowlands occupy the south, with monotonous surface of faint relief; and between these two there is an intermediate Central plain of Cretaceous and Triassic beds, traversed by long, narrow ridges of trap. All of these divisions extend beyond the political limits of New Jersey. In describing them we shall begin with the oldest land surface of which there is any trace still remaining, and take up after it as many others as may be found in the order of their development.

[1] A fuller discussion of this plan of classification is presented in a paper by the senior author on "Geographic methods in geologic investigation," National Geographic Magazine, I, 1888, 11.

THE HIGHLANDS.

5. *General account of the Highlands.* When standing on one of the Highland plateaus, the observer must be struck with the nearly uniform elevation reached by all the surrounding uplands. The profile of one mass after another rises close to the common standard of height and there maintains an even outline with much constancy. The flat-bottomed valleys sink deep below the general upland surface, but there are no corresponding elevations above it. Schooley's mountain may be taken as a good example of one of

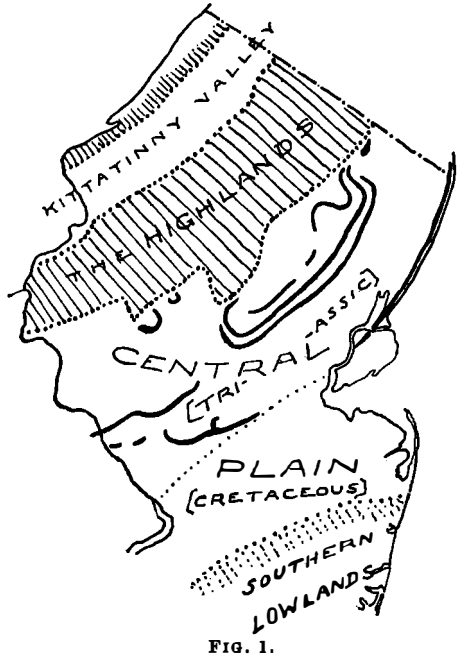

FIG. 1.

these Highland plateaus. In the neighborhood of Budd's lake, its surface rises to ten or eleven hundred feet above the sea level and maintains this elevation with moderate inequality over broad stretches; on the southeast, the broad German valley is drained by the south branch of the Raritan at a height of about six hundred feet; on the northwest the Musconetcong flows in a wide-open valley about a hundred feet lower. A walk over the mountain from one valley-railroad to another can easily be accomplished in a few hours

and can be made within a day, even if one has to start from New York by train in the morning and return there in the evening. A fine round-trip excursion can be made by taking a morning train on the Morris and Essex division of the Delaware, Lackawanna and Western railroad to Waterloo station in the Musconetcong valley, walking over the mountain past Budd's lake, and on the way passing from the glaciated to the non-glaciated area, and descending in the afternoon to the German valley at Bartley station, whence the return to New York is made by an interesting ride on the Central railroad of New Jersey. The justice of the following description by Professor Cook will then be appreciated.

"The Highland mountain range consists of many ridges which are in part separated by deep valleys and in part coalesce, forming plateaus or table-lands of small extent. Some of the included valleys are quite as deep as the red sandstone plain on the south and the Kittatinny valley on the north and west . . . . . A characteristic feature is the absence of what might be called alpine structure or scenery. There are no prominent peaks or cones. The ridges are even-topped for long distances and the average elevation is uniform over wide areas. Looking at the crests alone and imagining the valleys and depressions filled, the surface would approximate to a plane gently inclined toward the southeast and toward the southwest . . . . . The new atlas of the state will show how remarkably even-topped these ridges of the highlands are and enable the reader to construct for himself the plateau indicated here by these crest lines . . . . . The more prominent and larger of these high levels are the country south of Dover and east of the German valley, Schooley's mountain range, Scott's mountain and the country from lake Hopatcong, extending northeast . . . . . They are not to be understood as level, but as diversified by the ridges which rise from 100 to 300 feet above the deepest depressions, the latter being 400 to 600 feet above the adjacent valleys and plain country. Once upon them, the so-called mountains disappear and sink into hills, whereas, when viewed from the valleys, the plateau or table-land rises up as a mountain . . . . Near the valley, the apparently lofty ridges are designated as mountains; in the ridges, away from the valleys and outside plain country, names are often wanting for even the highest crests, as they are called hills[1] . . . ."

[1] Geol. Survey of New Jersey, Annual Report, 1883, 27-29.

After describing the great distortion and folding of the highland rocks, Professor Cook continues: "It is to be remarked that there is a great degree of uniformity in the altitudes of the mountain ranges of the Highlands. A large area south of Dover and Rockaway and west of Morristown has an average elevation of 800 to 900 feet. And the traveller attaining the summit of this plateau, as it were, recognizes the general level as characteristic of it. The broad Schooley's mountain range, extending southwest to where the Central railroad crosses it, is another example of this uniformity of height, having an average elevation from 1000 to 1200 feet. Scott's mountain has about the same average height. Another remarkable table-land is in the northeastern part of Sussex and the western part of Passaic counties. Its mean height is probably over 1200 feet, as there are many summits over 1400 feet, and scarcely any depressions less than 1000 feet. The surface is by no means level or even an approximation to a plane; but there are no very prominent peaks or ridges, nor any deep hollows or valleys. This uniform feature of the surface is not accidental, but must have had its origin in some way related to the original uplifting and folding of the strata, modified greatly by the subsequent erosion due to the drainage and glacial action in part."[1]

6. *Development of the Highlands.* It may now be asked what was the antecedent land-form from which the present Highlands have been developed; and if any trace of this antecedent form still remains, the geographer may legitimately extend his inquiry to include its examination.

We know from the general principles of valley-making and land-sculpture that any surface exposed to denudation is worn fastest along the stream lines, until they approach baselevel, and is wasted slower on the interstream surfaces. Given a plateau, for exam-

FIG. 2.

ple, whose baselevel is *B–L*, its profile in successive stages of development might be roughly illustrated in fig. 2. The heavy line may be taken as the average present form of the Highlands. Then

[1] *Id.*, 60, 61.

the antecedent form may be restored, with sufficient accuracy for our purpose, by filling up the valleys nearly to the height of the uplands between them, as Professor Cook suggested; and it is manifest from an examination of the maps or from a view of the country, that the restoration would be a broad surface of very gentle undulation, so smooth that we may call it almost a plain, that is, a *peneplain*.[1] It is then from such an old peneplain surface that the present rugged Highlands have been carved. The old peneplain remains but slightly attacked on the interstream plateaus, such as the broad summit of Schooley's mountain; its destruction has been carried farthest on the softer rocks, where the valleys have been deepened and widened.

7. *Origin of the old Highland peneplain.* How could the old plain surface of the uplands originate? It was not a constructional plain, like that of the Red river of the north, between Minnesota and Dakota, for there is no reason to suppose that it was ever by any means perfectly level. The rocks of the Highlands are chiefly crystalline gneisses and schists, with slates and limestones, all greatly disturbed;[2] if there be any truth in the prevailing theories that account for the present condition of such rocks, both the formation of most of them and the deformation of all must be ascribed to processes working at depths of thousands of feet below the surface of the earth. Moreover, the folia of the gneisses and schists and the strata of the bedded rocks northwest of them are commonly seen standing at steep angles, and their present outcropping edges manifestly do not mark their original extension. It must, therefore, be surely concluded that the old upland peneplain was not the original constructional surface of the underlying rocks, but was a surface produced by the action of destructive forces on a once much larger mass. It remains to be seen why a tolerably even surface was produced by these destructive forces.

Examples may be quoted in plenty from the region of the western plateaus to show that destructive forces produce even surfaces when they denude a cover of softer rocks and encounter a hard stratum; but, in such case, the hard stratum must be horizontal. The peneplain of the Highlands cannot be explained in this way, for its rocks are strongly tilted, as has been stated above. The peneplain had

[1] This term was used by the senior author in describing the restored forms of the uplands in Connecticut, which are believed to be of the same age as those here considered. Amer. Journ. Science, XXXVII, 1889, 430.

[2] Ann. Rep. Geol. Surv., N. J., 1884, 44; 1886, 89, 119.

no sympathy with the underlying rock-structure and must have been produced independently of it.

The only way in which an even surface, that is discordant with the rock-structure, can be explained is to regard it as the form to which all land-masses are ultimately reduced by denudation, from whatever initial form they may have had, provided only that the denuding forces have had time enough to act; and this is true whether the ultimate form is the subaërial baselevel plain of land denudation, or the subaqueous platform of marine denudation. Given sufficient time, the wasting away of the land under the air or at the edge of the sea will result in a low, even surface; and in one or the other or both of these ways, we may hope to explain the peneplain of the Highlands.

It is worth while to recognize clearly that this explanation rests on the principle of exclusion; a principle that must be employed cautiously. Some process adequate for the production of a certain old plain is searched for; several processes are suggested; some of them are manifestly insufficient; then the true explanation must be sought among the remaining processes. The postulate of this argument is that all the processes by which plains can be produced have been considered; otherwise the true explanation might escape us. But it may also be recognized that nearly all geological argument is of this character, and that it becomes safer as the progress of the science makes it unlikely that any adequate process has been omitted from the discussion. The reader must judge whether it is safe, in the present state of geology, to conclude absolutely that plains can be formed only in the four ways above named; if he can suggest other ways, the conclusion of the preceding paragraph is invalid.

But if it may be safely concluded, as we think it may, that the old peneplain of the Highlands was either a subaërial baselevel plain or a submarine platform, it follows that the land must have stood lower than it now does when the lost material was worn away. The baselevel of that time must have been B′ L′, fig. 2. The present upland must then have been a lowland, and the opportunity for cutting the present valleys must be ascribed to a general elevation at a later date. This will be returned to farther on.

8. *Difference between plains of subaërial and submarine origin.* It remains for us to inquire whether the old Highland peneplain was the product of subaërial or submarine processes. Thirty years

ago, the latter explanation would probably have been accepted without a question. At present, many students would almost as unhesitatingly accept the former. But it must be admitted that, as far as our inquiry has progressed, both are adequate, and some better method of discriminating between them than the fashion of the time must be devised. We find no established guides in this inquiry, but the following considerations may be suggested.

A subaërial baselevel plain is gradually completed by the action of ordinary forces on all parts of its surface. Reduction to baselevel is slowest along the divides on the harder rocks, and quickest along the streams on the softer rocks. The valley bottoms therefore approach and practically reach baselevel long before the interstream areas are reduced so low.

A submarine platform is essentially completed strip by strip, once for all, as far as it goes; its advance is rapid at first, very slow at last. Its landward margin is surmounted by a sinuous cliff or slope with a level base, facing the sea and separating an interior of greater or less relief from a smooth sea-bottom, unconformably veneered over with the deposits from the land. If the transgression of the sea over the land be aided by a depression of the land, many inequalities of the surface might be preserved beneath the unconformable cover of marine deposits. Such a surface, when again lifted and somewhat denuded, might be indistinguishable from one that had not been submerged. The occurrence of unconformable deposits on an even foundation cannot alone be taken as evidence that the foundation is a surface of marine denudation; it may be a subaërial baselevel plain depressed below sea-level and covered with sediments from an adjacent portion of the same that was not submerged.

The ultimate forms of the two kinds of plains are probably much alike, and it may be hopeless to seek to distinguish them after they have been elevated and roughened by subsequent erosion. But the penultimate forms of the two might be separated; one would be gently rolling, its residual inequalities being of the hill and valley type; the other would be smoother, and might be very smooth if its veneer be regarded as its surface, but it would have a definite margin, beyond which the penultimate subaërial plain would be found. The two forms are of course often associated.

9. *Value of contoured maps in geographic study.* We have tried to detect on the restored surface of the old Highland pene-

plain some indications of its origin according to the above criteria, and in such work contoured maps are essential. They have a quantitative accuracy, while shaded or hachured maps give only a qualitative idea of form. It would be quite impossible to carry on careful geographic study without the knowledge of height, such as contours give, as well as of length and breadth; for the study of the form of the land is a study of three dimensions. The contoured map of New Jersey is invaluable in this regard.

10. *A restoration of part of the old Highland peneplain* was made by copying from the contoured maps on a sheet of tracing paper the heights of all the broad, topmost elevations of the plateau divides between the streams. The principle has already been stated that the valleys, which have been deepened quickly in a geographic sense, were once almost as high as the interstream plateaus, which must have wasted away much slower; and this warrants our believing that the interstream elevations may be taken as giving some indication of the form of the surface before the valleys were made. Contours are drawn on the tracing paper in accordance with these elevations, and a fair map of the old Highland peneplain is thus constructed. It should be noted that the restoration thus secured may have somewhat less relief than the old plain possessed; for it is only a generalization, on which much detail is lost. The old plain is at once seen to be broadly undulating, and the undulations seem to be too strong to be considered as belonging to an ancient submarine platform. The plain is therefore best regarded as an area of subaërial denudation, not entirely worn down to the ultimate form of an absolute plain, but reduced from a mountainous maturity to very mild relief in its old age.

The penultimate stage of subaërial denudation would give essentially such a surface as has been discovered in our restoration. It may, however, be suggested that the old surface was a true submarine platform, subsequently somewhat deformed, perhaps at the time of general elevation. To this it can hardly be answered that no traces of the platform sediments have been found on the plateau, for they might easily have been swept away during the excavation of the deep and wide valleys that now traverse the Highlands; but it may be fairly argued that a final subaërial baselevel plain could be similarly distorted; and it may be strongly urged that, since the higher parts of the restored surface coincide with the areas of harder rocks, as the penultimate elevations of an old baselevelled area must,

it is not likely that distortion is accountable for the gentle undulations of the ancient plain.

11. *Conclusions as to the origin of the Highland peneplain.* We may therefore conclude that, whatever was the earlier history and form of the Highland region, it once stood with its present upland surface but little above sea-level for a period long enough to be worn down to a lowland of moderate relief, and that it was subsequently lifted bodily to its present elevation.

This may on first reading seem out of place in a geographic essay; but just so much of the past as is needed to explain surface forms still in existence is fairly within the province of systematic geography. Certain it is that no sufficient comprehension of the geography of the New Jersey Highlands can be gained without thus turning to the past for an explanation of their broad uplands. Geology need not grudge what seems at first like a trespass on its province; it has enough to do with the still earlier history of the Highlands, the discussion of their rocks and of their ancient dislocations that have left no mark on the present surface; indeed the trespass, if it be such, may be to the advantage of geology in suggesting points of view before unnoticed.

12. *The Schooley baselevel.* The general altitude of the surface of the sea with respect to the land during the development of the present upland surface of the Highlands constitutes an important plane of reference, which will be named the "Schooley baselevel;" and as we have concluded that the greater part of the denuded area was reduced to a surface of gentle relief by subaërial forces, the surface itself as then worn down, although by no means perfectly flat, will be called the "Schooley baselevel peneplain," or more locally "the Highland peneplain." We shall also speak of the "Schooley cycle," meaning thereby the time spent in the development of the old plain.

Geographic inquiry hardly leads us further in the past than to the time when the Highlands were lowlands. There is no longer any remnant of earlier surfaces in the topography of New Jersey—though there may possibly be inheritances from them in the position of certain water courses, as Mr. McGee has suggested to us. If the reader should, however, desire to reconstruct the still earlier antecedent form of the region, from which the Highland peneplain was developed, we believe good reasons could be given for arguing that it was probably a faulted mountainous region of parallel

ridges, with Appalachian trend, having bold bluffs to the east, and gentler slopes to the west; these slopes themselves being nearly baselevelled surfaces of a still earlier Triassic date; in many ways like the present form of the Sierra Nevada of California,[1] although of not so great relief.

13. *Extent of the Schooley baselevel peneplain.* The ancient base-level peneplain of the Highlands cannot have been limited to northern New Jersey; it was the product of far extending as well as of long existing conditions; it must have stretched beyond arbitrary political boundaries of which even the present natural lines are in good part of a date subsequent to its production. It is believed that the same ancient peneplain determines the general community of height and the prevailing level crest-line of Kittatinny mountain on the northwest border of New Jersey and of the associated ridge lines and upland surfaces of the Alleghanies and of the plateau farther west in Pennsylvania;[2] but on this, final decision can hardly be reached till the Keystone state follows the example of its smaller neighbor and prepares a contoured map of its surface, than which that of no state in the country offers more interesting problems. We can say less of the extension of the northern part of the plain into New York; but its southeastern extension across New Jersey is open to our investigation.

14. *The Watchung mountains.* Standing on one of the front members of the Highlands, such as Sheep Hill, north of Boonton, one sees the long, even, parallel crest-lines of the Watchung mountains rising over the Triassic area to the southeast. These are the bevelled edges of two broad sheets of trap, intercalated in the beds of sandstone and shale of the Triassic formation; their steep outcrop faces look to the east, and on the west their slopes descend gently at an angle somewhat less than the dip of the accompanying beds; they are trenched at several points by water gaps, through which streams carry back-country drainage across them, and by notches or wind-gaps; but between the gaps their crests extend in unbroken levels for long distances.[3] The question arises here as in the Highlands, under what circumstances could crest-lines as even

[1] J. LeConte, Amer. Journ. Sci., xxxii, 1886, 167; J. S. Diller, Bulletin 33, U. S. Geol. Survey, p. 12, 1, *et seq.*

[2] Compare an essay by the senior author on the Rivers and Valleys of Pennsylvania, Nat. Geog. Mag., I, 1889, 197.

[3] A view of the Watchung ridges back of Plainfield, as seen from the east, is given in Ann. Rep., N. J. Geol. Survey, 1882, pl. 1.

as these be developed? A geological examination of the district leads to the conviction that the trap-sheets, like the sedimentary beds between them, have formerly had a great extension upward along the plane of their dip into the air, just as they still have an undetermined extension downward into the ground; their present edges simply mark the lines back to which the sheets have been consumed by denuding forces of one kind or another. If the land had stood at its present altitude during the long time needed for the consumption of the lost portion of the sheets, the long, level crest-lines between the transverse gaps could find no explanation in accordance with the general laws of land-sculpture, as they are at present understood; they might in such case be rounded, as in fig. 3*a*, but could not be even, as they are shown in fig. 3*b*. The

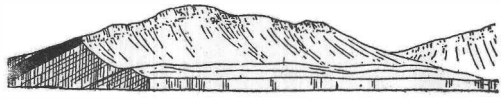

FIG. 3*a*.

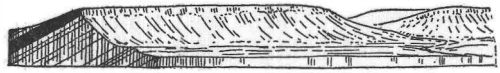

FIG. 3*b*.

only satisfactory explanation of their evenness is to be found in the supposition that their crests are remnants of a plain of baselevel denudation, formed when the land stood lower than now. The valleys between and alongside of the parallel ridges, and the transverse gaps that cross them, have been worn out since this plain was elevated to about the height of the present crest-lines.

Several other trap ridges of similar form call for a similar explanation. Sourland and other ridges in the southwest, Rocky Hill on the south, and the Palisades on the east all have tolerably even crest-lines, and are presumably remnants of extinct plains that once stretched away to either side of the ridges at the level of their tops.

It may be reasonably inquired whether these extinct plains were not, at the time of their fullest development, parts of one and the

same surface with the Highland peneplain; and the best answer that can be made is in the affirmative. A long period of lower continental stand is needed for both; this period was closed by a massive uplifting at a time far enough back in the past to allow the subsequent erosion of deep and steep-sided valleys in the hard rocks of the Highlands and to permit the excavation of broad lowlands on the softer sandstones and shales between the hard trap-sheets of the Triassic area, leaving the trap projecting as even-topped ridges. Moreover, when the restoration of the Schooley baselevel peneplain is extended southeastward by the process already described, the highest crests of the various trap-ridges being taken as indices of the former surface of the Triassic area, a tolerably consistent series of contours can be drawn, showing a broad eastward extension of the baselevelled area. We conclude therefore that the Schooley peneplain stretched southeastward, as well as westward; it was a geographic feature of great importance in the earlier history of our country. But although the broad plain of faint relief thus restored must have been a nearly level lowland before it was elevated, its remnants do not indicate that it was uniformly elevated into a level highland; for while it falls slowly below sea-level about New Brunswick, where the Palisade-Rocky Hill crest-line dips underground for a distance of twenty miles, it rises gently to the north, northwest and southwest as a faintly warped and inclined surface. This unequal elevation is natural enough. Nothing can be more likely than that the elevation of the extinct plain should have been uneven and greater at one place than another. Irregular upheavals of every degree are clearly seen in the deformation of bedded rocks that once lay horizontal, and it is natural enough that similar irregularity of upheaval should appear in the elevation of our old, once nearly horizontal peneplain.

15. *Extension of the Schooley peneplain over the Triassic area.* Let the observer now visit some of the more commanding points of view on the crests of the long Watchung trap-ridges and attempt to reconstruct the extinct geography, of which the remnants are so suggestive.

Westward there is the broad valley of the Passaic, worn out on the sandstones that overlie the trap-sheets; this must in imagination be filled up to the surface that is defined by the summit of the Watchung ridges on the southeast, and by the front of the Highland plateau on the northwest. Washington valley is hollowed

out on the shales between the parallel trap-ridges. Eastward and southeastward, the broad lowlands from north of Paterson to Newark and Elizabeth and thence westward beyond Bound Brook, must also be refilled; the chief defining lines here being the Watchung ridges on the west, the Palisades on the east and Rocky Hill on the south. It may be confidently believed that the last two ridges are parts of a single trap-ridge—the edge of a single trap-sheet—depressed and buried under Cretaceous deposits at its middle about New Brunswick, and rising thence northward and southwestward in accordance with the deformation that the ancient peneplain has suffered. No statement can be made as to the extension of the old peneplain beneath the cretaceous deposits above referred to; but the geological structure of the region clearly demonstrates that, after this part of the plain had been made, it was submerged by a transgression of the Atlantic, and buried under detritus from some adjacent land. This is considered further in section 19.

To one who is unaccustomed to the magnitude of the work of erosion in fashioning the surface of the earth, it may seem almost incredible that so great an amount of material as is indicated by the amount of filling just called for should have been worn away; but the more the surface of the world is examined, the more necessary it is to admit that the land as we see it is carved deep in the land as it has been. If evidence is asked for in confirmation of this, we need only turn to the vast beds of stratified rocks, twenty to forty thousand feet thick in the central Appalachians and as much in parts of the Cordilleran region, to discover some of the depositories of ancient destructive work of this kind. There may again be doubt when one is asked to accept the fact of heavy erosion in New Jersey on what may seem at first like imperfect and insufficient evidence, as presented above; but we are persuaded that the more the matter is studied, the fuller confidence will be gained that the evidence of the crest lines is susceptible of no other interpretation than that here adopted. We may later ask what has become of the waste carried from the land, first in making the Schooley peneplain, and later in roughening it again.

The reader must guard against making too artificial a conception of the smoothness of the Schooley peneplain at the time of its elevation. The harder rocks, such as the gneisses and the traps, undoubtedly resisted the destructive forces successfully enough to maintain rolling elevations above the general surface in the late

maturity of the region, and they may not have been quite smoothed down even at their latest stage; but the weaker rocks, such as the limestones of the Highlands and the red shales of the Triassic belt were probably worn down very flat, for they are so easily weathered that they must have been reduced close to a baselevel surface at a relatively early date; just as at present they have been cut deep in valleys and widely opened in lowlands before the gneisses and traps have lost all indications of the extinct plain from which the valleys and lowlands have been eroded.

16. *General conception of baselevels and baselevel plains.* The definition of baselevel may be purely geometrical, and the ultimate form of the surface developed on it might theoretically be a flat plain; but such conceptions are too rigid for application in geology and geography. The Schooley baselevel that we have been considering must not be regarded as a definite surface, absolutely fixed with reference to the Highland mass; it was more likely the average position of many small oscillations of sea-level down towards which the ancient land mass was gradually reduced; and the Schooley baselevel peneplain was rather a general approach to a smooth surface, prevailingly low and nearly featureless, but by no means a surface of geometrical uniformity, absolutely coincident with its controlling baselevel. While it might be possible that endless time and stationary attitude would result in geometrical simplicity of land form, we need not expect to find such a result in natural occurrence, for the land is too unsteady to allow it.

When Powell first introduced the term "base level," he employed it in two senses. He said " we may consider the level of the sea to be a grand base level, below which the dry lands cannot be eroded:" this is the general and persistent baselevel of a region so long as the relative level of the land and sea does not change. He then adds, "but we may also have, for local and temporary purposes other base levels of erosion, which are the levels of the beds of the principal streams which carry away the products of erosion."[1] The context shows clearly that these two uses of the term are employed. These "local baselevels of erosion" are described, in ascending the Colorado and Green rivers,[2] each one being determined by the passage of the stream for a distance over par-

[1] Colorado River of the West, 1875, 203. [2] *l. c.*, 207.

ticularly resistant rock; the softer rocks next up stream being widely opened while only cañons are eroded on the harder ones. We have in New Jersey similar local and temporary baselevels, whose general recognition will greatly improve the popular conception of our topographic features. The hard sandstones of Kittatinny mountain form such a baselevel for the up-stream country of the Delaware river; and the trap sheets of the Watchung mountains exert similar control over the upper basin of the Passaic. Powell on another page speaking of the Appalachians, says "the base level of erosion of the entire area would have been the level of the sea:"[1] this is the general and ultimate sense of the term; to this final baselevel must all temporary and local baselevels be reduced, if time be allowed.

Other American geologists have also used the term in two senses. Dutton uses it in the plural when he refers to the base levels of a river system, thus indicating the recognition of local controls in different parts;[2] and he also says: "all regions are tending to base-levels of erosion, and if the time be long enough each region will, in its turn, approach nearer and nearer, and at last sensibly reach it. The approach, however, consists in an infinite series of approximations like the approach of an hyperbola to tangency with its asymptote."[3]

Several European writers have suggested terms closely allied to the one under discussion. La Noë and Margerie[4] use "niveau de base" in the same general and local senses as attach with us to baselevel; but it seems to me that they have misapprehended Powell's definition of the term, for they quote from him only that part of his statement that refers to the temporary baselevel. Heim at an earlier date wrote of the mouth of a river basin as the "basis" for valley making in the whole area concerned.[5] But the conception of the relation of denudation to its fundamental controlling datum plane does not yet appear to be general or definite enough to call for the introduction of a special term, such as base-level, with which to name it in text books of geology. It is still customary to illustrate the work of erosion with examples of its

[1] *l. c.*, 209.
[2] High Plateaus of Utah, 1880, 23, 45.
[3] Tertiary history of the Grand Cañon District. U. S. G. S., Monogr. II, 1882, 76.
[4] Les Formes du Terrain, Paris, 1888, 54, 57.
[5] Mechanismus der Gebirgsbildung, 1878, I, 296.

smaller accomplishments, such as valleys or even cañons, instead of with baselevelled plains.

A conception related to the one here considered under the name of baselevel has been introduced by Dausse,[1] Philippson;[2] La Noë and Margerie.[3] When a river has deepened its channel so far as materially to reduce its slope and therewith its carrying power also, and at the same time opened extended valley walls whence it receives an increasing load of detritus, it reaches a condition of quasi equilibrium, in which the further deepening of its valley is slow; but deepening is only retarded and delayed, not stopped, and the entrance of a river into this stage of its history is by gradual transition, not by abrupt change. While thus slowly deepening the valley, it represents in a general way the local baselevel of its region; but this must not be confounded with the absolute and ultimate baselevel.

The more frequent employment of the conception of baselevel has been accompanied by a natural evolution of its terminology. Powell said "base level of erosion." Later writers omitted the last half of the phrase and said more briefly "base level" or "base-level," the fully expanded expression being too cumbersome for frequent use. In this essay, we have omitted the hyphen, and write "baselevel" as a single word, a necessary scientific term. At the same time, the word has become a verb, for we often hear such an expression as "given time enough, and a river will baselevel its basin;" and an adjective, as in saying "a baselevelled region;" and even a noun applied to the form produced by the baselevelling process, as "the upper Wisconsin baselevel," "the old Appalachian baselevels," meaning here the plains or peneplains of denudation by which these districts are characterized. This is quite as it should be, and illustrates the practical value of the idea expressed in the term.

17. *Correlation of geographic development and geologic time.* The deformation of the old Schooley peneplain has left part of its east-

[1] "Profil d'équilibre." Etudes relatives à l'endiguement des rivières et aux inondations. Mém. sav. étrangers Acad. des Sciences, XX, 1872. Here quoted from La Noë et Margerie, as below.

[2] "Erosionsterminant;" Ein Beitrag zur Erosionstheorie, Petermann's Mittheilungen, 1886, 67.

[3] État de stabilité ou d'équilibre; Les Formes du Terrain, Paris, 1888, 55, 56. Hilber has lately made a review of this question. Zeitschr. f. wiss. Geogr., VI, 1888, 201.

ern extension below sea-level, where certain stratified deposits of later date conceal the depressed middle portion of the Palisades-Rocky Hill trap sheet about New Brunswick; the same deformation has lifted the western part to a height that allows the excavation of deep valleys below the old baselevel surface.

Several questions now arise. We may ask the geologic date of the completion of the Schooley baselevelling, in order to associate it properly with other topographic features of the same age. We may inquire into the geographic conditions of the origin of the stratified deposits that now bury the Palisades-Rocky Hill trap sheet, and ask if they give indication that the eastern part of the Schooley peneplain is a platform of submarine origin. The further original extension of the same deposits to the northwest must be considered, in so far as they may have had geographic consequences in controlling the development of our existing stream-courses. Finally, the date of the elevation of the Schooley peneplain must be discovered, in order to gain some comprehension of the rate of subsequent geographic growth, measured in geologic units.

18. *Date of the Schooley baselevelling.* The general sequence of events by which the geological date of the Schooley baselevelling is determined is as follows. The great Appalachian revolution culminating in Permian time produced a mountain range of strong constructional relief, and presumably of strong actual relief for a certain period after the disturbances. But in the area occupied by the Triassic belt, the topography seems to have been reduced to a moderate relief before Triassic deposition began; this we know because the southeastern margin of the Triassic formation, where it joins with older rocks, is a rather even line across the Triassic-Cretaceous peneplain of to-day. From this it must be concluded that the foundation on which the Triassic beds lie is also a peneplain, the product of pre-Triassic erosion on a mass of mountainous structure. The great mass of sediments accumulated in the Triassic cycle has suffered tilting and probably faulting also, and there is good reason to think that this disturbance extended over a considerable area on either side of the present Triassic belt: this produced a new mountainous topography, of less elevation and of much less structural distortion than that of Permian time, but still of considerable strength, as suggested in paragraph 12; and it is the old age of the forms of this cycle of development that we have de-

scribed under the name of the Schooley baselevel peneplain. This peneplain, with the unconformable cover of Cretaceous beds that subsequently transgressed over its eastern margin, was at some later time elevated in the interior, and in the declining surface of the plateau thus formed the valleys of the Highlands and the lowlands of the softer Triassic beds have been cut out, at times and to an amount that will be considered farther on. The Appalachian chain, as we now see it, is therefore not to be regarded as the residual relief of an elevation given once for all at the time of the great Permian folding. The first and probably the greatest Appalachians were worn down low before and during Triassic time; they were regenerated to a considerable strength by the post-Triassic faulting, tilting and elevation, and again worn down low and faint to the Schooley baselevel peneplain; and the ridges that we now see are simply the parts of this old peneplain that have as yet withstood the erosion consequent on a still later uplift. The first elevation was accompanied by tremendous crushing and folding; the second was accompanied by little more than monoclinal tilting and faulting; the third, as well as other minor oscillations of later date, were chiefly massive uplifts of moderate amount and gentle inequality.[1]

It appears then that the period of the Schooley baselevel was of later date than the post-Triassic tilting, that it was of earlier date than the oldest of the strata that lie upon it in the New Brunswick district, and according to recent determinations these are of low Cretaceous or perhaps late Jurassic time. From this it may be concluded that the Schooley baselevel attitude was taken and maintained during Jurassic time; and that the baselevelling of the older Highland mountains into the old Highland peneplain was well advanced in the same period.

19. *Character of deposits overlying the Schooley peneplain.* The southeastward extension of the Schooley peneplain may be followed beneath the unconformably overlying Cretaceous beds;[2] and from this we must conclude that at least this portion of the plain suffered some depression after its baselevelling and before its elevation to its present altitude. This forms a subdivision of the Schooley cycle. The depression occurred after the deep denudation of the Triassic shaly area, for the northwestern margin of the overlying

[1] Compare Willis, Nat. Geogr. Mag., I, 1889, 299.
[2] McGee's Potomac formation is here included with the Cretaceous.

beds appears as an essentially straight line on the peneplain of today, and hence their foundation must have been a peneplain. But it is very probable that the area of the Highland crystalline rocks was not so soon worn down; these rocks are much harder than the shales and most of the sandstones of the Newark belt, and when the latter were reduced to their lowest topographic terms, the former may still have shown hills of considerable height. But the denudation of the Highlands continued during all the time of Cretaceous deposition, and this great interval following on the previous one appears to have been sufficient for the production of the Schooley peneplain even over the area of the hard crystalline rocks.

If the southeastern part of the Schooley peneplain were a platform of marine denudation, the lowest of the superposed beds would be made of fragments derived from the closely adjacent landward part of the plain; but numerous exposures in the clay pits about Amboy have demonstrated that the lowest members of the Cretaceous series, even where lying directly on the red shales of the Triassic formation, contain very few fragments of red shale, and are in great part derived from some other source. Its sands and white quartz pebbles might certainly have come from the Highlands. This confirms the idea that the Highland plain was of subaërial origin. Its Atlantic shore-line must have stood southeast of New Brunswick and Amboy at least until the relatively soft Triassic beds were baselevelled; then a small submergence would cause so rapid a transgression of the sea over the land to the northwestward that the shore waves would not remain long enough at any point to accomplish much work at the bottom; after the submergence, the shore line would probably be found west of the Triassic area on the edge of the hard crystalline rocks, whose reduction to baselevel was slower. The fine waste from the shore might supply the sands and marls of the Cretaceous beds with little admixture from the red shales on which the beds were deposited.[1]

All this accords better with the subaërial origin of the Highland plain, above adopted, than with its submarine origin.

[1]The absence of the fragments of shale in the Cretaceous beds is so nearly complete that it has been suggested that the land from which they were derived lay to the southeast of the present coast, and has since then sunk out of sight (Geol. N. J., Report on Clay Deposits, 1878, 30). But the bottom clay beds do contain some fragments of red shale (*id.*, 40, 41, 43, 162, 168), and the explanation given above seems to us more in accordance with the geographic development of New Jersey and with the general geologic history of the Atlantic slope.

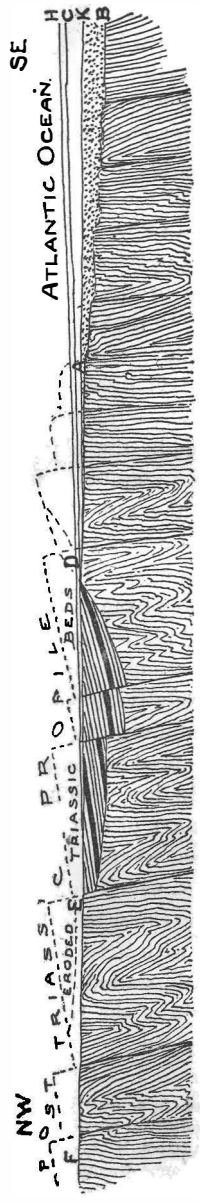

FIG. 4.

This may be made plainer by reference to fig. 4,[1] which gives a general northwest-southeast section of the region. The profile that would have resulted from the post-Triassic monoclinal faulting and tilting without erosion may be typified by the uppermost dotted outline. The ocean then stood at the Schooley baselevel, AC, with the shore at A. Long continued erosion during a stand of the land at about this position reduced the surface to the Schooley baselevel plain, FED, the shore waves having in the meantime eaten into the land from A to D; the land waste is transferred to the ocean bottom A B K. The soft Triassic portion, DE, of the old plain was worn down sooner and smoother than the hard crystalline portion EF. At about the end of Jurassic time, the old plain was somewhat depressed, especially to the southeast; the ocean level rose from C to H, and the shore line was thereby carried inland from D to E. The rapid transgression of the sea over the smooth plain, DE, did not allow the waves time to gather much Triassic material for the sediments that were formed; but when the advance of the shore line was checked by reaching the higher ground at E, marls and sands were supplied in moderate quantity from the low hilly country of slowly disintegrating crystalline rocks. These form the relatively thin Cretaceous deposits that were spread over the new sea-bottom, EDK, thin towards their shoreward margin, but thicker in deeper water. It is likely that there were minor oscillations of sea

[1]The location of this section and of several other diagrams is given in fig. 8,

level and of shore line during Cretaceous time, but the changes do not appear to affect the present topography of the country. During all this time, the more resistant crystalline rocks were worn lower and lower, and so the almost completion of the old Schooley base-level plain in Cretaceous time followed the good beginning made in Jurassic time.

Since first reaching the above conclusion, McGee's articles already referred to[1] have given us information of an oscillation of level that took place after the early wearing down of the Highlands had been well advanced. It was in the sense of an elevation during which narrow valleys of moderate depth, from one to two hundred feet, were cut to be filled again when depression allowed the accumulation of the lowest member of the superposed series, the Potomac formation of this author. Another elevation is recorded by the unconformity between these first deposits and the superposed members of the Cretaceous series. This was followed by a second depression. These facts were discovered by observation on the ground and are of manifest geologic importance; but they do not appear to be recorded in the present topography of the country, and were not discovered in our study of the maps. If of more recent date, they would be visibly recorded in the form of the surface; and it will be seen that as we take up the later chapters of the history of New Jersey, brief subdivisions of time marking slight oscillations of level attain importance. Similar subdivisions of ancient time would be called for by a full knowledge of past history; and the Schooley cycle must be regarded as containing many sub-cycles, not traceable in our method of study. In the general sequence of geographic development, our conclusions agree substantially with those reached by McGee.

20. *General drainage system in the Schooley cycle.* The introduction to our essay has explained what is meant by a geographic cycle. We must now consider the conditions of drainage during the cycle of development when the land stood at the Schooley baselevel, and the sub-cycle at the end of this division of time, when the land was somewhat depressed, allowing the transgression of the Cretaceous ocean. It does not appear practicable at present to inquire closely into the early stages of Highland drainage, for this would carry us into questions of geological structure on which there is not yet reached any general agreement. Our own feeling is that the early

[1] Amer. Journ. Sci., xxxv, 1888, 134, 135, 141.

stage of most of the Highland streams was in general of consequent arrangement, the stream courses being taken in accordance with the deformations that had in early Jurassic time tilted and faulted the Triassic beds and the subjacent and adjacent crystallines, briefly outlined in paragraph 13. The reasons for this belief are drawn as much from the history of the Triassic in the Connecticut valley[1] as from New Jersey, and will not be considered here. Whatever the early stages were, it is very probable that in late Schooley time, when the land was worn low, the streams had lost many of their original courses in the process of mutual adjustment as explained by Löwl, and were thus more dependent on internal structure than on original deformation. The streams in their old age must have flowed along the strike of the soft beds for the greater part of their course, escaping to the sea by not infrequent transverse streams, some of which, like the Pequannock,[2] may have been located on ancient fault lines ; and to streams thus well established a special name should be applied, inasmuch as no one of the names now current is fairly applicable. They may be called streams of mature adjustment.[3] The old streams of the Schooley plain surely were of this kind. Most of them must have finally settled down on the softer beds, and therefore then as now there must have been streams in the Kittatinny and Musconetcong valleys ; and these must have found outlet to the sea by transverse master streams, such as the Delaware. Thus many of our present streams may have had their antecedents in the Schooley cycle, from which they have descended by what we shall call "revival," caused by massive elevation of the country, as will be further considered below.

Whatever may have been the drainage of the Triassic portion of the old baselevel plain in the Schooley cycle does not now appear, for as has been indicated in the section on the geological date of the Schooley cycle, after this portion of the plain had been baselevelled, it was moderately depressed beneath the sea of Cretaceous time and buried in Cretaceous sediments. The stream courses of the Schooley cycle on the Triassic area were thus extinguished. This will be seen to be of importance when the development of the central plain in the next cycle is considered.

[1] Amer. Journ. Sci., XXXVII, 1889, 432. [2] Geol. N. J., 1886, 122.
[3] Nat. Geogr. Mag., I, 1889, 206.

THE CENTRAL PLAIN AND THE HIGHLAND VALLEYS.

21. *Elevation of the Schooley peneplain and its consequences.* We now enter a later cycle in the development of the state. The lowlands, which were so broadly worn in Jurassic and Cretaceous time on the Schooley baselevel and partly sealed over along their coastward margin with Cretaceous sediments, are now no longer lowlands, but have at sometime in the past been elevated; and wide valleys and lowlands of a second order have been opened in their formerly uniform surface. The geographic cycle in which these newer valleys and lowlands have been produced is now to be investigated. Certain general considerations may precede the special study of the case. We know that while the old Schooley baselevel peneplain has been elevated, it was not necessarily raised at once from its original to its present position; it may have, for a time, resided at some other altitude, perhaps at an intermediate height between its former and its present stand; and the present position of the land may have been assumed only after a second or third change of elevation. Again, if the land has stood at any altitude intermediate between the Schooley baselevel and the present for a considerable time, there should be topographic indication of it in the occurrence of topographic forms developed with respect to the position referred to. Finally, forms of this kind will be most apparent in the region of the softest rocks, for there the rate of development is most rapid.

We therefore now take the area of the weak Triassic and Cretaceous formations as the region for first examination. It is as proper to select this district in the present case while we are looking for the signs of relatively recent geographic development, as it was to take the area of the hard crystalline rocks of the Highlands in searching for records of a long past time.

22. *The Central Triassic and Cretaceous plain on the Somerville baselevel.* The interstream surface of the Triassic lowlands where traversed by the railroads west and southwest of Bound Brook are, clearly enough, dissected portions of a once continuous plain of moderate elevation, but high enough for the streams to sink distinct channels below it. The same process of reasoning as that employed in studying the old Highland peneplain leads to the conclusion that this Triassic plain marks an old baselevel; it is not a constructional surface, in sympathy with the rocks below, for the red

shales all dip at a moderate angle northwestward or thereabouts. It is, indeed, a more recent and more evident baselevel plain than that of the Highland plateaus. We have given it the name of the Central plain from its position in the state. The baselevel, with references to which it was denuded, may be called the Somerville baselevel, from the excellent development of the plain in the neighborhood of that town.

The Central plain is developed with considerable distinctness over most of the Triassic formation, where the soft shales have been quickly degraded from the Schooley baselevel. On crossing the Delaware to Pennsylvania at Yardley by the Bound Brook railroad, the broad fields that stretch far and wide at corresponding heights on either side of the Delaware are conspicuous illustrations of the surface of this extensive plain, showing that it is not limited to New Jersey. Thence northeastward, it forms the general surface of the lowlands between the trap ridges, until its smoothness is concealed by the addition of the morainic hills between Plainfield and Elizabeth. Along the Pennsylvania railroad it is almost unbroken from Princeton nearly to New Brunswick, being developed here on the lower strata of the Cretaceous formation. Farther southeastward, it is continuous for some distance, as along the railroad from Monmouth Junction, for example, almost to Jamesburg; but there it is much broken, and further on it is difficult to trace; southwestward, along the Delaware, it is trenched by streams, and its higher parts are much broken.

The northern extension of the plain into the glaciated area has not been closely examined.

The production of the Central plain on the Somerville baselevel illustrates to a nicety the different rates of development of a plain on rocks of different hardness. In the region of the crystalline rocks, the Somerville plain is not perceptible, unless in the limestone valleys; and even there it is altogether subordinate to the great mass of the little broken plateaus on either side. In the Triassic region, the greater part of the rocks are soft enough to allow the Central plain to take on good form; but there are portions of the Triassic mass that are hard enough to retain in good preservation remnants of the Schooley peneplain, namely, the trap ridges and the Hunterdon plateau of hard sandstone; the former are so hard as to form long, continuous ridges of even height, whose value in restoring the Schooley plain has been recognized. In the Cre-

taceous portion of the Central plain, even a greater share of the beds are soft enough to have been worn down to baselevel; and the only parts that have withstood this reduction are certain loosely cemented conglomerates and sandstones, associated with the green sands, which still seem to stand above the general level of the plain that surrounds them. They appear in a range of disconnected hills from Navesink southwestward; Pine Hill near Perrineville, at the head of the Millstone river, is of this class. It is in a country of remnants like these, especially when the region is complicated by the erosion of a later cycle still, that we find the greatest difficulty in tracing out ancient plains of denudation, and hence the restoration of the Somerville plain in the southeastern part of the state is at present uncertain.

Inasmuch as the above mentioned Cretaceous hills remain on the seaward part of this plain, and as it extends with about as much distinctness back of Rocky Hill and Sourland mountain as in front of them, we have concluded that it is a product of subaërial and not of submarine erosion.

23. *Date of the Somerville cycle.* The Central plain is manifestly of younger date than the Schooley plain, for the former is excavated below the surface of the latter. Baselevelling has been accomplished at the Somerville level only on the softest rocks. The Highlands were subjected to erosion during the same period and yet were only channelled by deep valleys with strong sloping sides; but the soft Cretaceous and Triassic beds were less successful in resisting erosion and hence were reduced so low as to form broad-open lowlands, broken chiefly by the trap ridges, whose crests retain something of the Highland altitude, as already described. The Somerville attitude was therefore maintained for a considerable period, but for by no means so long a time as the Schooley cycle endured. Finally, since the Central plain was lifted, the streams have accomplished only a small share of the new work offered them; post-Somerville time has not been nearly so long as Somerville time. The moraine on the northeastern part of the plain has not been nearly as much eroded as the plain itself. These statements may be summarized as follows: the Somerville baselevel was maintained for a considerable part of post-Cretaceous, that is of Tertiary time; the elevation that put an end to the development of the plain with reference to this baselevel took place in late

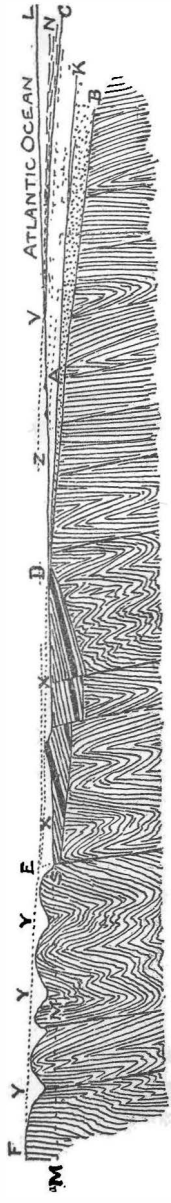

FIG. 5.

Tertiary time, and the valleys excavated in it were well advanced toward their present stage by the time of the glacial period.[1]

These changes from the Schooley peneplain may be more clearly conceived by comparing fig. 4 with fig. 5. The restored Schooley peneplain is *FED*. The soft limestones of the crystalline region *FE* are worn down to valleys *YY;* the weak Cretaceous beds *EDV* are stripped off for many miles from their ancient western edge *E* and are worn down low, except where a few harder beds hold out a little way against the forces of destruction; and the soft Triassic shales thus laid bare are opened out into lowlands, *XX*, between the hard trap sheets which still hold their crest lines near the surface of the Schooley plain. The material eroded below the surface of the Schooley peneplain, *FED*, and its partial cover, *EDV*, has been transferred to the ocean floor, *VCN*, where it probably forms those Tertiary beds which are not represented within New Jersey.

24. *Somerville cycle of drainage in the Highlands and on the Central Plain.* A deductive consideration of the origin of valleys gives reason for suspecting that the valleys by which the drainage of the Somerville cycle was carried on were of two kinds: one originating on that part of the Schooley peneplain that was never transgressed by Cretaceous beds; the other originating on the Cretaceous cover that overlapped the southeastern part of the peneplain.

[1] In this connection, the reader should consult McGee's study of the Columbia formation, in which the production and the elevation of this and other baselevelled areas are correlated with the first glacial epoch, *l. c.*, 376, 465.

Consider first the valleys formed on that part of the peneplain that was never covered by Cretaceous beds. Even the smoothest part of the uncovered crystalline rocks of the Highlands cannot have been reduced to absolute flatness at the end of the Schooley cycle; the restoration of their surface that we have attempted has shown that a residual relief of some distinctness probably remained before the present valleys were begun. The harder rocks resisted weathering more stubbornly while the softer ones were worn down to the lowest level, and this difference must have been maintained, though with decreasing distinctness, to the end. Just before the elevation of the Highlands that we are about to consider, the streams must have wandered sluggishly with almost imperceptible slope along broad lowlands of northeast and southwest trend, between faint dividing swells of land of the same direction. Many such longitudinal streams would find escape southeastward in a single transverse master stream, after the fashion of old mountain drainage in general. When the whole area was lifted and tilted to the southeast, the sluggish streams were revived and entered a new cycle of their long life. The smaller streams followed the lead of their masters, but without changing their position, although the tilting of the old plain might in some cases reverse their direction of flow. All would be in accord with the slope of the country that they drained, but as the slope was in most cases the residual of the relief of the old plain and not necessarily in accord with any ancient constructional slope, the streams should not be called "consequent" in the meaning of that word, as it was first employed by Powell. Whatever their origin on the ancient plain, they are now simply "revived."

The case would be different with that part of the old Schooley plain that had been submerged under the shallow Cretaceous sea and that now rose with the Cretaceous cover on its back. Here the land, as it rose from beneath the waters, would appear as a smooth surface, with gentle seaward slope; and the streams that ran out across it from the crystalline area, or that headed upon it, would follow its slope to the retreating ocean in the southeast. Then after a moderate amount of channel cutting, the unconformable underlying rocks would be discovered, and the streams persisting in the courses taken on the smooth Cretaceous surface, would of necessity traverse the under rocks with little reference to their structure. Valleys cut by such streams have been called "superimposed" by

Powell, "epigenetic" by Richthofen, and "inherited" by Shaler; and they may be recognized even after the cover from whose slope they inherited their epigenetic courses, has been entirely consumed. Their discrimination from the simpler revived valleys is a mat-

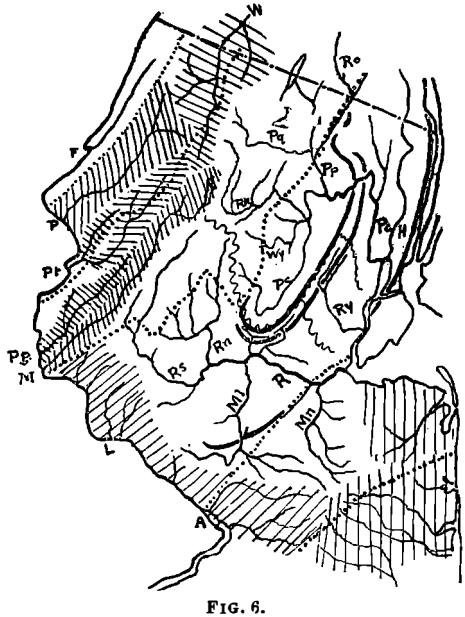

FIG. 6.

ter of interesting study, and is of manifest geologic as well as of geographic importance. Two special examples may be considered, in illustration of revived and superimposed streams.[1]

[1] Figure 6 presents an outline of the drainage areas of northern and central New Jersey, that may serve as an index to locate the various streams referred to here and in later pages. The abbreviations are as follows:

A. Assanpink.	P. Paulinskill.	Rn. Raritan, north branch.
F. Flat.	Pc. Passaic.	Rs. Raritan, south branch.
H. Hackensack.	Pg. Pohatcong.	Rk. Rockaway.
L. Lopatcong.	Pp. Pompton.	Ro. Ramapo.
M. Musconetcong.	Pq. Pequannock.	Ry. Rahway.
Ml. Millstone.	Pt. Pequest.	W. Wallkill.
Mn. Manalapan.	R. Raritan.	Wy. Whippany.

The rectangular course of the Delaware on the west and the fjorded channel of the Hudson on the east are too well known to require naming. The shading of lines in various directions indicates the several drainage basins, the linear forms of the Highland

25. *Revived Streams.* The Musconetcong, fig. 7,[1] follows a remarkably straight southwesterly course for forty miles, from its head in the centre of the Highland plateau to the Delaware a little below Easton. The branch that carries the overflow of Lake Hopatcong to the main stream is very likely a post-glacial tributary, and is omitted from the figure; with this exception the Musconetcong basin is hardly over five miles wide; all of its side streams are short, and nearly all of them have a direct course down the slopes of the enclosing mountains to the main stream. These mountains are of resistant gneisses and schists, while the longitudinal valley is excavated along a synclinal band of limestone. This example is the very ideal of a valley cut out by a revived stream whose course had been finally adjusted in a previous cycle to the structure of the old land that it channelled. Its relation to the long lost constructional form of the land cannot now be deciphered.

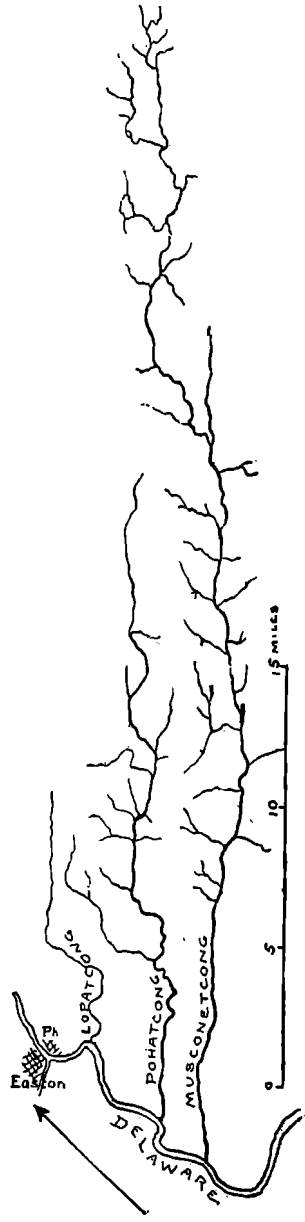

FIG. 7.

valleys being clearly apparent. The great area drained by the Raritan and the Passaic, with the little Rahway between them, is left unshaded.

The line of heavy dots from the Ramapo to the Musconetcong marks the southeastern border of the Highlands; a lighter dotted line from the Assanpink to the mouth of the Raritan is the approximate position of the fall-line; and a dotted line running southwest from the Atlantic coast indicates the vague northern border of the southern lowlands.

[1] Fig. 8 (see p. 398) is a guide to show the locations of fig. 7 and several others in their appropriate parts of the state.

The branches of such streams may sometimes be independent of any streams in the previous cycle and owe their existence simply to the backward gnawing of lateral gulleys and ravines; such would be called "subsequent" branches of revived streams.[1]

The control exerted on the form of the Highland valleys by the (apparent) synclinals of limestone that lie between (apparent) anticlinals of gneisses, etc., is finely illustrated at several points, perhaps nowhere better than in German valley, where the South Branch of the Raritan has its source. This valley is deep and wide as far as it is cut on limestone, but at its southern end the bottom of the limestone trough appears to have risen above the Somerville baselevel, and consequently the stream has here sunk a narrow gorge about five miles long in the gneiss. The exit from the constricted gorge to the broadly rolling Triassic plain at High Ridge is highly suggestive, when it is remembered that the difference of form between the gorge and the plain is not due to difference of age, but to difference in hardness and consequent difference in rate of wasting of their rocks.

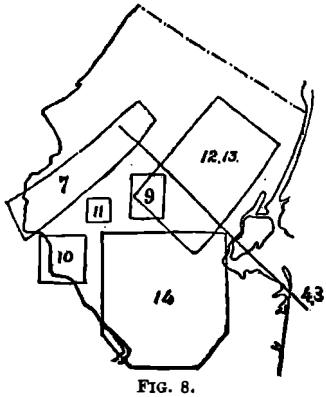

FIG. 8.

The Musconetcong in its lower course, about six miles from its junction with the Delaware, cuts into a longitudinal saddle of gneiss that separates the limestone troughs of its upper and lower course: this is also probably a disclosure made by the river in the Somerville cycle. The same may be said of the transverse escape of the Pequest from one longitudinal limestone valley to another, seven miles east of Belvidere; the location of the cross-cut was probably determined by a sag in the intervening anticlinal of gneiss which allowed the limestone here to wrap over the gneiss from one synclinal valley to the other. All these examples where the streams have cut down from limestone to a much harder rock, that would not otherwise be chosen for stream courses, may be regarded as "locally superimposed." The relative length of the Musconetcong and the Pohatcong, fig. 7, is

[1] Nat. Geogr. Mag., I, 1889, 207.

determined in the same way: the former is sunk on a long limestone belt; the latter on a much shorter one.

26. *Superimposed streams; the North Branch of the Raritan.* The course of this stream, figure 9,[1] appears to be as distinctly inherited from rock structures that have now disappeared as that of the Musconetcong is consequent on structures that still exist. The North Branch rises on one of the front masses of the Highlands and flows southerly through a deep oblique valley between Mendham and Peapack to the Triassic lowlands. On the way at Roxiticus, it crosses a belt of limestone that trends south-southwest, reaching the border of the Highlands north of Peapack. Now if the North Branch had been revived from a course dependent on the slope and structure of the elevated old Highland peneplain, it must surely have followed the relatively soft limestone out to the lowlands; but its indifference to this line of easy valley-cutting can be explained by the hypothesis of inheritance of its course from the slope of some now extinct overlying beds; and these must have been the Cretaceous. The Cretaceous beds must therefore be regarded as having once extended across the Triassic area and a little way over the margin of the crystalline rocks of the Highlands, from which they were derived.

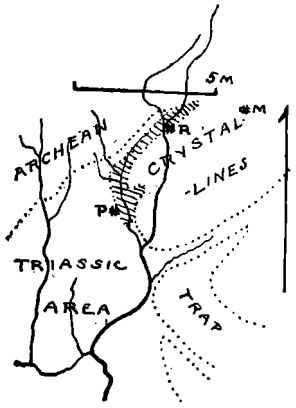

FIG. 9.

It might be suggested that the present course of the North Branch results from the backward gnawing of a "subsequent" stream that began as a ravine on the front of the Highland plateau and at last captured a back country stream and led it away from the limestone valley by the present deep gorge. There are two objections to this suggestion. In the first place, streams that are undoubtedly of subsequent origin, such as those that flow into the Ramapo from the front bluff of the Highlands near the northern border of the state, are much shorter than that part of the North Branch from

[1] Fig. 9 represents a portion of the North Branch of the Raritan, where it leaves the Highlands, near the southwestern hook of the Watchung crescent. The limestone belt that it traverses is shaded by transverse lines. The neighboring towns are P, Peapack; R, Roxiticus; M, Mendham.

the front of the Highlands to the limestone belt; therefore, it cannot be admitted that the North Branch has yet had time to cut its valley back as far as the limestone by the very slow process of headwater gnawing. In the second place, if there had been time enough for the suggested process, it would be the stream on the soft rock that would capture the headwaters of the other one whose outlet was on the harder rocks, and not *vice versa;* and indeed there is some possibility that this capture may yet be made. The divide on the limestone belt is at a height of 470 feet between the North Branch and the little tributary of the Peapack which follows the limestone out to the lowlands, and there joins the North Branch below the gorge. The North Branch is at an elevation of 360 feet on the limestone just below Roxiticus; and from here to the divide above mentioned is a distance of a mile. Where the Peacock joins the Raritan, the river is only 140 feet above the tide-level.

Some observers see evidence of a fracture in the gorge of the North Branch rather than an inheritance from an unconformably overlying formation;[1] and it cannot be absolutely denied that such may be the case. But the fault cannot be of large throw, for the transverse limestone valley is not dislocated on the line of the gorge; indeed there has not as yet been presented any complete evidence of the existence of fractures in this district of sufficient importance to outrank the limestone belts in giving location to matured river courses, in cases where either course was open to natural selection. If any fault exist in this neighborhood, it is more likely along the Archæan-Triassic boundary than in the line of the river. In general it appears that the more closely rivers are studied, the less attention they seem to pay to fault-lines; and the most probable conclusion in the present case does not appear to be in favor of accepting a fracture as a guide.

27. *Distribution of revived and inherited valleys in and near the Highlands.* Most of the streams of the Highlands are parallel to the general structure of the region and follows its softer rocks; and of the several transverse streams, none can give so clear indication of an inherited course as the North Branch of the Raritan. The Delaware needs no such explanation; it is essentially a revival of the master-stream that gave outlet to a large area of back

[1] Nason, Geol. Survey N. J., Ann. Rept., 1888, 43. Britton states that the Pequannock is located on a transverse fault. Ann. Rep., 1886, 122.

country drainage on the old peneplain. The Rockaway and the Pequannock are much smaller than the Delaware, but are sufficiently explained in a similar way; they flow southeast from the highest part of the Highlands and carry the waters of a few longitudinal streams with them. All of these are probably revivals of the Schooley cycle of drainage. Faults may have had in that or some still earlier cycle some share in locating these transverse streams; but this question has not been definitely settled. The irregular course of the Rockaway by Boonton is the result of drift obstructions in its simpler preglacial course, and need not be referred to an inheritance from the Cretaceous cover. But the Lockatong, fig. 10, a small branch of the Delaware, flowing across the sandstone plateau of West Hunterdon between Flemington and Frenchtown, can hardly be regarded as a simple revived stream; if such had been its history its headwaters must have escaped by Warford creek (*a*, fig. 10), on a short course along the strike of the beds to the neighboring master river, instead of crossing the beds for twice this distance. Indeed, this adjustment cannot be much longer delayed. The upper Lockatong runs over the plateau in a very shallow valley, and near the flat divide between it and Warford creek, the stream is at an elevation of 470 feet. The head of Warford creek is only a quarter of a mile away, and this stream falls 300 feet in its course of two miles and a quarter along the strike of a relatively weak stratum, while the Lockatong makes the same descent in about seven miles across the strike of harder strata.

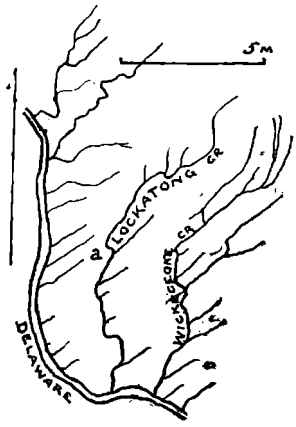

FIG. 10.

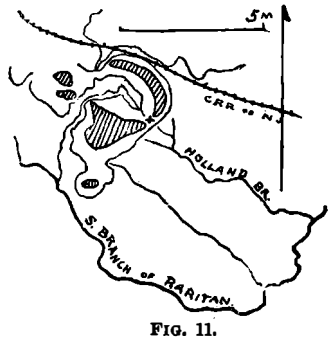

FIG. 11.

The notch, x, fig. 11, in the curve of Cushetunk mountain, one of the smaller trap ridges near the Highlands, where the wagon

road finds entrance to Round Valley from the southeast, is probably the abandoned site of a superimposed stream, whose beheaded remnant is Holland brook and whose headwaters have been led off westward to the Raritan by Prescott brook; the change that is in store for the Lockatong being here already accomplished.

On the other hand, the Ramapo, joining the Passaic near Pompton, is a good illustration of a stream whose course shows no dependence whatever on the Cretaceous cover; it follows the line between the Triassic and the Crystallines, gathering small branches from either side, and not only giving no sign of inheritance from some extinct structure, such as the North Branch of the Raritan showed so clearly, but flowing in as close accord with the present structure as the Musconetcong.

Taking these streams as guides, it may be concluded that the overlapping of the Cretaceous that resulted from the transgression of the Atlantic over the Schooley peneplain at the time of its slight depression, reached all across the Triassic formation in the middle and southwest side of the state, but not quite so far in the northeast. It undoubtedly oscillated back and forth many times about this line. The occurrence of inherited streams above the head of Chesapeake bay at some distance inland from the present margin of the Cretaceous cover,[1] and the general correlations allowed by the suppositions here brought forward, lend support to a conclusion that might otherwise be more easily questioned.

28. *Drainage of the Triassic area of the Central Plain.* The streams of the Triassic area generally do not give unequivocal evidence of inherited courses. They are on the one hand susceptible of explanation as the revived successors of old streams whose position was determined during the long development of the old Schooley peneplain; and on the other hand they might be regarded as superimposed from the drainage of the extinct Cretaceous cover. They are therefore not like the Lockatong and the Raritan in demanding the former inland extension of the Cretaceous formation over the Triassic area; but as that extension seems to be well proved, the best understanding of the Triassic drainage can be gained by regarding it as inherited. This conclusion seems to be more accordant than any other with the conditions of drainage farther south along our Atlantic slope.

[1] McGee, *l. c.* 133, 134. It is the Potomac formation that McGee regards as having here stretched over the peneplain.

Let us consider, therefore, the transverse streams which rose on the crystalline lowland peneplain in the latest part of Schooley time; they flowed across the strike of the rocks, that is, in a general way, to the southeast and entered the shallow Cretaceous sea somewhere near the line above indicated as marking the limit of its northwestward transgression; but later, as the whole region was elevated and the even sea-bottom became a land area of smooth surface and gentle southeastward slope, the transverse streams from the Highlands must have prolonged their courses in the same direction.

The examination of the present altitude of the remnants of the Schooley peneplain, in paragraphs 15 and 21, gave us reason to think that when this plain and its cover were lifted, the slope of the cover was not uniformly to the southeast; for the crest of the Palisades-Rocky Hill trap ridge is not now a level line, as it must very nearly have been on the Schooley peneplain; it is lowest from Amboy to New Brunswick, where the Cretaceous cover still buries it; and it rises northward and southwestward from these points. The unequal lifting of the Cretaceous sea-bottom, thus indicated, gives reason for the convergence of the Passaic and the Raritan from the north and west and explains the location of their passage across the Palisades-Rocky Hill sheet where it is still buried.

We cannot say how much additional length the streams from the Highlands gained as they crossed the newly lifted Cretaceous plain, but the process by which it was gained has a modern homologue in the growth of the streams that flow southeastward across the lowlands of southern New Jersey, where the uplift from the sea is so recent and so slight that the streams have not trenched their channels through the beds on which they took their birth. But in the Triassic portion of the Central plain under consideration, the elevation by which the rivers grew longer was long ago and the uplift was of considerable measure at the margin of the crystalline area, whence the surface of the Cretaceous beds sloped with distinct fall to the coast of that time, perhaps not far from the present coast line. Time, elevation and slope all being allowed, the lengthening streams from the Highlands have been able to trench their channels deep below the Cretaceous beds on which they took their birth and to reveal the unconformable underlying Triassic formation, which they traverse in superimposed courses. How far can we find evidence in favor of this sketch of their history? A peculiar portion of the Central plain may now be examined in this connection.

29. *Drainage of the Watchung Crescent.* Many of the streams that took courses across the Cretaceous cover of the submerged portion of the Schooley peneplain soon encountered the buried edges of hard trap ridges beneath the soft Cretaceous beds and from this time forward there was frequent opportunity for one stream to rob another and to become confirmed in this habit of robbery as time went on. To illustrate this, suppose the land were raised some two hundred feet higher than it now is. The Raritan would then soon encounter the Palisades-Rocky Hill trap sheet, fig. 1, under the Cretaceous beds below New Brunswick; being a large river, it would with relative quickness cut a deep gorge or gap through the resistant sheet. But the smaller Rahway river, encountering the same obstruction a little farther north, would be so slow in cutting down its gap that, before it was safely trenched close to base-level, some side branch of the Raritan, such as Bound Brook, would eat its way back and tap the headwaters of the Rahway and lead them away by the deeper passage prepared by the larger river. Thus strengthened, the Raritan would be still better enabled to perform the same piratic act on other rivers, and hence the number of streams that cross the trap sheet would be lessened and at last reduced to a small number at the time of mature adjustment. Is it not likely that some such process as this is to be considered in explaining the present course of the streams in the region of the curved Watchung mountains? In the discussion of this problem, we must refer to fig. 12, which is reduced from a tracing of the region from the relief map of the state.[1]

We have concluded that the Cretaceous cover once stretched over the Watchung ridges when they made but faint relief on the old Schooley peneplain. The streams born on the newly elevated and gently sloping Cretaceous cover cannot be thought to have taken courses as circuitous as these that now lead the drainage out from the Highlands. It is true that part of the present complexity is certainly due to obstructions by glacial drift: for example, the round-about outlet of Great Swamp is pretty surely determined by the great morainic barrier, stretching from Morristown to Chatham and traversing the Triassic lowland that had in Somerville time

[1] The Highland plateau in fig. 12 is separated from the Triassic lowland by a line of heavy dots. The fine dotted line is the contour of three hundred feet; the heavier broken line of five hundred feet. The several parts of the three trap ridges composing the Watchung mountains are marked I, II and III. Several cities and towns are abbreviated thus; B. Br., Bound Brook; Bn., Boonton; Mn., Morristown; N. Br., New Brunswick; Pat., Paterson.

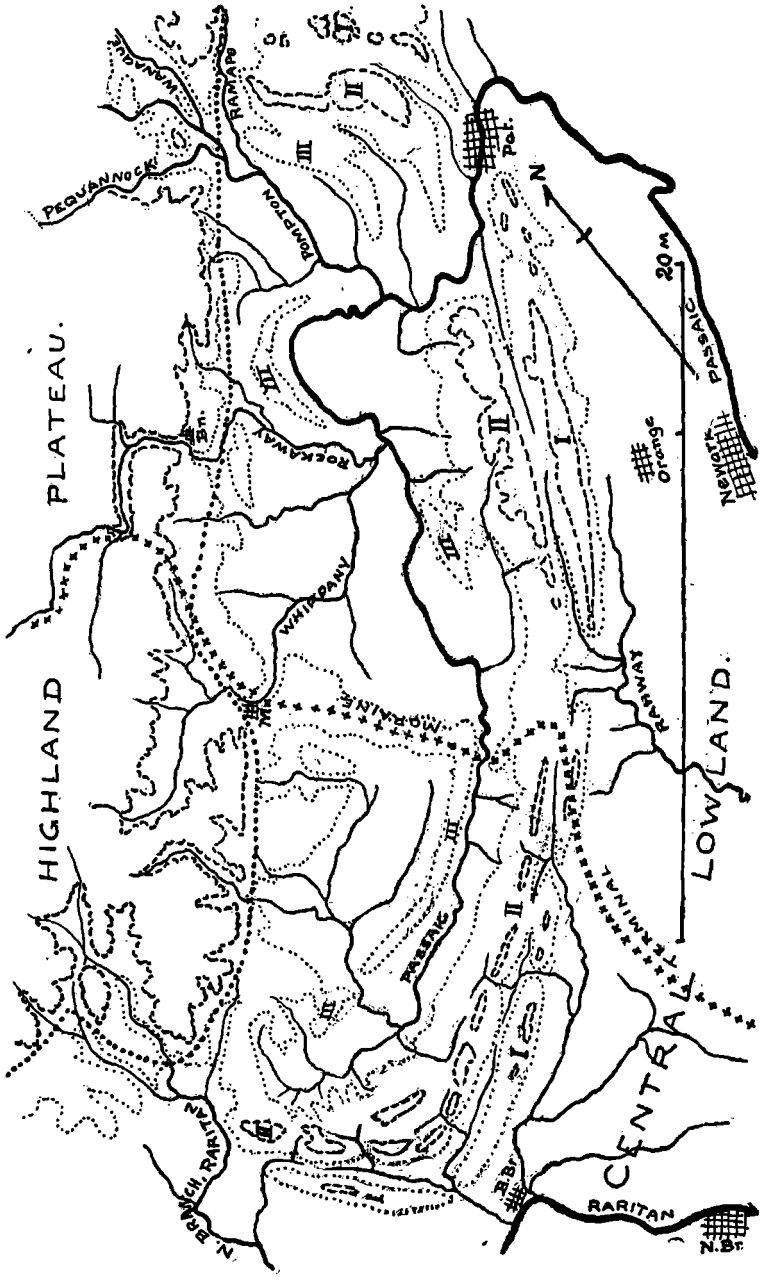
HIGHLAND PLATEAU.
CENTRAL LOWLAND.
PEQUANNOCK
RAMAPO
POMPTON
ROCKAWAY
WHIPPANY
MORRIS CANAL
PASSAIC
RARITAN
N. BRANCH RARITAN
Orange
Newark
Pat.
N.B.
20 M
I
II
III

FIG. 12.

been opened behind the Watchung ridges. But the general concentration of all the back country drainage at Paterson is not what would be expected of a system of rivers still persisting in courses taken on the Cretaceous surface sloping gently to the southeast. It might truly be suggested that the trap ridges were not entirely buried or that their residual relief on the Schooley peneplain was not entirely concealed by the Cretaceous cover; and, in that case, the passage of the Passaic at Paterson might mark the passage of some old stream of the Schooley cycle, where the drainage from the back country would naturally pass when the Cretaceous plain rose from the sea. Between this suggestion and the explanation by mature adjustment following superimposition as already indicated, we must choose by means of the accordance of one or the other hypothesis with such details of drainage as a careful examination of the country may disclose. The best test that can be applied in choosing between the two hypotheses is found in the location of water and wind gaps in the Watchung mountains. If they are not distributed at random, but manifest an arrangement that seems to be in accord with a systematic development of many superimposed streams, more confidence may be felt in one hypothesis than in the other.

The essential peculiarities of a drainage system that would be developed by the adjustments of superimposed streams would be the occurrence of wind gaps near the water gaps of the master streams, and the persistence of water gaps followed by small streams at a greater distance from the masters. This seems to be actually the case to a certain extent, as appears in fig. 13.[1]

The interpretation that we would give to the rivers of this area is as follows. The northern part was drained by a large transverse stream rising in the Highlands, *AA*, and composed of what are now

[1] Fig. 13 gives an hypothetical interpretation of the actual drainage arrangement indicated in fig. 12. The initial courses of several superimposed streams, chosen on the sloping surface of the elevated Cretaceous cover, are marked by waving lines, *AA*, *BB*, *CC*, *DD*, corresponding with parts of existing streams whose names are given in Fig. 12. The most important diverting stream is marked by a heavy, broken line, *EFG*. Wind gaps and a few divides in stable positions are marked *O*. Inverted streams have dots along side of their lines. Divides not yet pushed by the inverted streams to a stable position are marked □, and these are all in the south. The moraine is indicated by *XXX*, heavy where it acts most effectively as a divide. Streams whose courses have been much changed by a glacial drift are cross-lined, as the Passaic, *GKR*, and the Rockaway at Boonton, *M*, and below. Divides, where capture may yet be made, are marked △, as on the north branch of the Raritan, *H* (see paragraph 26) and on the old drift-filled course of the Rockaway, *L*. The terminology of diverting, diverted, inverted and beheaded streams is explained in Nat. Geogr. Mag., I, 1889, 210.

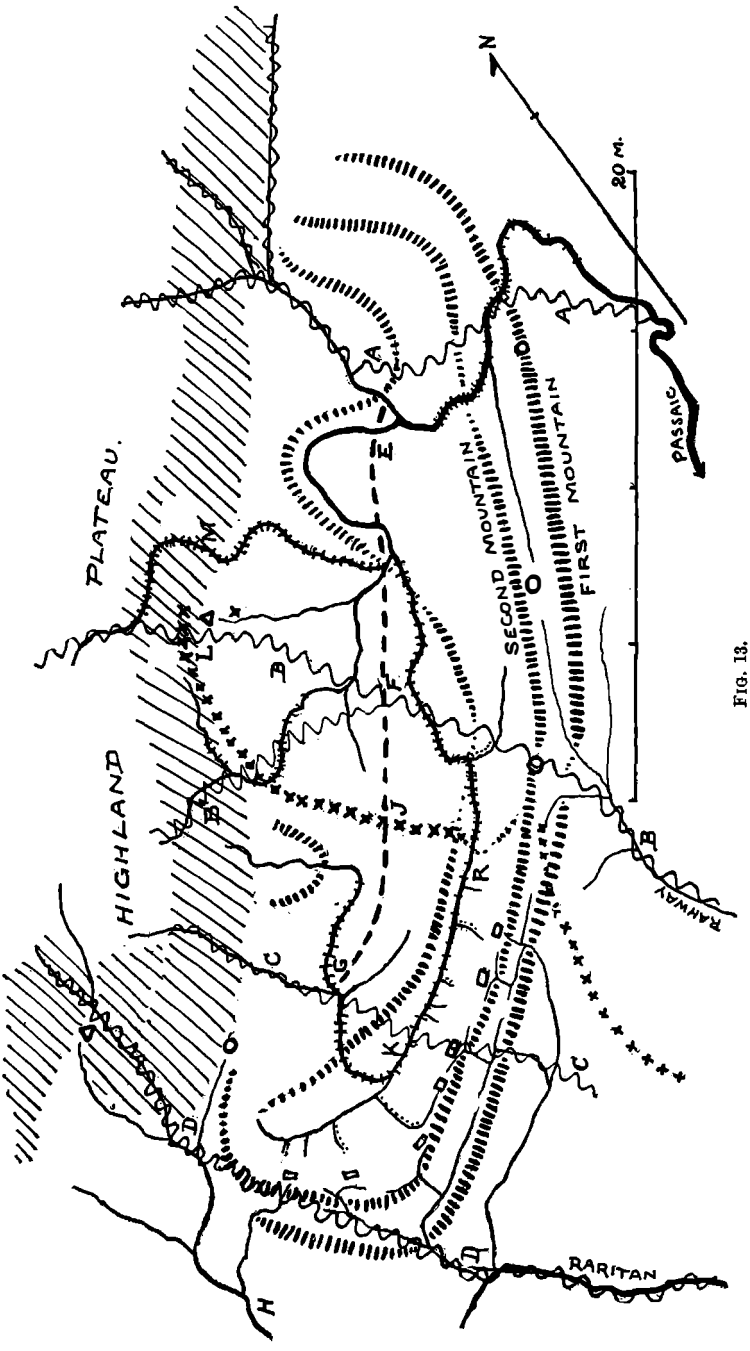
N
20 M.
PLATEAU.
HIGHLAND
SECOND MOUNTAIN
FIRST MOUNTAIN
PASSAIC
RAILWAY
RARITAN

FIG. 13.

called the Pequannock, Pompton and lower Passaic, with the Wanaque and Ramapo as branches, of revived origin in and near the Highlands, but superimposed farther east. The Rockaway-Rahway *BB*, was another stream of the same kind, draining across the middle of the Watchung crescent. The headwaters of the present Passaic perhaps constituted the upper portion of a third stream, *CC*, that found its lower part somewhere about Plainfield. All these streams flowed across the buried Triassic area upon its Cretaceous cover. Of the three named, the first has certainly now and probably then had the largest drainage basin, and the last had the smallest. The first would therefore, other things being equal, excel the other two in the rate of channel cutting, and thus would find opportunity to capture their headwaters at some point above any hard reef that they might encounter. The record of an early capture of this kind is seen in the Notch in the First mountain, just south of Paterson, now followed by the New York and Greenwood lake railroad. We cannot say what were the headwaters of the stream that once flowed here, but it is tolerably evident that after it had accomplished a good beginning towards cutting down a water gap, its headwaters were led away by the more successful river, which thereby became all the more able to compete with the remaining streams. Every time that the river thus captures the headwaters of its neighbor, it gains strength to acquire other headwaters; and we must therefore regard river capture of this kind as one of the normal lines of progress in river development. Possibly the Pequannock and Wanaque at first had independent courses across the trap ridges, and joined forces by one capturing the other, thus forming the Pompton; the Pompton then still further deepened the gap at Paterson; its side streams pushed away the lateral divides more rapidly than before, and thus the Rockaway was caught and led to the larger stream at *E*. It must be noticed that at this time the original Rockaway, *BB*, did not leave the Highlands at Boonton, *M*, but by the now drift-filled valley, *L*, farther south, whence we supposed it crossed the sandstone basin towards Summit, where its gaps were cut across the two trap ridges; thence forward it continued as the Rahway. It was probably tapped midway on its course, as at *F*, by a branch of the Pompton; the divide between the diverted and beheaded parts of the once continuous river slowly migrated eastward, until it took a stable position on the trap sheet of Second mountain; the water gap in this ridge thus became a wind

gap and is marked *O*, like several other stable divides that appear to have been adopted after the ancient capture of one stream by another; while the diminished lower part of the stream continued to the sea as the Rahway. The Passaic-Plainfield river, *CC*, was next captured at *G*, its divide between the lower beheaded and the upper diverted portions also at last migrating towards the Second mountain. But as the distance from the gap of the master stream at Paterson increases, its diverting branch, *EFJG*, has less favorable conditions for capture of the other streams; hence in the southern part of the Watchung crescent, there are still several small streams draining outward across both trap mountains, whose divides have not yet been driven to a stable position on Second mountain, as has happened in every case farther north. It is correspondence of this kind that lends color to the hypothesis of superimposition and adjustment that we offer; but whether it is the color of truth or not can hardly be decided at present. The diverted course of the upper Passaic was not in the valley, *KR*, that it now follows between the second and third trap ridges, but along the then open basin from Great Swamp, *G*, northeastward, past *J* to *F;* the present course of the river being determined by the heavy morainic barrier, *XXX*, stretching from Morristown to Chatham. This compelled the stream, *GJF*, to turn back and flow over the courses of several streams, *GKR*, that were presumably independent of one another in preglacial time. So with the middle course of the actual Passaic, *RE;* it is certainly much affected by drift, flowing through swamps for long distances, and it cannot be taken as a close indicator of the maturely adjusted stream by which the crescent was drained to the northeast in the Somerville cycle.

When the trap ridges were disclosed by the wearing away of the Cretaceous cover, it may be that some inequality in their thickness or some fractures may have exercised a control in locating some of the streams. For the two main sheets we have no indication of this, unless it be at the gap in First mountain, where the Rockaway-Rahway river, *BB*, is supposed to have crossed it. When standing on the south end of Orange mountain, as the outer ridge north of the gap is locally called, one may look to the south and see that there appears to be an imperfect alignment with the southern member, suggesting some dislocation or irregularity in the sheet; but the conclusion is not definite. At the same place, the greater depth of the gap in First than in Second mountain is also apparent and calls for explanation; for it is not easy to see how the beheaded

remnant of the former river could have cut so deep a gap in the front ridge. It is possible, however, that the inequality of depth is only apparent, and is really due to a heavy drift filling in the wind gap of the second ridge, where the moraine crosses it. This seems very likely.

Inequality of thickness in the lava sheets does not appear clearly in First and Second mountains, but it is probably characteristic of the third sheet, which is thinner than the others, and is worn down low in part of its length, so low as to suggest structural weakness rather than concentration of destructive processes. Its several parts have different local names; Long hill, Rikers' hill and Hook mountain.

The conception of the Highland plateau, as an old baselevel plain, elevated and partly cut away again, may now be recalled once more. Returning to one of the high points of view on the front of the Highlands, and in imagination filling up again the Highland valleys and the Triassic lowlands to the general level of the crystalline plateaus and trap ridges as described in paragraph 15, we must now stretch the Cretaceous cover over the Triassic area to the margin of the crystalline Highland plain, a cover formed of materials washed from the inner non-submerged portion of the Highlands. From this as the initial condition of the Somerville cycle, the greater part of our existing geography appears to be developed.

30. *Drainage of the Uinta Mountains of Utah.* It thus appears that while the present Watchung drainage is in greatest part accordant with the structure of the district, it is also in a small way characterized by such significant discordances that its origin is best referred to superimposition. As a corollary of this, it follows that superimposed drainage is to be recognized by its full discordance with structure only during its youth, and that in its more mature age it may come to be almost or fully accordant, thus simulating consequent drainage. Antecedent drainage may in the same way lose its initial discordances. With this in mind, we have looked over Powell's account of the drainage of the Uinta mountains, where he first proposed the terms antecedent, consequent and superimposed,[1] the idea embraced in the latter term having been previously stated by Marvine.[2] The drainage of the Uinta mountains is concluded to be chiefly antecedent; not only the Green river being thus regarded,

[1] Expl. Colorado River of the West, 1875, 163, 166. Geology of the Uinta mountains, 1876, 12.

[2] Hayden's Surveys, Report for 1873 (1874), 144.

but also a number of smaller streams which join it. The reasons given for this conclusion are that the location of the streams is not accordant with the initial structural surface of the range, for a number of the branches of the river join it by monoclinal instead of synclinal valleys. But inasmuch as the region is one of enormous denudation, it does not seem unlikely that such monoclinal side valleys may be adjusted courses of consequent or superimposed streams, instead of persistent courses of antecedent streams; for the process of adjustment by which hard courses are deserted for easier ones was not then considered. But this indoor correction of an outdoor conclusion is suggested only in a tentative way.

31. *The Kittatinny Valley.* While the Central plain was developed on the soft Triassic and Cretaceous beds, and the valleys of the Highlands were opened by their revived streams, the broad area of limestones and slates between the Highlands and the heavy outcrop of Medina sandstone near the northwestern line of the state was denuded into a broad lowland known as Kittatinny valley: all this being the work of the Somerville cycle. If the observer climb to the commanding summit of Jenny Jump mountain, one of the outlying masses on the northwest side of the Highlands, near the Delaware, he may see a great length of the Kittatinny valley lowland in New Jersey and Pennsylvania, bounded on the west by Kittatinny mountain. The slates, that are associated with the limestones on the northwestern side of the valley, are more resistant and form hills not yet reduced to the Somerville baselevel; they are thus homologues of the hills formed on the harder Cretaceous beds on the southeastern part of the Central plain. In the same way, the even crest of Kittatinny mountain corresponds with the even crests of the Watchung ridges, still preserving the general elevation of the Schooley peneplain. The extension of this peneplain into Pennsylvania and its relation to the development of valleys in that state have been elsewhere discussed by the senior author.[1]

The Millstone Deformation of the Central Plain.

32. *Present attitude of Central Plain.* The Central plain has been unevenly lifted from the position that it held during its development, for it is not now so low or so level as it was then. Its present altitude is naturally the result of the summation of all the small

[1] The rivers and valleys of Pennsylvania. Nat. Geogr. Mag., I, 183–253.

movements it has suffered since it was formed; but we shall not now attempt to detect the individual elevations and depressions of which the total is composed; the geological evidence by which they may be proved is not yet all worked out, and with exceptions that will be mentioned in later paragraphs, the minor oscillations that have probably occurred have been without geographic consequences recognizable on the maps.[1]

The plain is lowest about Bound Brook, where its interstream surface averages only about seventy feet over present sea-level; it rises thence to the south, and along the back of Rocky Hill reaches one hundred and twenty to one hundred and thirty feet; from Somerville towards Flemington and White House, it rises from one hundred to two hundred feet; the latter altitude is maintained near the Delaware by Lambertville and above Trenton. From Trenton across the country to New Brunswick, there is another low strip ranging from eighty to a hundred feet; farther south about Hightstown, the surface rises to one hundred and thirty or one hundred and forty feet; near the Atlantic-Delaware divide, the plain is two hundred feet above the sea. It appears from this that the Central plain is no longer a level or continuous surface. It has been tilted and dislocated, its two parts dipping at a gentle angle to the north or northwest; and the step by which they are separated marks the location of the fall-line dislocation, as described most fully recently by McGee, of which more below. It seems to be necessary to regard the two parts into which the Central plain is thus divided as formerly joining in a continuous surface; for they are both baselevelled plains of post-Cretaceous erosion, and they have both been channelled by comparable amounts in later time. If the two parts of the country had held their present relative positions while the lower part was baselevelled, as it is so perfectly about Monmouth Junction, it is impossible that the upper portion could have retained as much of its interstream surface unworn as appears around Princeton. The two parts have been baselevelled together; their unequal heights now indicate subsequent unequal elevation. As the fall-line dislocation follows close along the boundary between the Triassic and Cretaceous formations, the two parts into which the Central plain is now divided may be named after these geological areas.

[1]The deltas and shore line deposits of the Columbia formation described by McGee, not being represented by special colors on the geological map of New Jersey, are not here considered.

Although the dislocation may at first sight seem somewhat surprising, it does not appear to differ from many well known facts. The forces of dislocation know nothing about baselevelled regions: they act where the resistance of the whole mass subject to them is least, and it is indifferent to them whether the plane of action outcrops on the surface of the constructionally level lava plains of southern Oregon or on the once baselevelled plains of central New Jersey. The result in either case is dislocation and tilting of what was before level and continuous.

Other portions of the lowlands produced in the Somerville cycle also give evidence of change of level. The Kittatinny valley-lowland has suffered elevation since it was reduced to a peneplain, for its interstream surfaces now stand at an altitude of four hundred or more feet. This is decidedly greater than the height of the corresponding surface of denudation in the Central plain about Bound Brook, but it has not yet been possible to determine whether the inequality is due to warping or to faulting. The Highland valleys are not broad enough to give definite record of the position of the Somerville baselevel on the contoured maps, but a brief sight of them from a railroad excursion gave encouragement to think that deliberate examination on the ground might solve the problem; the streams appear to have sunk young trenches below the general valley bottom.

33. *Valleys of the Millstone cycle.* The elevation of the country from its Somerville attitude has revived the streams and carried them into a new cycle of work. The streams in well marked valleys, such as those of the Highlands, where Somerville time was not nearly sufficient to accomplish baselevelling, give no indication of any change from their Somerville courses; but, as suggested above, they seem in some cases to have trenched new channels in the flat-bottomed valleys of earlier (Somerville) date. This is much more apparent in the Kittatinny valley, where the Delaware flows in a steep-sided valley a hundred or more feet below the general valley-lowland, and its side streams trench the lowland as it has given them opportunity. The Lehigh from Easton to Bethlehem in Pennsylvania exhibits this relation with great clearness, and many other examples might be named.

The same thing appears in the Central plain: the traveller on the Pennsylvania railroad cannot fail to be impressed by the narrow cut of the Raritan at New Brunswick; or, if crossing the state

by the "new route," he must notice the little-stream valleys that interrupt the general interstream plain between Trenton and Bound Brook. These are all the product of the Millstone cycle. The valleys are of moderate width, and hence this cycle is not far advanced.

The depth to which a stream may cut its channel depends on the altitude of its drainage area above its baselevel. Lowlands can therefore never acquire the intensity of topographic relief that characterizes the maturer stage of highlands. It is for this reason that the valleys that have been cut in different parts of the Central plain are of different depths. The valleys of the Delaware and Lehigh, above mentioned, are much deeper than the valley of the Raritan at New Brunswick; not because the former are older, but because they have had a higher mass in which their trenches were to be cut. So again with the Raritan at New Brunswick and at Bound Brook; the stream has insignificant fall from one place to the other, but its trench deepens from fifty feet below the Central plain at Bound Brook to a hundred and thirty feet below it at New Brunswick, because the surface that it trenches rises in that direction. The Millstone river, fig. 14,[1] after which the cycle under discussion is named, is even more interesting in this respect. Its various head branches rise in the Cretaceous plain, where their trenches are sunk from twenty to forty feet below the general interstream surface; the streams thus cross the depressed portion of the plain south of Princeton, and then uniting into a single river they enter the higher part of the plain northwest of the fall-line, here cutting a valley a hundred feet deeper than before, because the plain is now a hundred feet higher; but the depth decreases as the river crosses the Triassic plain to its northwestern lower side, and in the neighborhood of the town of Millstone, the stream is about fifty feet below the plain, like the Raritan which the Millstone there joins. The headwaters of the Millstone have not yet had time to sink their channels close to baselevel; for their discharge to the sea is by a long roundabout course by which their slope is decreased; and on the way their outlet stream crosses the hard trap sheet of Rocky Hill, where the deepening of the channel is retarded. In contrast with the delayed deepening of these head-

[1] Fig. 14 includes the drainage of the Millstone river: BB, Bound Brook; C, Clarksburg; J, Jamesburg; N. Br., New Brunswick; Pr., Princeton; S, Somerville. The fall line is dotted from Trenton to Lawrence Brook.

waters, we see the strong channelling of neighboring streams like Lawrence brook, that reach the sea by short courses over soft rock, of which more will be said below.

34. *Persistent and reversed streams of the Millstone cycle.* Most

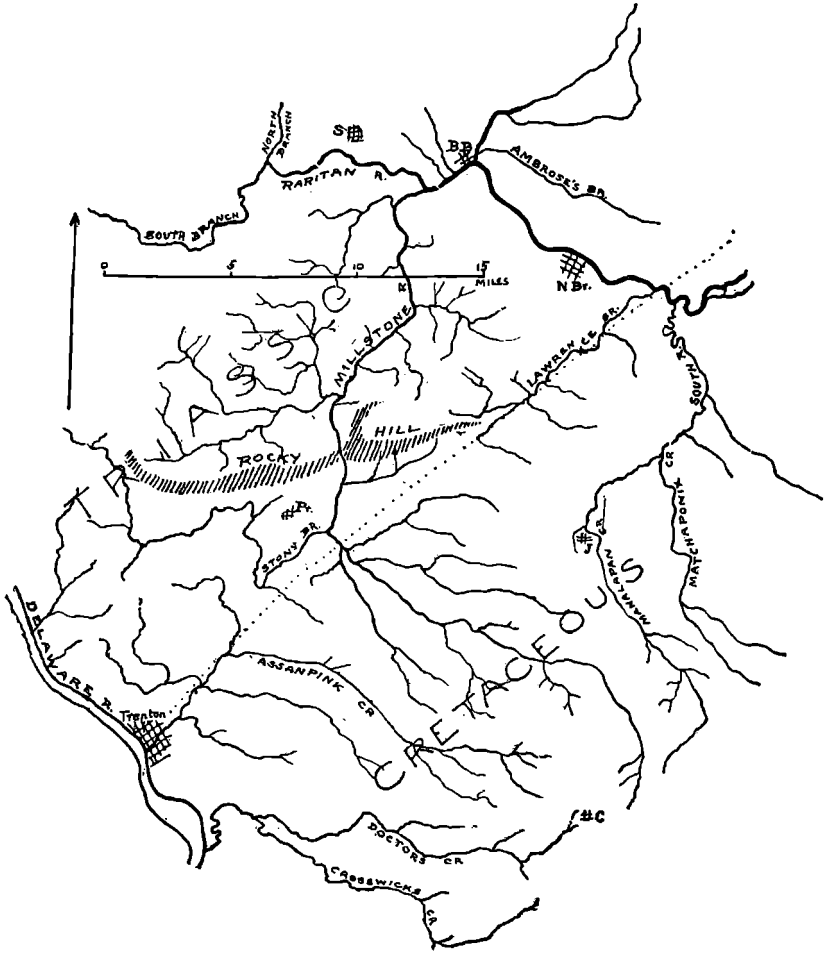

FIG. 14.

of the streams that have trenched the Central plain, the Highland valleys or the Kittatinny valley-lowland in the Millstone cycle exhibit no peculiarity of location or direction that cannot be satisfactorily referred to the Somerville or even to the Schooley cycle.

The streams in the Highland valleys are well hemmed in, and their present trenches are simply the product of Millstone revival on the Somerville valley bottoms, just as the Somerville valleys resulted from the revival of the streams on the Schooley peneplain. The same appears to be true of the Delaware and its side streams in the Kittatinny valley-lowland. The Raritan also seems to retain in good measure its Somerville course, for it runs against the slope of the plain from Bound Brook to New Brunswick after the fashion of antecedent streams; but its traverse of the lower part of the plain near Bound Brook suggests that the Millstone tilting of the plain may have turned it somewhat to this special location.

On the other hand, several smaller streams manifest in their directions so distinct an accordance with the slope that has been given to the Central plain since its formation, that they must be regarded as consequent upon the slope. Ambrose's brook, fig. 14, is an excellent example of this kind: it lies two or three miles northeast of the Raritan where the latter runs from Bound Brook to New Brunswick; but while the larger stream flows southeast against the slope of the plain, the smaller one flows northwest with the slope. A number of streams to the west of the Raritan are probably of similar origin.

But the most remarkable case of this kind is that of the Millstone. Here we have a river of some length, with a number of head branches, all flowing northwestward, as if they had been given that direction by the tilting of the Central plain. The same course is seen in the Rancocas, and in other smaller streams farther southwest, on the same Cretaceous portion of the Central plain. But the Millstone has not only this reversed course; it crosses the fall-line dislocation against its uplift; and in this it has no fellow as far as the fall-line has been traced.[1] The history of the case appears to be as follows.

35. *Reversal of the Millstone river.* All that is known of the processes of the Somerville cycle indicates that central New Jersey must then have acquired a drainage directed in general to the

[1] In McGee's maps of the fall-line displacement, Seventh Ann. Rep. U. S. Geol. Survey, Pls. LVII and LXVII, South river is also drawn as if crossing the fall-line against the heave before joining the Raritan; but it appears more probable that the prolongation of the main line of displacement runs as here drawn though perhaps with diminishing throw; and that the northeast-southwest course of South river is due to another, parallel and subordinate displacement. Farther south in Pennsylvania, Delaware, Maryland and Virginia, all the streams that cross the fall-line run from the northwest to the southeast.

southeast. The Cretaceous beds on which the drainage was first established have a southeastward dip in all cases; and indeed Professor Cook has shown that the dip of these beds is about equal to the present slope of the reconstructed Schooley peneplain in the Highland area.[1] The southeastward drainage is a general feature of our whole Atlantic coastal slope, and was probably thus introduced over its entire extent. There are two ways in which the streams of a region might be reversed from this prevailing direction. They might be reversed by capture, an inverted northwest course then being taken as the divide is pushed from the point of capture to its final stable position, and we have examples of such inversions on the inner slopes of Watchung mountains; or they might be reversed by a tilting of their drainage area, as appears to be the case in Ambrose's brook above named.

It is impossible to explain the northwestward course of the Millstone by regarding it as the inverted middle portion of a southeastward river, whose northern head-waters were captured by the Raritan. In that case, the inverted stream must have had its head on the north side of the gap in Rocky Hill, near Princeton; the rest of the original southeastward river would continue from the south side of the gap in its normal direction as a beheaded stream: the gap would be a wind gap, not a water gap.

The other explanation seems more acceptable. Conceive the Millstone as one of many southeastward streams, born on the Cretaceous cover at the beginning of the Somerville cycle. It was unfortunate enough to sink on the Rocky Hill trap sheet, by which the down-cutting of its head-waters was retarded; some of its head streams may then have been captured by the more fortunate Raritan, which happened to choose a soft course on its way to the sea. But we must suppose that enough drainage area was left to the Millstone north of Rocky Hill for it to cut down its gap in this ridge close to baselevel before the end of the Somerville cycle. This is not unreasonable; for the perfection of the baselevelling of the Central Plain could not have been attained before a good sized stream would have cut a deep channel even across a hard stratum. Now it is precisely in the old age of a stream, when its gradient is small, that a moderate tilting may suffice to reverse its slope and change its course. Hence the fully baselevelled channel

[1] Ann. Rep., 1883, 28. The Artesian water supply along the coast depends on this general southeastward dip. Ann. Rep., 1885, 109, 123.

of the Millstone river at the close of the Somerville cycle must have been very liable to reversal of slope if an active change of level then took place. There is no measure of the activity of such a change of level, save in its effects. The Millstone now flows in a direction that clearly indicates an active uplift and tilting at the close of the Somerville cycle, and hence the active uplift may be accepted. The highest elevation reached by the Central Plain and still retained by it is in its Cretaceous portion, in the neighborhood of Clarkesburg: here it is about two hundred feet above sea level. The change suffered by the Plain still farther southeast will be briefly considered in a later paragraph. The question here before us is whether such an uplift, perhaps coupled with slight actual depression toward Bound Brook, might not reverse the hypothetical southeastward course that the Millstone river is supposed to have had before. If the Central plain had not been dislocated, the reversal of the river would not be so difficult to believe; but when it is remembered that the river in its hypothetically reversed course had to cross the fall-line dislocation against the uplift, that is, from the thrown to the heaved side of the fault, one may still hesitate to accept an explanation so peculiar. Still, as far as can be seen, there is no other solution than this. The reversal probably occurred before the dislocation; and the dislocation at this point appears to have been slow and of moderate amount, for otherwise the Millstone headwaters would have found exit along the thrown margin of the fault, either southwest to the Delaware at Trenton or northeast to the Raritan below New Brunswick. Indeed, if the dislocation continue in the future, one or the other lateral escape of the Millstone headwaters is highly probable.

The case is interesting as an apparent example of a rare occurrence in the history of rivers. Few cases of the kind have been described.

36. *Deflection of the Delaware along the Fall-line Displacement.* The Delaware, like some other streams of great age that have been revived from the Schooley to the Somerville and from the Somerville to the Millstone cycle, follows an ancient course across the Kittatinny valley and the Highlands,[1] and a superimposed course inherited from the Cretaceous cover of the Triassic belt from about the edge of the Highlands to Trenton; but here it turns abruptly to the southwest. McGee has found explanation of this singular

[1] *Cf.* McGee, *l. c.*, 135.

deflection in the depression that accompanied the fall-line dislocation, and has shown that similar deflections characterize other rivers when they reach this important structural line.[1] This large river might easily have overcome the difficulties presented by the elevation of the southeastern part of the Central plain and have persevered against them, as the Raritan did; but it was led astray by the temptation offered in the depressed belt along the southwest, and thus New Jersey gained greatly in area if not in wealth. The deformation by which the Delaware and other large rivers were deflected was presumably greater and more rapid than that which the Millstone overcame.

Many streams of moderate size that enter the Delaware below Trenton from the southeast seem to have gained their present courses at the same time with the deflection of the Delaware, and with the reversal of the Millstone. The divide between many of these and the Atlantic streams is at present southeast of the outcrop of the more resistant Cretaceous beds; most of the Delaware streams have relatively short courses in sharply cut valleys to the Delaware, while the Atlantic streams have long gentle slopes in flat swampy valleys to the sea. The Rancocas is the chief exception to this statement. In such cases of headwater opposition of streams, there is practically no record of any migration of the divide that may have taken place toward the flatter slope.

37. *Shifting of divides in the Millstone cycle.* The adjustment of stream courses, and particularly the establishment of stable divides that was undertaken within the Watchung areas during the Somerville cycle, is still continued in the Millstone cycle. There is still possibility of the diversion of the upper North Branch of the Raritan to the limestone valley that it now traverses, or of the upper Lockatong to the little stream that may lead its headwaters to the Delaware along the strike of the beds that it now crosses. In addition to these, there are certain adjustments of drainage lines dependent on the conditions of the Millstone cycle alone. The most distinct of these are in the debatable area between the eastern branches of the upper Millstone and the branches of the Manalapan near and above Jamesburg. It is highly probable that some captures have been already made here; for there are several depressions in the prolonged lines of streams that have no explanation either in the structure or in the present drainage of the coun-

[1] Seventh Ann. Rep., U. S. Geol. Survey, 1888, 616.

try. For example, the low pass from Jamesburg northwestward to Pigeon swamp, and from Monmouth Junction northwest by the railroad to the gap in Rocky Hill. It may be supposed that the Manalapan once flowed along these depressions, and that it was captured at Jamesburg by South river and in Pigeon swamp by Lawrence brook; but much more work on the ground is needed before such suppositions need be accepted. No other place in the state offers so good an opportunity for investigations of this kind. The example of river piracy recently described by the senior author in eastern Pennsylvania[1] belongs with these cases in the Millstone cycle.

38. *Marine erosion of the Central Plain in the Millstone cycle.* The altitude given to the Cretaceous portion of the Central plain by the uplift that closed the Somerville cycle has been described as a gentle ascent southeastward from the fall-line: but the ascent ceases about the headwaters of the Millstone and Manalapan, and the surface continues with fairly uniform height for some distance further. Here the streams flow eastward; they have trenched the plain rather strongly and at places it is much broken up; but from the occurrence of sands and gravels in the broad valleys and from the appearance of steeper slopes on the seaward side of some of the hills, we have supposed that the ocean has had a share in the opening of this country, in some portion of what is here called Millstone time, when the land stood lower than at present; but how far this is the case cannot now be determined. It is interesting to notice in this connection that here for the first time do we find the shore waves responsible for determining an element in the topography of the state.[2] The Central plain appears to be purely a subaërial product as far eastward as it has been traced. The Triassic portion of the Schooley peneplain has been for good reasons regarded as of subaërial origin, although later buried under marine deposits. The Highland portion of the same peneplain and its extension far and wide into Pennsylvania fail of evenness by just such amounts as a plain of nearly ultimate land erosion should; and the intermediate strip, where the shore line oscillated during Cretaceous deposition, has not yet been identified as bearing marks of littoral erosion. We therefore suppose that except during the Cretaceous transgression and the much smaller invasion of the sea

[1] A river pirate. Science, XIII, 1889, 108.

[2] McGee's Columbia shore line, already referred to, is an exception to this statement.

now under consideration, the coast line of Old Jersey has stood farther east than the present margin of the Atlantic. In later times, submergence and transgression appear to have occurred at least once.

During the depression of the land, as mentioned above, the topography of the coastal margin of the region must have been much like that now presented in Chesapeake bay: an irregular shore line, on which the sea waves fretted and from which they carried sands and gravels and clays to be spread out a little farther seaward as late Tertiary or Quaternary strata. The actual shore line of this time has not yet been identified, and is therefore probably not well defined: it may have shifted from one level to another, nowhere enduring long.

39. *The Southern Lowland Plain.* A later subdivision of Millstone time saw the gravelly and sandy beds raised from the sea floor into the Lowland Plains of the southeastern and southern portion of the state; and since then, comparatively little work has been done. The elevation was distinctly greater in the south than in the north; and hence the plains increase in width in that direction. About Long Branch and farther north, they are hardly visible, unless in the valleys: here the sea is still at work not far from the line that it occupied while the southern plains were forming; here it has straightened out its shore line into a rather mature form. In the southern part of the state, there are occasional residual hills[1], of small size and moderate height; these seem to be remnants of beds not wholly destroyed either by subaërial or marine erosion, but the time of their deposit is considered to be post-Cretaceous and their deposition and erosion may imply oscillations of level not here considered. Between these hills, the streams wander over the broad plains in the simplest consequent fashion, merely flowing down the slopes offered them to the sea. They have cut only shallow valleys, and broad areas between them are untouched. East and West Plains in Burlington and Ocean counties are surfaces of this kind; they are barren, bare of trees ever since the country has been known, but low bushes and dwarf pines and oaks grow in places; an object as tall as a man can be seen here for many miles.[2] The contoured maps show local gradients of only five or ten feet to a mile. A slight depression has estuaried the mouths of the streams for a small distance all along the coast and up Delaware

[1] Geol. N. J., 1886, 133. [2] Geol. N. J. 1868, 78.

bay, and long sand bars or "beaches" have been built by the waves off shore.[1] The previous greater depression, by which the Yellow Gravel[2] or Columbia formation[3] was deposited and from which the land has recovered, has left small geographic record; gravelly deltas were formed at the mouths of the larger rivers; terraces and bars were left along the shore line; and stones and gravel sometimes twenty or more feet thick, were spread over the submerged part of the Central plain and Southern Lowland: for further account of which the student should refer to McGee's papers already often quoted.

40. *Effect of the Glacial Invasion.* Brief mention may be made of the numerous lakes within the glaciated area; of the mounds and ponds along the morainic belt; of the drowned lands along many streams; of the occasional changes in stream courses due to drift barriers; and of the washed drift that spreads over many extra-morainic valleys; but the reader can refer to the annual reports of the New Jersey survey for detailed information on these headings.[4] The temporary glacial lake within the Watchung crescent[5] also calls for mention, as its deltas and shore lines are delicate geographic features of to-day.

The most considerable change of river course by drift barrier is that of the Passaic already mentioned. The heavy morainic ridge from Morristown to Chatham stands athwart the pre-glacial valley; Great swamp now lies behind or south of this barrier, and the Passaic makes its escape by a roundabout course to the east. The Rockaway is also deflected from its ancient course by the moraine at Denville; it turns northward over a divide between two lateral valleys, and descends rapidly over rocky reefs past Boonton on its new course. Many other examples will in time be described.

41. *Review.* The details with which an essay of this character is necessarily encumbered make the clear presentation of its theme a difficult matter. The effort to shorten what is necessarily so long gives at times more definiteness of statement than is desirable in subjects that are still wide open to discussion; but certain facts appear to stand out clearly enough. The Highland plateau is an elevated and faintly tilted peneplain of denudation, dissected

[1] Geol. N. J. 1885, 72. [2] Merrill, Geol. N. J. 1886, 129. [3] McGee, *l. c.*, 367.
[4] Especially in the Reports for 1880, 14; 1884, 112.
[5] Annual Report, 1880, 63, with map in frontispiece.

since its elevation by numerous valleys. The same peneplain determines the crest lines of Kittatinny mountain and of the many similar ridges of Pennsylvania on the west, and of the Triassic trap ridges on the east. It may be seen descending below sea-level where the Cretaceous beds lie on it below New Brunswick. Most of the streams that have opened valleys in the Highland portion of the peneplain are simply revivals of old streams of an earlier geographic cycle; but in the Triassic area, most of the streams are descended from courses superimposed upon the present rocks by the cover of Cretaceous strata that once stretched across them: and many of the streams appear to have been much affected by adjustments following upon their discovery of the trap ridges across which their initial courses had been unwittingly chosen. The elevation of the ancient peneplain occurred so long ago that its weaker rocks have been again baselevelled; and thus we find explanation for the even interstream surface of the Central plain. Another elevation of the land allowed the opening of shallow valleys in the plain, and in this shape we find it. The moderate distortion and numerous oscillations that accompanied the latest cycle of change still need much study, particularly with reference to their effect on river courses. As the preparation of good topographic maps is continued over the other states of our Atlantic slope, there will be opportunity to test many of the statements made here, for the sequence of changes we have considered is not local but widespread.

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November, 1889.