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THE PLIOCENE HISTORY OF NORTHERN AND CENTRAL MISSISSIPPI

BY

EUGENE WESLEY SHAW

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THE PLIOCENE HISTORY OF NORTHERN AND CENTRAL MISSISSIPPI.[1]

By Eugene Wesley Shaw.

INTRODUCTION.

The record of Pliocene time in northern and central Mississippi is generally assumed to be scant or lacking. The published geologic maps of this region show no Pliocene formations, and the only deposit in the region that has been assigned to the Pliocene is the unmapped so-called Lafayette formation. This formation, however, in recent years has lost some of its good standing, for several students have become convinced that the material constituting the "Lafayette" in Mississippi has been altogether misinterpreted, most of it being simply more or less weathered material belonging to various underlying formations. Heretofore no stratigraphic record of early and middle Pliocene time and no physiographic record of any part of this epoch have been recognized in this region, and hence if recent views concerning the "Lafayette," commonly regarded as late Pliocene, are correct, knowledge of Pliocene events in this part of the State is very scant indeed. However, recent work on the later Tertiary and Quaternary geology of the Mississippi embayment has brought to light an unexpected amount of data bearing on the Pliocene history of Mississippi, and the object of the present paper is to present some of these data in preliminary form and to point out their apparent significance. They pertain not only to the deposits of the region but also to the surface features. Space is not available for more than an outline of the basis of the conclusions set forth, and the life of the epoch is barely mentioned.

The field work upon which this report is based was done in the years 1912 to 1916, inclusive, and is a part of a general study of the Mississippi embayment planned and arranged for by T. Wayland Vaughan, chief of the section of Coastal Plain investigations of the United States Geological Survey. For several years before 1912 the writer had been studying the surficial geology of the upper part of the Mississippi basin, and thus, although the report deals primarily with only a portion of Mississippi, it is based upon a general study of both the upper and lower parts of the Mississippi basin. It has been the writer's good fortune to see also deposits and surface features more or less closely related to those under discussion in other parts of the Atlantic and Gulf Coastal Plain, including eastern Mexico. In the field work in Mississippi he had the advantage of frequent consultation with Dr. E. N. Lowe, State geologist.

CORRELATION OF DEPOSITS AND SURFACE FEATURES OF LOWER AND UPPER PARTS OF MISSISSIPPI BASIN.

One of the principal objects of the study of the embayment area was the correlation of the late Tertiary and Quaternary deposits and physiographic features of the Mississippi embayment and Gulf coast with those of the upper part of the Mississippi basin. The need for such correlation has long been felt. For example, concerning the field work of R. D. Salisbury in 1889 T. C. Chamberlin[2] says:

> The especial object of this investigation was to determine the relationships between the valley deposits of the lower Mississippi and the glacial deposits of the upper Mississippi. By examining these deposits at the supposed point of their junctions with the border of northern drift it is hoped to demonstrably establish their time ratios and their genesis.

The eleventh and twelfth annual reports of the Survey contain similar statements as to Prof. Salisbury's work. No area offered greater promise for valuable results, for here extensive

[1] In its basis of field work and in its conclusions this paper is closely related to a recent paper by G. C. Matson, entitled "The Pliocene Citronelle formation of the Gulf Coastal Plain" (U. S. Geol. Survey Prof. Paper 98, pp. 187-192, 1916. The writers of the two papers visited critical points in the field together and compared their data and conclusions.

[2] U. S. Geol. Survey Tenth Ann. Rept., pt. 1, p. 129, 1890.

Coastal Plain deposits of late Tertiary and Quaternary age were believed to be contiguous to if indeed not actually interstratified with glacial deposits, and a great trunk stream, along which terraces and other alluvial deposits might be expected flows from one part of the area to the other. In New Jersey, however, deposits of the two classes were found to be more closely connected, though no large stream flows from the deposits of one class to those of the other. As a matter of fact, north of Cairo, Ill., there is a gap of about 40 miles between glacial and Coastal Plain deposits, and in this gap the Mississippi flows through a rather narrow gorge in which there are practically no terrace deposits, so that it is almost impossible to determine the relation of any Quaternary formation of the upper part of the Mississippi basin to any of the lower part. The loess deposits of the two areas, however, can be correlated with a considerable degree of certainty.

Along the lower Wabash and Ohio not only the loess but also two or three low terrace deposits form a practically continuous connection between the Coastal Plain and glacial formations. On both the southeast and southwest borders of Illinois there are scattered patches of gravel that have been called Lafayette and are commonly regarded as late Tertiary. If, as the writer believes, they are of late Tertiary age, they should be of some use in correlating the formations of the two areas. In southwestern Indiana, however, small areas of such gravel have been referred provisionally to the Eocene,[1] because of their position on a plain thought to be Eocene.

Although the correlation of formations and surface features of the upper and lower parts of the Mississippi basin is thus difficult and somewhat unsatisfactory, nevertheless certain significant facts have been ascertained and certain inferences are more or less probable. Some conclusions by the author and others regarding pre-Pliocene and also Quaternary geology and physiography are included in this paper, for upon them depends in part the identification of the Pliocene deposits and surface features of Mississippi. The conclusions having to do with Quaternary geology may be summarized as follows: (1) The main loess of the upper part of the Mississippi basin has been traced almost continuously to that of the lower part, and apparently there are at least two other deposits of loess in both areas, one older and one younger, but both Pleistocene. (2) Two low stream terraces, one probably Illinoian and the other Wisconsin, may be traced from the north into the Mississippi embayment, where both dip down to the present flood plain of the Mississippi. No record of early Pleistocene time (Kansas or Nebraskan) has yet been found adjacent to or near the upper end of the Mississippi embayment. (3) Certain rather extensive gravel deposits along the lower Mississippi are believed to be terrace deposits of Pliocene age and are correlated with most of the scattered patches of gravel in the upper part of the Mississippi basin.

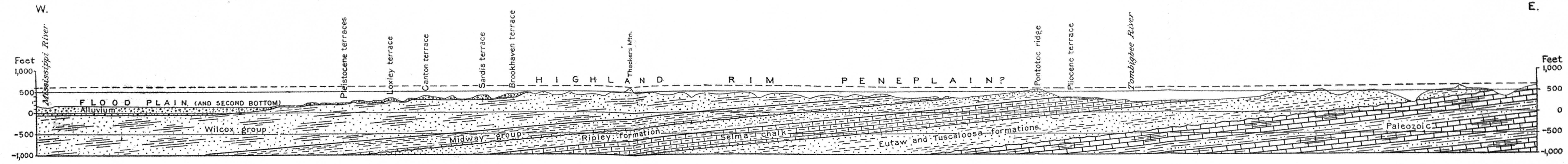
[1] Fuller, M. L., and Clapp, F. G., U. S. Geol. Survey Geol. Atlas, Patoka folio (No. 105), 1904.

SEDIMENTARY RECORD.

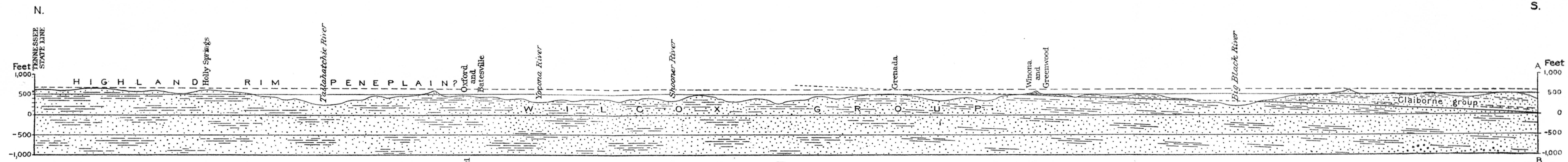
The sedimentary record of Pliocene time in northern and central Mississippi is believed by the writer to consist principally of a part of the materials that have been included in the "Lafayette formation." This formation has heretofore been regarded as the only record of Pliocene time in this region, but some revision in the interpretation of material referred to it is suggested in the following pages. In order to give a clear idea of the basis on which the previous inferences concerning this formation rest, it is necessary to describe briefly the the nature of the underlying formations.

GENERAL CHARACTER OF PRE-PLIOCENE FORMATIONS.

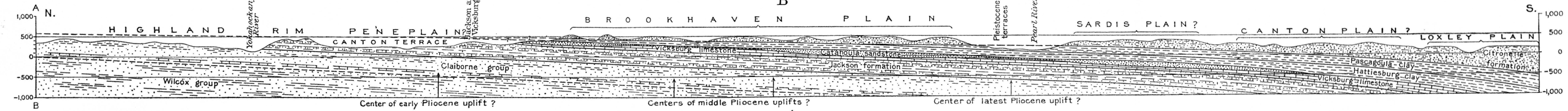
The general distribution of the materials underlying central and northern Mississippi is indicated in figure 21. From this map it is to be seen that these portions of the State are underlain by formations ranging in age from Devonian to Oligocene, and that a large part of the area is underlain by Eocene strata. No Pliocene strata are shown, the "Lafayette" mantle not being mapped. Most of the formations shown consist, like the "Lafayette," largely of irregularly bedded silty sands, but a few consist of limestone or clay. The individual formations have been identified and traced principally by means of their fossil content, lithologic character, and stratigraphic relations, but their fossil content is commonly meager, their lithologic character is



A



B



B′

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

5 0 5 10 15 20 25 30 MILES

Generalized East-West and North-South Sections of Mississippi, Each Representing Diagrammatically the General Form of the Surface and Nature of the Underlying Rocks in a Belt 30 or 40 Miles Wide.

A. EAST-WEST SECTION THROUGH OXFORD.

Near the east end the line of the section bends to the northeast. The dip of the paleozoic rocks is not known with certainty, but apparently its direction is southwest, though presumably not at the same rate as that of the coastal plain deposits.

B AND *B′*. NORTH-SOUTH SECTION REPRESENTING A BELT THROUGH THE CENTRAL PART OF THE STATE INCLUDING OXFORD AND JACKSON.

Shows the effect of pliocene (?) uplifts in the south-central part of the state which carried pliocene gravels to a comparatively great altitude.

extremely varied, and their stratigraphic relations are somewhat difficult to determine. All three lines of evidence taken together are so commonly inconclusive that opinions differ as to the identity of some of the most accessible strata—those lying near the surface, abundantly exposed, and known as Lafayette. Some have inferred that most of the beds lying close to the surface belong in this surficial formation, which is described as differing markedly in many respects from the underlying formations; others, particularly more recent workers, have thought that the concept of a blanket formation is incorrect and that most of the sands and other materials so classified belong in fact with the several underlying formations. Indeed, as shown in Plate XLV, most of the "Lafayette" of Mississippi is found where the underlying beds are very sandy.

IDENTIFICATION OF PRE-PLIOCENE FORMATIONS.

The confusion concerning the "Lafayette" appears to be due partly to the lack of diagnostic features in that formation itself and partly to the irregular distribution of such features in underlying formations. Concerning the older rocks, the testimony of fossils is in many places incontrovertible. Remains of land plants are fairly common in some formations and sea shells in others, but nevertheless the mass of material whose age can be directly determined from fossils is a small fraction of that involved in this discussion. In many exposures fossils are not to be found, and in many others only certain beds can be classified with certainty by means of fossils.

The lithologic character of only a few of the formations is sufficiently distinctive to be usable in identification and mapping. The Selma chalk is easily recognized by both its lithologic character and its fossil content, but most of the formations in this region and also in much surrounding territory in the Coastal Plain are made up largely of irregularly stratified sand and silt which include very few beds that are identifiable by their lithologic character.

Many of the individual pre-Pliocene strata are not persistent and hence can not be correlated by continuous tracing over wide areas or by comparing stratigraphic relations. It is therefore difficult to identify much of the material that lies far from beds of known age.

Thus Tertiary and Cretaceous strata that aggregate thousands of feet in thickness and crop out over an area of thousands of square miles include few layers sufficiently persistent and identifiable to be traced far with certainty as to their exact stratigraphic positions. Yet these strata were long ago divided into forma-

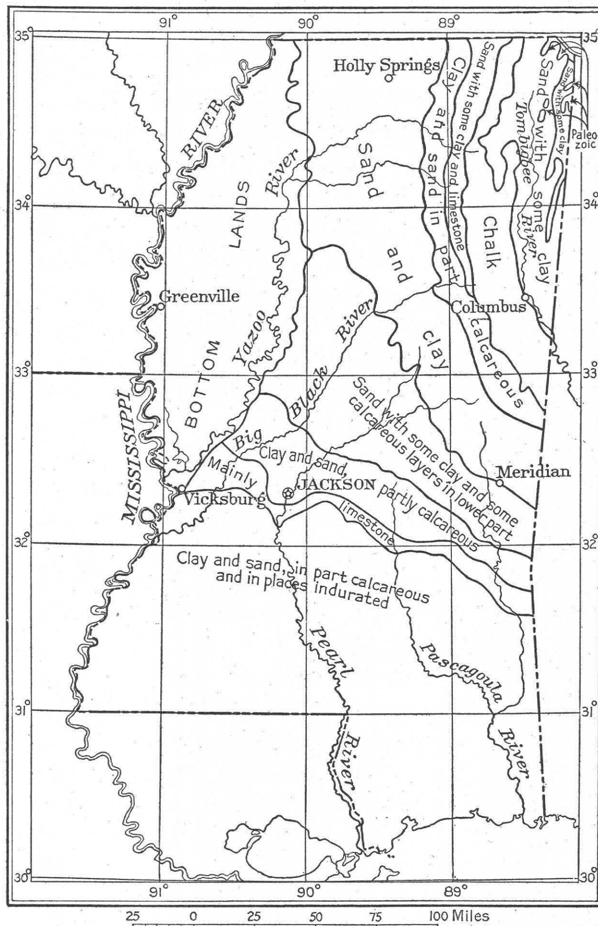


FIGURE 21.—Diagram showing general nature and areal arrangement of materials underlying the surficial deposits of Mississippi.

tions, concerning whose general positions and areas of outcrop there can be no doubt, notwithstanding the fact that there is a lack of agreement as to whether the most accessible strata in the region—those immediately underlying the surface and abundantly exposed in cuts and washes—belong with the underlying strata or constitute, as has been thought for many years, a distinct surficial formation. In the opinion of the writer and others much if not most of the material in central and northern Mississippi which has been called Lafayette or Orange sand belongs in fact with the underlying formations and differs from them only in being on the whole more reddened and otherwise weathered. The very fact, however, that such an idea, though tenable, has been so slow in arising is expressive of the difficulty in identifying and tracing the beds.

"LAFAYETTE FORMATION."[1]

GENERAL NATURE.

The "Lafayette formation" as heretofore described[2] is a late Pliocene or early Pleistocene mantle deposit which crops out throughout most of the Coastal Plain of eastern North America and some adjoining territory, an area of more than 200,000 square miles. It consists largely of more or less deeply iron-stained gravel, sand, clay, and loam, the upper part generally massive and the lower stratified. In thickness it ranges from 1 foot to 200 feet or more. Fossils are generally rare, and those that have been found are regarded as out of place and range in age from Devonian to Pleistocene, inclusive. As described, the formation shows little detailed or consistent relation to altitude, topography, physiography, or geologic features. However, though it rests upon rocks of all ages, from pre-Cambrian to late Tertiary, it is scantily developed in the high country of Paleozoic and older rocks bordering the Coastal Plain. Its surface and base are roughly parallel to the present surface, and it underlies uplands, hillsides, and terraces alike. Other Coastal Plain formations have roughly concentric areas of outcrop, the youngest being nearest the sea, but this one mantles all the others.

INTERPRETATIONS.

The interpretations of the "Lafayette formation," though showing more or less variety, fall into four principal classes; the first assumes that it was deposited by flood water from Pleistocene glaciers; the second, that it was laid down during a marine submergence of the Coastal Plain; the third, that it is the product of a less catastrophic process of stream deposition induced by broad uplifts of the Appalachians; and the fourth, that much if not most of it is a more or less weathered portion of the older and underlying formations of the region, a part of it being made up of material of other kinds.

Although Bartram,[3] the Rogerses,[4] Booth,[5] Conrad,[6] Mather,[7] Lyell,[8] and Tuomey[9] had done some work on similar deposits along the Atlantic coast, and Wailes,[10] Safford,[11] and Harper[12] in Tennessee and Mississippi, Tuomey[13] seems to have been the first to attempt an extended interpretation of the "Lafayette" of the Gulf coast. He called it the "Southern Drift" and correlated it with the glacial deposits of northern United States. Wailes had called it "Diluvium or Northern Drift" without attempting an explanation, and Safford and Harper had called it "Orange sand."

It should be remarked that there has been a lack of complete harmony as to what should be included in the formation. Modifications have been made at different times in the 80 years of work upon it, so that although "Southern drift," "Orange sand," and "Lafayette formation" have in a general way a similar significance, they differ somewhat in meaning from time to time and from author to author.

Safford,[11] who introduced the term "Orange sand," applied it not only to what later became McGee's Lafayette and Columbia, but also to deposits of Wilcox age (Eocene), and he classi-

[1] A more complete discussion of the status of the "Lafayette formation" is in preparation.

[2] See particularly the description by Hilgard (Geology and agriculture of Mississippi, 1860) and McGee (U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, pp. 347-521, 1891).

[3] Bartram, William, Travels through North and South Carolina, Georgia, east and west Florida, pp. 28-30, 1791.

[4] Rogers, W. B., Report of the geological reconnaissance of the State of Virginia, p. 13, Virginia Board Pub. Works, Philadelphia, 1836. Rogers, H. D., Report on the geological survey of New Jersey, 2d ed., p. 17, 1836.

[5] Booth, J. C., Memoirs of the geological survey of the State of Delaware, pp. 94, 97, 1841.

[6] Conrad, T. A., Observations on a portion of the Atlantic Tertiary region; Nat. Inst. Proc., vol. 1, p. 177, 1842.

[7] Mather, W. W., Geology of New York, pt. 1, pp. 246, 261-268, 274-275, 1843.

[8] Lyell, Charles, jr., On the newer deposits of the Southern States of North America: London Geol. Soc. Quart. Jour., vol. 2, pp. 405-406, 1846; A second visit to the United States, vol. 1, pp. 344-346, vol. 2, pp. 242-266, 1849.

[9] Tuomey, M., Geology of South Carolina, pp. 186, 188, 212, 1848.

[10] Wailes, B. L. C., Report on the agriculture and geology of Mississippi, pp. 245-253, 1854.

[11] Safford, J. M., A geological reconnaissance of Tennessee: Tennessee Geol. Survey First Bienn. Rept., pp. 148, 162, 1856.

[12] Harper, L., Preliminary report on the geology and agriculture of Mississippi, p. 162, 1857.

[13] Tuomey, M., Second biennial report on the geology of Alabama, p. 146, 1858 (transmitted for publication in 1855).

fied both as Cretaceous. Crider,[1] on the other hand, excluded much that had been included by McGee, saying:

He [McGee] likewise included in the term Lafayette 200 feet or more of the Wilcox which belongs to the Eocene. * * * The term as used in this [Crider's] report is restricted to the thin veneering of iron-stained pebbles and sand which overlaps unconformably all the other formations of the State, from the older Paleozoic rocks along Tennessee River to and including the Grand Gulf group of the late Miocene. * * * The thickness of the formation varies from a knife-edge to 50 feet.

Yet McGee[2] states that "It is separated from all of the underlying formations by a noteworthy unconformity."

It seems remarkable that there should be such certainty about the existence of a thing and such difference of opinion as to its whereabouts. The disagreements as to the location of the great unconformity at the base of the formation suggest the query whether it may not after all be at the top—in other words, whether there is any Lafayette.

The writer and others of the section of the Coastal Plain investigations of the United States Geological Survey have traced a part of even Crider's restricted Lafayette into older formations and suspect that a very large part must be so reclassified. For example, the extensive gravel deposits that are well exposed in the pits east of Iuka, regarded by Crider as Lafayette, have been found by L. W. Stephenson and the writer independently to pass beneath Cretaceous formations at Iuka.

Hilgard,[3] the chief student of the "Lafayette" in Mississippi, agreed with Tuomey in his interpretations of the "Southern drift," saying "His [Tuomey's] suggestions regarding the nature and origin of the water which deposited the Orange sand [or 'Southern drift'] formation appear to be confirmed by all the additional observations subsequently made by myself." He says further:

However different may be the geological detail of the Orange sand formation from that of the Northern drift deposits, the evident analogy of their lithological composition and general history would lead us to suppose the two formations to be genetically related. In both cases immense volumes of water destitute, or nearly so, of organic life rushed southward, bearing with them the fragments and detritus of the older formations. * * *

Whether or not the Orange sand deposits contain any material necessarily derived from a high northern latitude still remains to be determined, for thus far the materials for comparison are imperfect on both sides. By far the greater mass of the pebbles occurring in Mississippi appear to be referable to sources lying south of the Ohio River on either side of the Mississippi, while the rocks most common in the drift of Illinois—granite, mica schist, and metamorphic sandstone are either very rare or (like granite) entirely wanting.

Thirty-two years later Hilgard published another paper[4] on the "Lafayette" in which he says that the formation was laid down by running and violently agitated waters at a time of high elevation, particularly of the northern United States, and says that much erosion preceded and followed its deposition.

The hypotheses concerning the "Lafayette" may be summarized as follows, in the order in which they have been advanced and become more or less popular: (1) It was laid down by glacial floods; (2) it is a sea deposit made during rapid submergence; (3) it is a stream deposit; and (4) it is not a formation at all but a hodgepodge of parts of various formations. Parts of it have also from time to time been excluded because of their identification with other formations. But there have been many departures from this general trend. For example, Crider[5] as late as 1906 says that the quartz pebbles are "doubtless the fragments of the great northern drift carried southward by great volumes of cold fresh water at the close of the glacial epoch," thus not only subscribing to the glacial hypothesis but dating the formation at the end of that epoch, whereas most workers have considered it much more ancient. The end of Pleistocene time was probably not more than a tenth and perhaps not more than a twentieth or thirtieth as long ago as the beginning.

The second interpretation, that of deposition by sea water, was best set forth by McGee. By its excellence of logic and presentation of evidence his paper brought the name Lafayette into general use and crystallized ideas concerning its extent and interpretation. McGee's views are suggested by the following quotation:[6]

The record of Lafayette deposition is one of oceanic invasion, not of catastrophic swiftness, yet of such rapidity

[1] Crider, A. F., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, p. 45, 1906.

[2] McGee, W J, The Lafayette formation: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, p. 497, 1891.

[3] Hilgard, E. W., op. cit., pp. 27-28.

[4] Hilgard, E. W., The age and origin of the Lafayette formation: Am. Jour. Sci., 3d ser., vol. 43, pp. 389-402, 1892.

[5] Crider, A. F., op. cit., p. 45.

[6] McGee, W J, op. cit., p. 508.

that the waves rolled over the sinking hills without carving shore lines; without even building broad beaches such as the modern keys of the southern coast; and the inundation was not stayed until it reached inland, drowning the southeastern margins of the continent in a zone 100 to 500 miles wide. * * * The waves and currents spread * * * [the sediment] here and there along the new-made coast, mixing it with the materials gathered from the new-made sea bottom. In this way only could have been accumulated the widespread Lafayette mantle, composed chiefly of residua of slow rock decomposition and subordinately of material from local formations, together with great gravel beds about the waterways. * * * In age the Lafayette formation is many times older than the earliest known Pleistocene deposit, and much newer than any other well-defined formation of the Coastal Plain.

The third interpretation, that the "Lafayette" is a stream deposit, is well set forth by Chamberlin and Salisbury,[1] who say:

It is assumed that the [Pliocene] upward bowing [of the Appalachian province] was felt first in a relatively narrow belt along the predetermined axis, that the rise was gradual, and that the rising arch increased in breadth as it rose.

The result was renewed erosion and increase of load of the streams, and this load was too great for them to carry across the Coastal Plain to the sea. As the uplift progressed the deposit was spread farther and farther toward the sea. Hill and Vaughan [2] place a somewhat similar interpretation on the Uvalde formation, which they say is of the same age as the "Lafayette," though they do not assume a broadening area of uplift and a consequent gradual seaward shifting of gravel. They say: "It does not appear to the writers that it is necessary to postulate a marine submergence or an absolutely horizontal deposition level," and they describe the deposit as occurring on the seaward side of the Balcones scarp, suggesting as conditioning agents (1) cloudburst storms in an arid or semiarid region and (2) gradual uplift of the area on the landward side.

It will be noted that the "Orange sand" or "Lafayette" is regarded as Cretaceous by Safford (1856), as Pliocene by McGee (1891) and by Chamberlin and Salisbury (1906), and as Pleistocene by Tuomey (1855), Smith and Hilgard (different dates), and Crider (1906).

The fourth interpretation of the "Lafayette"—that at least part of it is in reality more or less weathered and slumped portions of underlying formations—may be illustrated by the following quotations from McGee, Vaughan, and Berry.

McGee [3] says: "It should be noted that a part of the deposits designated Orange sand by different geologists consists of rearranged residuary débris of the Tuscaloosa and perhaps other formations."

Vaughan [4] argues that the "Lafayette" around Mount Lebanon and Arcadia, La., is residual and states the grounds for his belief as follows: (1) In it are found "fossils as casts in ferruginous sandstones or as ferruginous replacements," and these fossils are the same as those in the underlying formation; (2) "the transition from the Eocene to the superficial deposits can be traced"; (3) "there are in the specimens from the superficial deposits no indications of their having been waterworn."

Berry [5] says:

In the exposures at Oxford the deposits are a unit with every graduation from unweathered materials below to oxidized and more or less ferruginous sands above. Nowhere in this region is there a line of unconformity or a pebble bed to mark the supposed time interval extending from the early Eocene to the Pliocene. The change in color of the materials, when marked at all, is at varying levels and is due apparently to the depth to which the ferric oxide in the sands has been dehydrated.

A distinct variety of this interpretation worthy of mention has been set forth by Harris,[6] who believes that the "Lafayette" is made up of parts of various formations but that those parts differed originally from other parts of the same formations. He says: "It has been my belief for several years that whenever the shingle of an old shore has been preserved, there will be found 'Orange sand,' be the age of such littoral beds Mesozoic or Cenozoic," and he postulates a gradual seaward shifting of the deposits during emergence of the land.

[1] Chamberlin, T. C., and Salisbury, R. D., Geology, vol. 3, Earth history, pp. 305-306, 1906.

[2] Hill, R. T., and Vaughan, T. W., Geology of the Edwards Plateau and the Rio Grande Plain adjacent to Austin and San Antonio, Tex.: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, p. 246, 1898.

[3] McGee, W. J., Three formations of the middle Atlantic slope: Am. Jour. Sci., 3d ser., vol. 35, p. 330, 1888.

[4] Vaughan, T. W., The stratigraphy of northwestern Louisiana: Am. Geologist, vol. 15, p. 219, April, 1895.

[5] Berry, E. W., The age of the type exposures of the Lafayette formation: Jour. Geology, vol. 19, p. 251, April-May, 1911.

[6] Harris, G. D., The geology of the Mississippi embayment with special reference to the State of Louisiana: Louisiana Geol. Survey, pt. 6, p. 33, 1902.

BASIS OF VARIOUS INTERPRETATIONS.

The question naturally arises, Why should there be so much difference of opinion concerning the content and interpretation of the "Lafayette"? Surely it is not because the material has failed to receive sufficient attention, for many able investigators have given long study to it in the field, and many others have written and theorized about it. Again, it is not because the formation is inaccessible, for it lies at or near the surface and is abundantly exposed throughout a populous region covering hundreds of thousands of square miles. Why then should ideas concerning it differ so much more widely than those concerning other formations?

In the first place the formation is generally described as being unique, both in development and in constitution, differing more or less markedly from any other ancient or modern deposit, and hence there are few opportunities for making enlightening comparisons. Second, although many investigators regard it as a unit having a persistent and recognizable character for example, McGee[1] says that "as a whole the formation maintains so distinctive and strongly individualized characteristics as to be readily recognized wherever seen * * * it is more uniform petrographically than any other formation of even one-fourth of its extent"; and E. A. Smith[2] says that "the Lafayette has a character * * * so well marked that the observer with any reasonable degree of experience will scarcely ever remain long in doubt as to its identity," yet, as McGee himself says, "this distinctive aspect of the formation is to some extent fortuitous." If it consisted of any single or any small group of diagnostic characteristics there would be less room for doubt. The difficulty arises out of the fact that it consists of a large group of features, several of which may be found together in another formation.

In correlating other deposits fossils are often used, but the "Lafayette," under all interpretations, is regarded as having no index fossils. Fossils are often found in material that had been regarded as Lafayette, but it is always inferred either that they are out of place, having come from some older formation, or that the stratum containing them and all below it should be reclassified and put into the underlying formation, for, remarkable as it may seem, the fossils that are certainly in place are always found to be just such as occur in the formation which happens to lie just below. Under the fourth interpretation the "Lafayette" thus becomes a combination of the nonfossiliferous outcropping portions of several formations.

Stratigraphic relations should be of some use in identifying the "Lafayette," for it is described as being everywhere unconformable at the top and bottom, as resting upon rocks of all ages older than Quaternary, and as lying either at the surface or just below some other surficial deposit. But throughout three-fourths if not nine-tenths of the region under discussion the unconformities can not be found or their location agreed upon. The remaining tenth or fourth is the area of the terrace-deposit phase of the "Lafayette" described below.

Stratification seems to be one of the principal features used in the identification of the "Lafayette," the bedding of which is commonly, especially in the area under discussion, extremely irregular, often being described as jumbled. But irregular bedding is also found in older formations, where it is of the same general type in so far as bedding so varied can be said to follow a general type of irregularity.

Lithology is of some value in identifying the "Lafayette," which lacks limestone and certain other kinds of rock, though it consists of materials so diverse as clay, shale, sand, sandstone, gravel, conglomerate, and iron ore. But the usefulness of lithology for this purpose is reduced by the fact that other formations in the region are lithologically similar to the "Lafayette," though perhaps none others show so great diversity.

Other criteria are often useful in correlation—color, physiographic expression, mode of weathering, etc.—and some of these are involved in the differentiation of the "Lafayette," but apparently no one of them is sufficient. Rather its identification seems to rest on an aggregate of many features, of which any one or even several may be found in some other formation. Some single features, however—for example, the common extreme irregularity of bedding, with clay masses in sand—have generally been believed to be somewhat more characteristic of

[1] McGee, W J, op. cit., p. 489.
[2] Smith, E. A., Am. Assoc. Adv. Sci. Proc., vol. 55, p. 374, 1906.

the "Lafayette" than of other formations. The writer and others regard these irregularities in bedding as characteristic of many Coastal Plain formations and believe that material near the surface does not differ in this respect from that farther down and that parts of the "Lafayette" are terrace deposits. (See Pls. XLVI–XLIX.)

In brief, the basis upon which the first three interpretations of the "Lafayette formation" set forth above have rested is about as follows: First, throughout central and northern Mississippi and also most other parts of the Coastal Plain of the eastern United States, to which all but a very small fraction of the material called Lafayette is confined, the material within 20 to 100 feet of the surface is redder than that below, no matter to what formation the lower material belongs. Second, the material from 1 to 15 or 20 feet below the surface is commonly more faintly stratified and many believe it to be more irregularly stratified than that below. Third, in some places the material within a few feet of the surface contains elements not found in the underlying formations and is set off from them by a rather sharply defined plane, being apparently susceptible of the interpretation that it consists of the remnants of terrace deposits.

Under the fourth interpretation it is contended that much of the "Lafayette" differs from underlying formations only in being, on the whole, redder, except that close to the surface the stratification is fainter or disturbed and the color in many places changed to brown or buff. These features are believed to be much more reasonably regarded as products of the weathering and slumping of the underlying sandy and silty formations, both at the time of their deposition and later than as characteristic of a single formation, especially because (1) the constitution of the material seems to depend everywhere on the constitution of the underlying formation; (2) there is generally no sharp lower limit to the redness and irregular or jumbled bedding, and, on the whole, the faintness of the stratification decreases downward; (3) notwithstanding the general irregularity of bedding and lack of persistent strata and fossils in the pre-Pliocene formations strata called "Lafayette" can here and there be traced continuously into strata belonging unquestionably to an underlying formation. Moreover, characteristic fossils of the underlying formation, particularly impressions of plant leaves, have been found by Lowe,[1] Berry,[1] and others in lenses of soft clay, some of which are extensive and evenly laminated, and therefore could not possibly have been taken bodily from some older formation and incorporated in the "Lafayette." It is regarded as a significant fact that the fossils from the "Lafayette formation" described as transported and redeposited are either silicified Paleozoic fossils in hard pebbles or are characteristic of the particular formation which happens to underlie the "Lafayette" at the place of their occurrence.

TERRACE DEPOSITS CORRELATED WITH THE CITRONELLE FORMATION.

LOCATION.

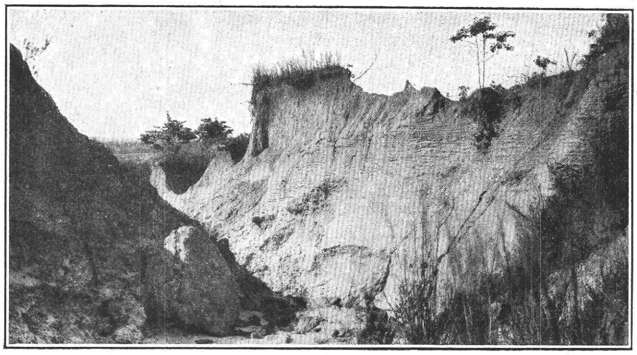
In discussing the constitution of the "Lafayette," Hilgard [2] says:

> There are within the State two distinct regions of occurrence in which this material [gravel] appears in force. One of these extends along the eastern edge of the alluvium of the Mississippi River, occupying, in northern Mississippi, parts of the counties of De Soto, Panola, Yalobusha, Carroll, Holmes, and Yazoo, gradually diminishing as the territory of the fossiliferous Eocene is approached and giving out almost entirely in the greater portion of Warren County. Then, below Vicksburg, it extends inland in a southeast direction and is found in numerous cuts on the New Orleans, Jackson & Great Northern Railroad down to the Louisiana line.
>
> The other region of occurrence of the pebble bed begins at the north on the Tennessee River, in East Tishomingo, and extends along the waters of Big Bear Creek to the eastern head of the Tombigbee, reaching the latter stream by way of Hurricane and Bull Mountain creeks, in Itawamba County. It then extends southward on the eastern side of the Tombigbee and is continued into Alabama, meeting the great pebble beds of the Warrior, which bear the city of Tuscaloosa.

Further study has confirmed the generalization that most of the gravel of the "Lafayette" borders the largest streams. In Mississippi it is found (1) in a belt of counties adjoining the Mississippi bottoms and extending from Memphis to Vicksburg, where the belt broadens and swings east across the State, and (2) in the northeastern counties of the State and a belt extending southward along the Tombigbee. The question naturally arises: Is it not possible that the gravel has been misinterpreted and that it is in part Cretaceous and Tertiary, be-

[1] Unpublished notes.

[2] Hilgard, E. W., Report on the geology and agriculture of Mississippi, pp. 11-12, 1860.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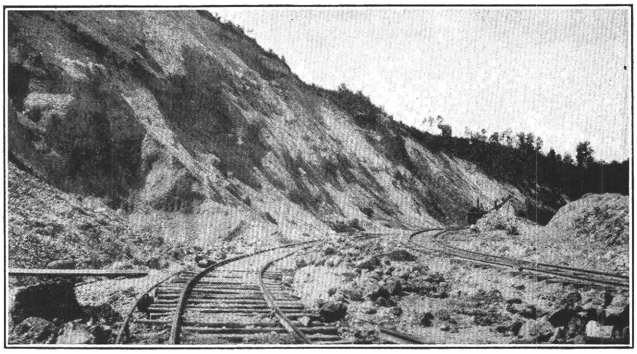
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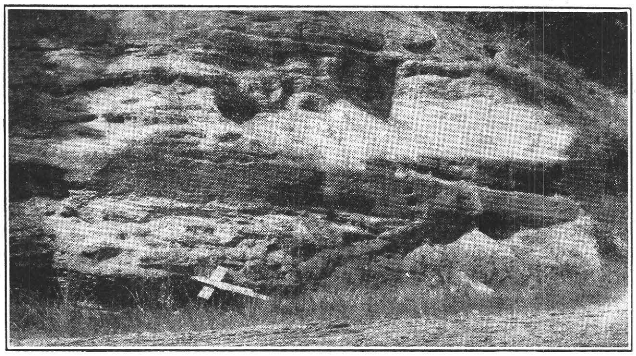
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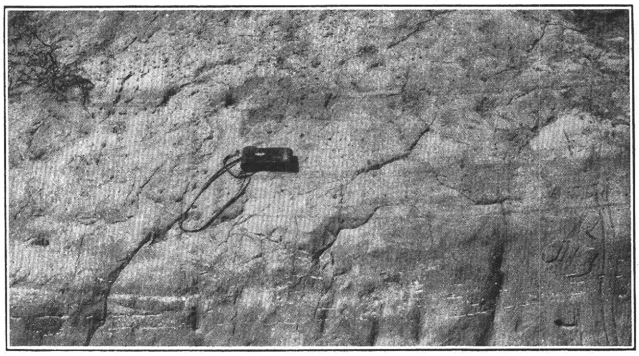
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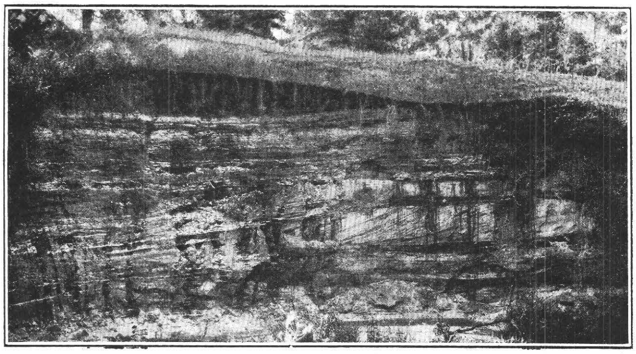
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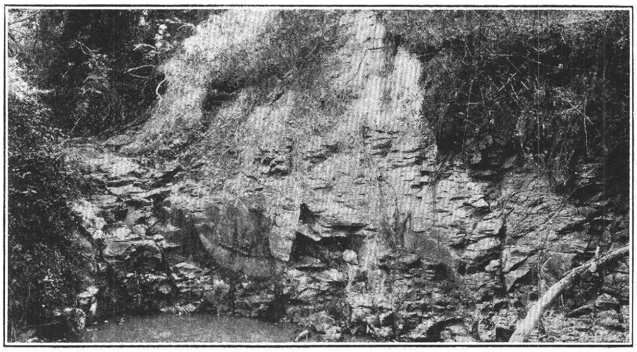
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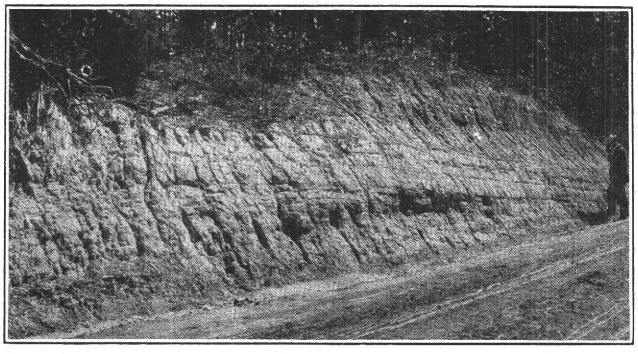
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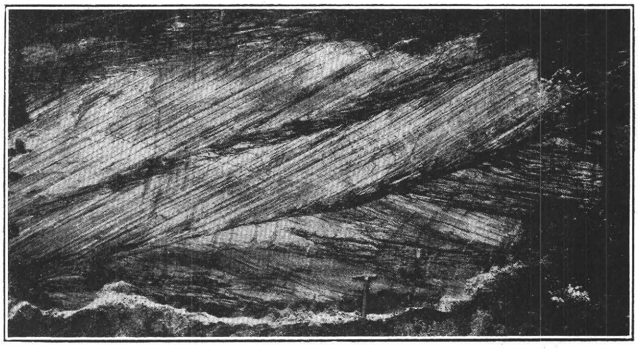
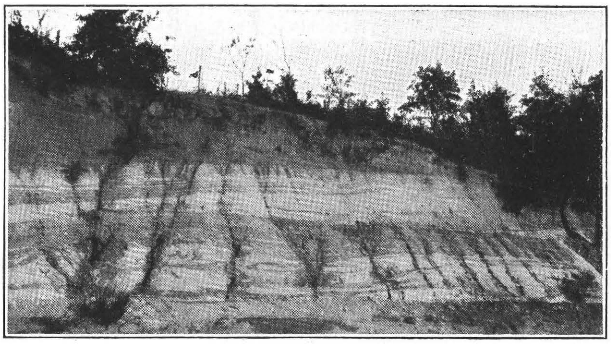

H.

STRATIFICATION AND GENERAL APPEARANCE OF MASSIVE, CROSS-BEDDED, AND LAMINATED MATERIAL FORMERLY INCLUDED IN THE "LAFAYETTE FORMATION," NOW INTERPRETED AS BELONGING WITH VARIOUS FORMATIONS UNDERLYING MISSISSIPPI.

A, Thin wavy-bedded silty sand with embedded fragments of iron-cemented sandstone 5 miles east of Batesville. *B*, Indistinctly cross-bedded gravel 5 miles southeast of Iuka. *C*, Cross-bedded sand, shale, and pebbles of Eutaw formation half a mile south of Iuka. *D*, Indistinctly cross-bedded sand of Eutaw formation (?), with clay pebbles and streaks, 1 mile east of Iuka; altitude 600 feet. *E*, Cross-bedded silty sand of Wilcox group at Baileys Spring, 1 mile southeast of square, Oxford. *F*, Massive purple clay of Wilcox group in bottom of Isom Ravine, Oxford. *G*, Thin, hard, evenly bedded white sandy clay 6½ miles southeast of Oxford. *H*, Doubly cross-bedded sand of Wilcox group half a mile north of Oxford.



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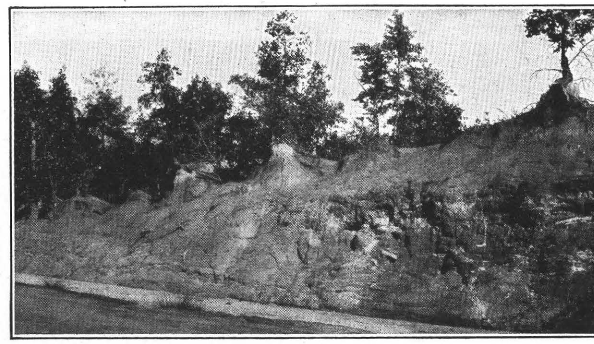

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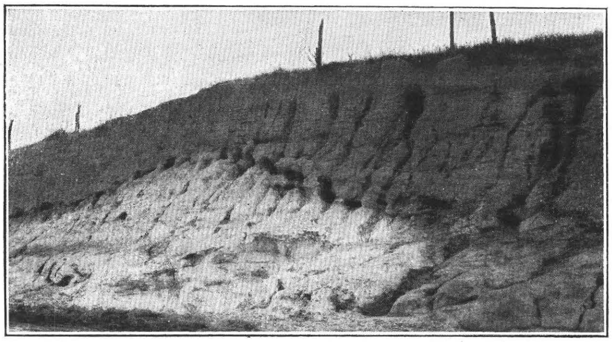

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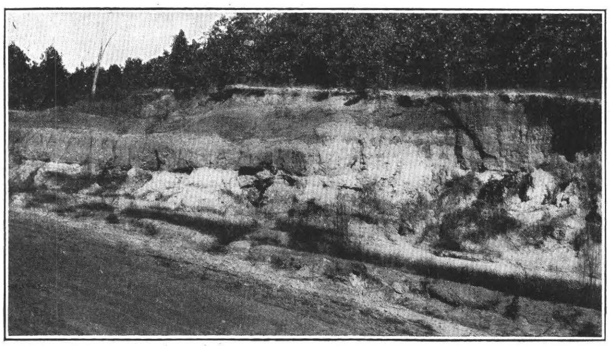

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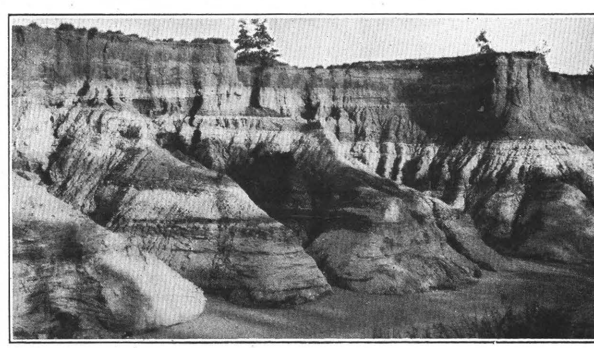

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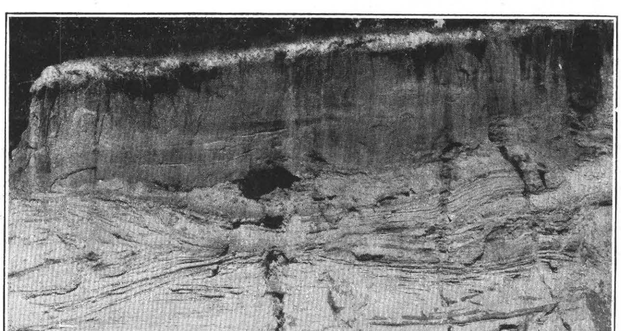

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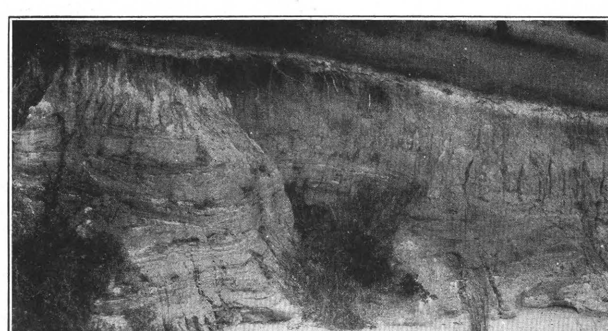
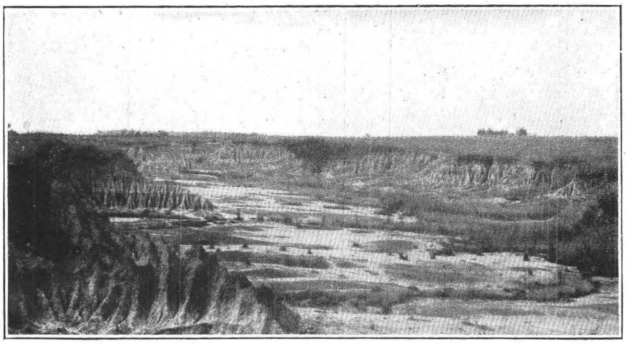


H.

STRATIFICATION AND GENERAL APPEARANCE OF MATERIAL FORMERLY REGARDED AS "LAFAYETTE FORMATION" AT AND NEAR OXFORD, THE TYPE LOCALITY, NOW REGARDED AS BELONGING TO THE WILCOX GROUP.

A, Uneven interfingering beds of clay and sand three-fourths of a mile north of Oxford. *B*, "Jumbled" clay balls and lenses 4 miles west of Oxford. *C*, Intraformational unconformity between stratified reddish sand and white clay half a mile east of Oxford. *D*, Somewhat indistinct, uneven interfingering beds of clay and sand three-fourths of a mile north of Oxford. *E*, Heavy beds of sand and clay 3 miles west of Oxford. *F*, Sharply defined interfingering beds of white clay and red sand 1 mile north of Oxford. *G*, Peculiar stratification of silty sand on east side of Fourmile Creek 2 miles east of Oxford. *H*, Irregular stratification of sand 1 mile south of Oxford.



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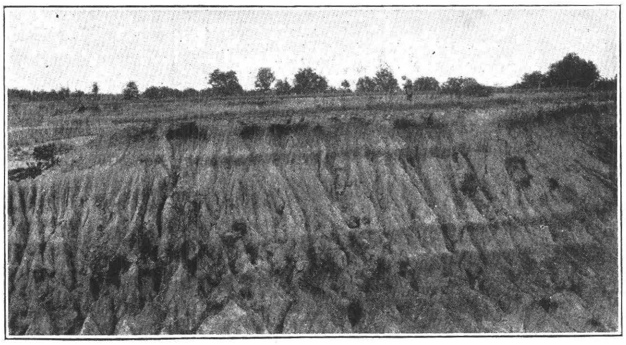

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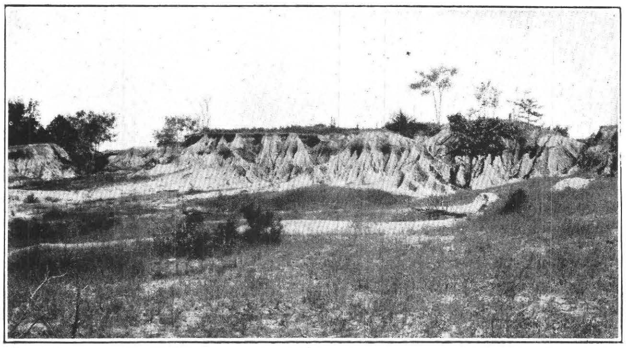

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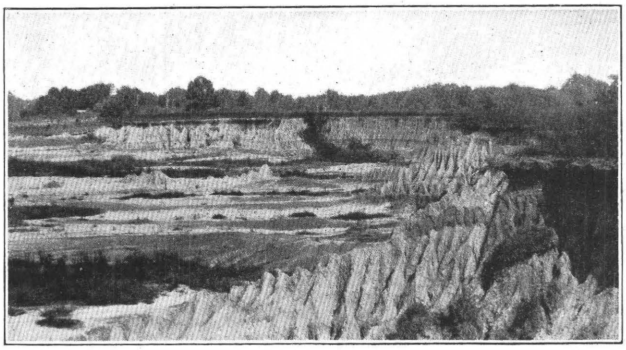

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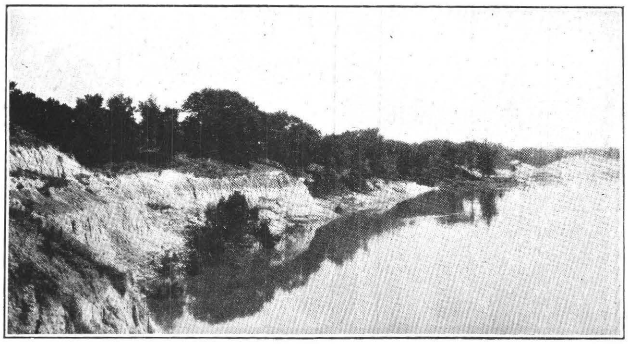

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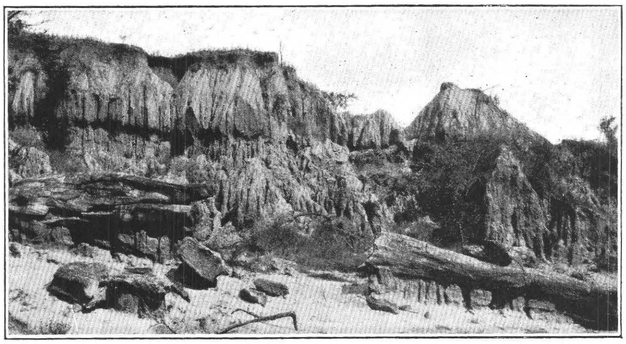

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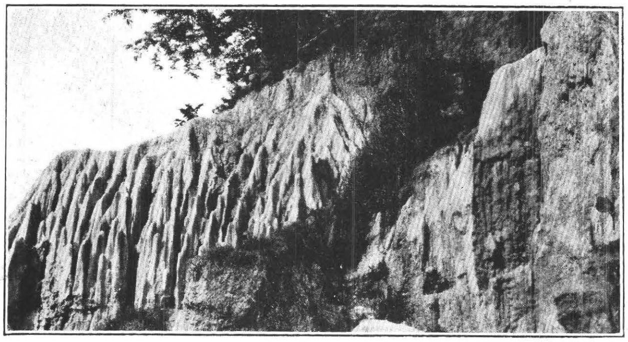

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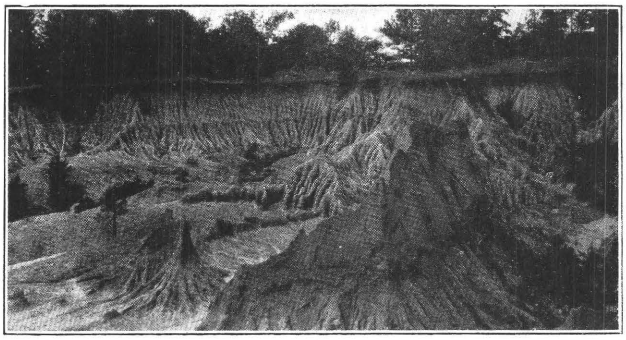
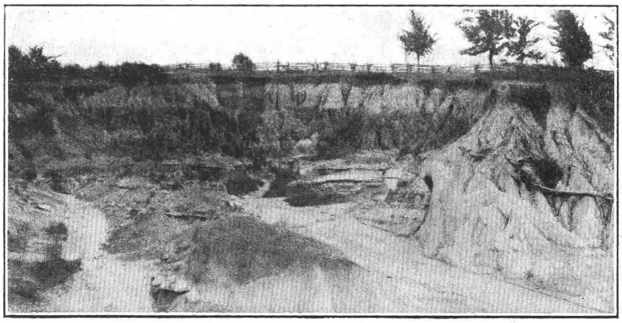


H.

STRATIFICATION AND GENERAL APPEARANCE OF PLIOCENE AND EARLY PLEISTOCENE TERRACE DEPOSITS, MOST OF WHICH HAVE BEEN CLASSIFIED AS "LAFAYETTE FORMATION."

The strata seem to range generally from 5 to 10 feet in thickness and to be comparatively persistent and yet lenticular, and these seem to be diagnostic features. *A*, 3½ miles east of Batesville, Miss. *B*, 3 miles east of Batesville, Miss. *C*, 6½ miles southeast of Oxford, Miss. *D*, 3½ miles east of Batesville, Miss. *E*, Part of type exposure of Port Hudson formation at Port Hickey, La., probably early Pleistocene but shows same general form of stratification as Pliocene terrace deposits. *F*, West end of main part of petrified forest 3 miles southwest of Flora, Miss. *G*, Detail from *E*, illustrating buttress form of weathering common in sandy clay deposited by Mississippi River. *H*, 8½ miles west of Grenada, Miss.



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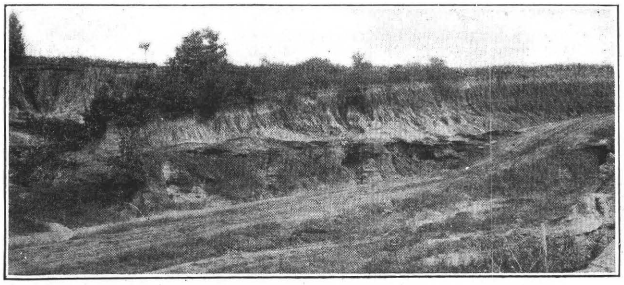

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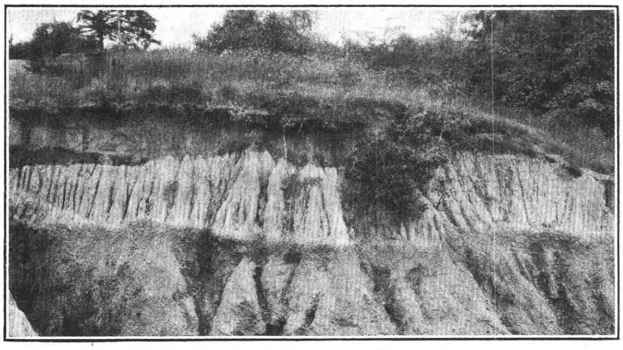

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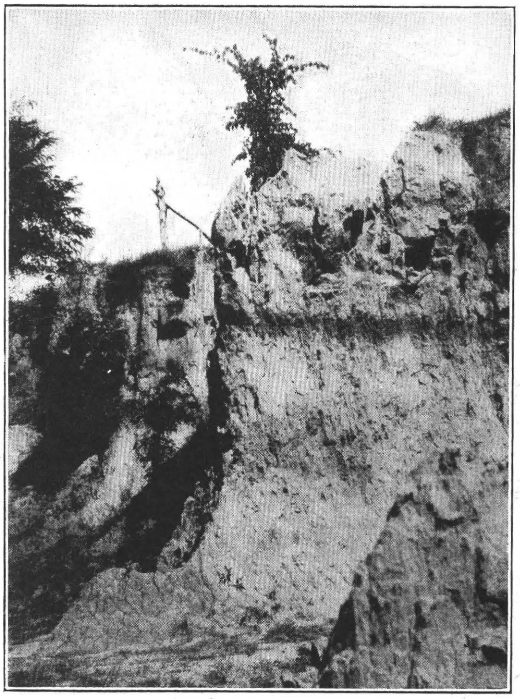

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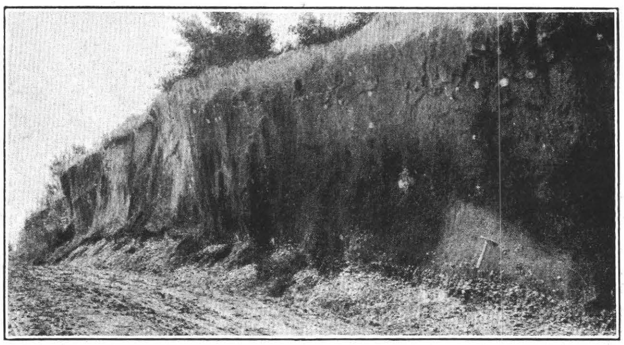

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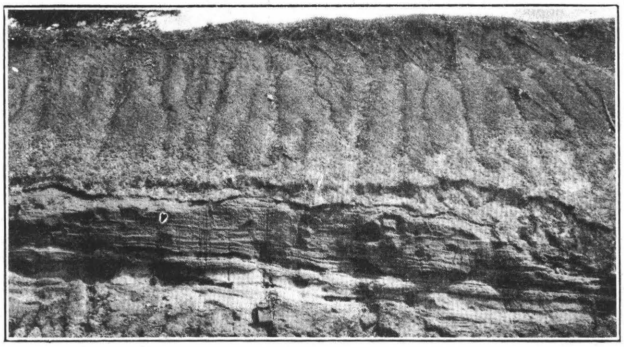


G.

STRATIGRAPHIC RELATIONS OF PLIOCENE TERRACE DEPOSITS.

A, Terrace deposit resting on strata of Wilcox group and overlain by 2 feet of loess 4½ miles east of Batesville, Miss. *B*, Terrace deposit resting on strata of Wilcox group and overlain by 2 feet of loess 5 miles northeast of Sardis, Miss. *C*, Reworked terrace gravel on deformed and eroded edges of Tuscaloosa formation, Cottondale, Ala. *D*, Eastern edge of terrace deposit resting on strata of Wilcox group and overlain by loess 2½ miles north of Batesville, Miss. *E*, Terrace deposit overlain by loess, with well-preserved old soil between, 15 miles east of Yazoo City, Miss. *F*, Terrace deposit overlain by loess 1½ miles south of Edwards, Miss.; apparent gradation from one to the other probably due to creep. *G*, Terrace deposit, perhaps somewhat shifted and reworked, resting on Tuscaloosa formation, Tuscaloosa, Ala.

longing in underlying formations, and in part a terrace deposit or a series of terrace deposits along the Mississippi and Tombigbee and perhaps other streams, thus differing markedly from and having little relation to the "Lafayette" of most of the broad regions between these rivers? The gravel exposed in the pits east of Iuka, for example, is evidently neither a Quaternary terrace deposit nor a mantle formation corresponding to descriptions of the "Lafayette," for it dips under Cretaceous strata and belongs in that system, as was inferred by L. C. Johnson[1] as long ago as 1887. Other gravels have been found to belong at other places in the Cretaceous and Tertiary systems.

The attempt to answer this question was begun by making a traverse westward from Oxford, Miss., in company with the State geologist, Dr. E. N. Lowe. The gravel area was entered about 9 miles east of Batesville. West of this point not only the deposits but also the surface features differ more or less markedly from those to the east, although the general altitude is not much lower. As discussed more fully under "Physiographic record," the principal difference in surface features is that to the east there are no extensive flat upland areas, whereas to the west the slightly lower interstream areas are commonly flat-topped, and from many points it is evident that several have almost exactly the same height, though different groups have different heights, suggesting several terraces.

Similar examinations were then made west of Holly Springs and near Grenada, Durant, Canton, Jackson, Vicksburg, Natchez, and Fort Adams, Miss., and St. Francisville and Baton Rouge, La. The same gravels were followed eastward across the State to the great deposits at Weathersby, Montrose, and other places, which Matson[2] has included in the Citronelle formation. The gravels in Tishomingo County, in the northeast corner of the State, and those along the Tombigbee and its branches, particularly in and near Greene County, Ala., were then examined. In some districts the evidence that the deposits are remnants of terraces is so strong as to be thoroughly convincing. Elsewhere, especially where the underlying rocks are limestone or clay, as near the junction of the Warrior and Tombigbee, the gravel remnants are small, far apart, and discordant in height. In the writer's opinion the discordance is due to the facts that the deposits are remnants of several terraces which stood at different heights, and that the underlying materials have suffered more or less erosion while they were capped with considerable bodies of gravel, which have thus been let down, with more or less lateral shifting. Some of the gravel, however, belongs in Cretaceous and Tertiary formations.

Although the terrace deposits are somewhat difficult to recognize, because they are not well preserved and because only a very small fraction of the region of their occurrence—the western part of Mississippi—has been topographically mapped, sufficient data have been gathered to warrant the conclusion that some of the material formerly included in the "Lafayette formation" is in reality several terrace deposits. These deposits differ markedly from the "Lafayette" of most of the area under discussion, in being dissimilar to the underlying formations, in containing elements that could not have been derived from the weathering of those formations, in having a sharp lower limit, and in lying at concordant altitudes. To illustrate, nearly all the material called Lafayette formation in Lafayette County, Miss., the type locality, falls in that part now interpreted as belonging in the underlying formation. It consists of reddish silty sand and clay, such as could readily have been formed by the weathering of the underlying Wilcox deposits, and it grades downward into those deposits. But in Panola County, immediately to the west, there are extensive deposits of gravel lying at concordant and somewhat lower altitudes and having sharply defined bases. These deposits could not have been produced by the weathering of the underlying formation and are evidently terrace deposits of the Mississippi Valley. Some of them have been so profoundly eroded that they are now scarcely recognizable as terraces, but their terrace origin is shown by the facts that the eroded remnants are, so far as determined, of concordant heights, that the material is rather sharply distinct from the other material formerly referred to the Lafayette but

[1] Smith, E. A., and Johnson, L. C., Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama rivers: U. S. Geol. Survey Bull. 43, pp. 115-116, 1887.

[2] Matson, G. C., The Pliocene Citronelle formation of the Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 98, pl. 38, 1916.

now regarded as belonging with the underlying formations, and that they occupy a belt along the side of the Mississippi Valley.

NUMBER AND NAMES.

The reasons for believing that the terrace-deposit portion of the "Lafayette" represents several distinct terraces are largely found in differences in altitude, which are discussed under "Physiographic record." No reasons for subdivision have yet been found in the nature of the materials, and apparently differences in degree of weathering or dissection are not sufficiently marked to be usable as criteria. The deposits along the Mississippi seem to lie at four different heights above the river bottom, and it is inferred that they are remnants of four terraces. In addition, there are also two or more lower terraces which are assigned to the Pleistocene, and these are considerably less gravelly. Exact and reliable determinations of altitude are scarce, however, as the deposits have been worn down and dissected considerably, and much gravel has crept or been washed down over the slopes of the valleys that streams have sunk into them. Hence inferences concerning the number of terrace deposits are uncertain and will probably remain so for many years, though the number of principal developments may be determined. In order to make reference to them easier, it has seemed desirable to name the four apparently well-developed terrace deposits, and Mr. Matson [1] and the writer have agreed to call them Brookhaven, Sardis, Canton, and Loxley, in order from oldest to youngest, each deposit being extensively developed and well preserved yet abundantly exposed at or near the place for which it is named. Brookhaven is in the southern part of Mississippi, 60 miles east of Natchez; Sardis is in the northern part, 50 miles south of Memphis; Canton is in the southern part, 25 miles north of Jackson; and Loxley is in Baldwin County, southern Alabama.

CONSTITUTION.

Although the terrace deposits are such as are ordinarily called gravel, the bulk of the material is sand through which pebbles are irregularly distributed. In some places the pebbles are contiguous, but they are rarely fitted so closely together that the interstitial sand and clay is reduced to a minimum. Generally the pebbles occur in irregular and poorly defined lenses having a wide range in size. In many places pebbles are scarce and the material is more or less clayey. The terrace deposits are comparatively poorly sorted, as illustrated by the following mechanical analyses.

Sample 1 was taken from the Sardis terrace 5 miles east of Batesville, and sample 2 from the Canton terrace 3 miles west of Canton. Each sample weighed about a pound and was taken from what seemed to be a single layer lying about 8 feet below the surface. The percentages of the coarser constituents were determined with wire screens; of the finer, with a microscope.

Mechanical analyses of samples of Pliocene terrace materials from Mississippi.

Size of grains in millimeters.	Approximate percentage.	
	1	2
16.000 –11.312	0.1	0
11.312 – 8.000	.1	0
8.000 – 5.656	.3	0
5.656 – 4.000	.5	0
4.000 – 2.828	1	.1
2.828 – 2.000	1.5	.1
2.000 – 1.414	2	.3
1.414 – 1.000	2.5	.5
1.000 – .707	3	.5
.707 – .500	3	1
.500 – .3535	3	1
.3535 – .250	3.5	1
.250 – .177	6	2
.177 – .125	8	2
.125 – .0884	13	3
.0884 – .0625	11	4
.0625 – .0442	11	6
.0442 – .0312	7.5	8
.0312 – .0221	6.5	8.5
.0221 – .0156	5	10
.0156 – .0110	4	11
.0110 – .00781	2.5	9
.00781– .00552	1.5	9
.00552– .00391	1	8
.00391– .00276	.5	6
.00276– .00195	.3	5
.00195	.2	3
	98.5	99

Samples of various surficial materials from Mississippi were sent to the Bureau of Soils, United States Department of Agriculture, with the request that they be analyzed according to the standardized method of that bureau. The results are valuable for comparative studies of terrace deposits and other surficial materials.

[1] Matson, G. C., The Pliocene Citronelle formation of the Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 98, p. 180, 1916.

Analyses of surficial materials from Mississippi.

[Made by Bureau of Soils, U. S. Dept. Agr.]

No. of sample.	Locality.	Fine gravel (2 to 1 millimeters).	Coarse sand (1 to 0.5 millimeter).	Medium sand (0.5 to 0.25 millimeter).	Fine sand (0.25 to 0.1 millimeter).	Very fine sand (0.1 to 0.05 millimeter).	Silt (0.05 to 0.005 millimeter).	Clay (0.005 to 0 millimeter).	Total.
	Recent alluvium.								
32	Mississippi River silt from bank of canal 3 miles northwest of Vicksburg, Miss.	0. 0	0. 0	0. 0	0. 1	0. 6	34. 9	65. 1	100. 7
38	Mississippi River silt from foot of bluff, Natchez, Miss.	. 0	. 3	. 2	. 6	13. 6	49. 1	35. 9	99. 7
1	Alluvium of Tennessee River at Riverton, Ala.	. 6	1. 9	4. 2	39. 1	15. 9	24. 1	14. 8	100. 6
724	Composite of 20 specimens of surface soil from Delay, Miss	. 6	1. 5	. 4	2. 6	8. 8	62. 8	22. 3	99. 9
	Pleistocene alluvium.								
41	Second bottom loam at west end of wagon bridge, Tuscaloosa, Ala	. 0	. 0	. 1	2. 1	4. 5	66. 6	26. 2	99. 5
36	Clay from thin lamina in upper part of Natchez formation, Natchez, Miss.	. 0	. 0	. 1	3. 2	12. 8	46. 8	37. 2	100. 1
37	Sand from thin lamina at top of Natchez formation, Natchez, Miss	. 0	. 3	1. 0	19. 1	26. 7	39. 4	13. 5	100. 0
54	Pseudoloess 4 inches below the surface, half a mile east of Kokomo, Miss.	. 0	. 6	2. 5	48. 0	9. 6	30. 6	8. 1	99. 4
	True loess.								
941	Loess 2 feet below surface near Edwards, Miss	. 0	. 0	. 1	. 2	3. 7	88. 1	8. 1	100. 2
942	Loess 4 feet below surface near Edwards, Miss	. 0	. 0	. 0	. 0	4. 2	82. 0	13. 4	99. 6
943	Loess 5¼ feet below surface near Edwards, Miss	. 0	. 1	. 1	. 3	4. 8	83. 4	10. 5	99. 2
944	Loess 5½ feet below surface near Edwards, Miss	. 0	. 0	. 1	. 2	4. 6	83. 9	11. 9	100. 7
945	Loess 6 feet below surface near Edwards, Miss	. 0	. 0	. 1	. 2	3. 2	85. 0	10. 7	99. 2
946	"Brown loam" 2 feet below surface near Edwards, Miss	. 0	. 1	. 2	. 3	1. 5	84. 0	14. 8	100. 9
725	Loess 6 feet below surface 1 mile southwest of Flora, Miss	. 0	. 0	. 0	. 2	4. 8	81. 6	12. 6	99. 2
727	Loess 20 feet below surface at south edge of Natchez, Miss. (contains fragments of shells)	. 1	. 1	. 0	. 2	5. 6	86. 9	6. 3	99. 2
731	Loess 8 to 10 feet below surface at Yazoo City, Miss. (contains fragments of shells)	. 3	. 4	. 1	. 2	9. 6	83. 3	5. 8	99. 7
732	Loess 12 feet below surface at Yazoo City, Miss. (contains fragments of shells)	. 1	. 1	. 0	. 2	6. 2	88. 2	4. 2	99. 0
734	Loess 30 feet below surface at Yazoo City, Miss	. 0	. 0	. 1	. 2	8. 4	87. 2	3. 8	99. 7
26	Loess 4 feet below surface 3⅓ miles west of Grenada, Miss	. 0	. 0	. 0	. 5	10. 4	75. 9	12. 6	99. 4
29	Basal ¼ inch of loess at Yazoo City, Miss.	. 0	. 5	. 3	1. 2	9. 4	80. 3	7. 7	99. 4
34	"Brown loam" near Edwards, Miss	. 0	. 0	. 0	. 2	5. 9	77. 2	16. 5	99. 8
35	Loess or "brown loam" 4 feet below surface 2 miles east of Chichester, near Edwards, Miss	. 0	. 0	. 1	. 5	5. 8	81. 5	11. 6	99. 5
39	Fossil-bearing loess, Natchez, Miss., from the loess clinging to several hundred fossils (contains fragments of shells)	. 7	1. 2	. 9	4. 9	10. 8	76. 0	5. 5	100. 0
40	Loess 2 feet above base of formation at Natchez, Miss. (contains fragments of shells)	. 1	. 1	. 1	. 2	9. 2	83. 2	7. 1	100. 0
49	Loess 3 miles east-southeast of Yazoo City, Miss	. 0	. 0	. 0	. 3	5. 5	80. 7	13. 1	99. 6
50	Loess (?) 10½ miles east of Yazoo City, Miss	. 0	. 0	. 0	. 4	8. 3	74. 0	16. 4	99. 1
51	Loess 16 miles west-southwest of Canton, Miss	. 0	. 0	. 0	. 4	6. 0	82. 0	10. 9	99. 3

Analyses of surficial materials from Mississippi—Continued.

No. of sample.	Locality.	Fine gravel (2 to 1 millimeters).	Coarse sand (1 to 0.5 millimeter).	Medium sand (0.5 to 0.25 millimeter).	Fine sand (0.25 to 0.1 millimeter).	Very fine sand (0.1 to 0.05 millimeter).	Silt (0.05 to 0.005 millimeter).	Clay (0.005 to 0 millimeter).	Total.
	Quasiloess.								
11	Upper 2 feet of "brown loam" 8 miles northwest of Oxford, Miss	0.0	1.9	3.7	6.1	5.9	69.1	13.1	99.8
13	"Brown loam" 18 inches below the surface 1 mile southwest of Oxford, Miss.	.0	.2	.1	.5	4.0	72.6	22.6	100.0
15	"Brown loam" 2½ feet below the surface 2 miles southeast of Oxford, Miss	.0	1.4	1.8	4.5	4.0	71.4	16.7	99.8
17	"Brown loam" 2 feet below surface ½ mile east of Oxford, Miss	.0	.4	.4	1.7	5.5	76.2	15.0	99.2
	Mixed loess, colluvium, residuum, and terrace deposits.								
7	"Brown loam" from a groove cut from top to base in a vertical face in the head of a ravine 3 miles northwest of Oxford, Miss	.0	.1	.2	1.0	5.1	74.4	18.2	99.0
9	"Brown loam" from a groove cut from top to bottom (5 feet) in a vertical cliff 8 miles northwest of Oxford, Miss	.0	.7	.7	2.5	7.5	72.0	16.4	99.8
16	"Brown loam" 2 feet below the surface at south edge of Oxford, Miss. (probably not true loess)	.0	.4	.5	2.1	6.6	72.1	18.1	99.8
24	Mixed loess 10 feet below the surface 2½ miles north of Batesville, Miss	.2	3.6	2.2	1.8	10.1	71.9	9.2	99.0
43	Loess (?) 2 feet below surface of divide 3 miles west of Holly Springs, Miss	.0	.2	.1	.3	3.0	71.1	25.0	99.7
46	Loess (?) 4 feet below the surface 1 mile south of Sardis, Miss	.0	.0	.1	.5	8.1	73.6	16.8	99.1
48	Loess (?) 16 miles west of Yazoo City, Miss	.0	.1	.1	.6	10.7	65.0	23.3	99.8
726	Material down to 4 feet below surface 3 miles west of Grenada, Miss	.0	.1	.1	.6	4.3	78.1	16.2	99.4
728	Material down to 2 feet below surface 1½ miles south of Oxford, Miss	.0	.4	.4	1.8	3.5	73.0	20.1	99.2
729	Material 2 to 4 feet below surface (mostly colluvium), same locality as 728	.5	7.6	5.9	18.4	5.1	44.9	16.9	99.3
	Washed loess.								
33	Loess or loess wash, Vicksburg, Miss	.0	.1	.1	.4	9.3	85.4	4.8	100.1
	Recent colluvium.								
12	"Wash creep" ½ mile south of station at Oxford, Miss. (composite of 20 small handfuls	.4	4.9	5.7	17.6	9.4	50.7	11.3	100.0
	Old colluvium.								
4	Sandy silt containing pebbles ½ mile west of station at Iuka, Miss. (composite of 20 small handfuls)	.0	.4	1.6	39.6	11.5	20.0	27.0	100.1
10	"Brown loam" (?) from top of exposure below schoolhouse, at Oxford, Miss. (May belong just below "brown loam")	.0	1.1	1.7	5.4	5.4	56.1	29.3	99.0
42	Washed loam 8 feet below the surface 10 miles southeast of Corinth, Miss	.0	5.0	14.1	45.8	3.2	24.8	6.8	99.7
	Pliocene sea-terrace deposits.								
30	Clay conglomerate 6½ miles east of Pinola, Miss	5.0	9.3	7.2	18.7	16.8	19.5	22.9	99.4
52	Lafayette (?) from groove 8 feet high, 6 inches wide, and 1 inch deep, cut in cliff in gully in northeastern part of Brandon, Miss	2.0	31.0	23.0	21.3	1.2	1.4	19.7	99.6
53	"Buttress clay," Woodville, Miss	.0	.1	.3	65.5	3.4	13.8	16.6	99.7

Analyses of surficial materials from Mississippi—Continued.

No. of sample.	Locality.	Fine gravel (2 to 1 millimeters).	Coarse sand (1 to 0.5 millimeter).	Medium sand (0.5 to 0.25 millimeter).	Fine sand (0.25 to 0.1 millimeter).	Very fine sand (0.1 to 0.05 millimeter).	Silt (0.05 to 0.005 millimeter).	Clay (0.005 to 0 millimeter).	Total.
	Pliocene stream-terrace deposits.								
27	Ancient stream silt (?) 10½ miles west-southwest of Grenada, Miss.	0.4	2.1	1.7	7.1	12.0	64.6	11.1	99.0
28	Laminated loess or ancient stream silt 30 feet below the surface at Yazoo City, Miss.	.3	1.1	.5	1.4	11.2	79.9	5.6	100.0
45	Loess (like silt) 6 feet below the surface 7 miles southeast of Vidalia, Miss.	.3	3.5	4.1	11.4	5.5	63.0	11.6	99.4
47	Terrace deposit (?) 6 miles north of Sardis, Miss.	.0	.6	3.1	22.4	13.3	30.2	30.1	99.7
	Residuum of Miocene deposits.								
31	Clay from Grand Gulf formation ¾ mile east of Pinola, Miss.	.0	.0	.0	.9	5.1	65.8	27.5	99.3
	Residuum of Eocene deposits.								
8	Wilcox or Lafayette formation 10 to 20 feet below the surface ½ mile east of Oxford, Miss.	6.0	60.0	16.0	15.7	1.1	.8	.6	100.2
14	Wilcox or Lafayette formation from thin sand lamina ⅔ mile north of station at Oxford, Miss.	.0	.0	.1	2.8	20.6	42.7	33.5	99.7
18	Clay lens in Wilcox formation 1½ miles south of Oxford, Miss. A layer of iron ore has been concentrated on top of clay	.0	.0	.0	.1	2.8	58.7	37.7	99.3
19	Leaf-bearing clay at Oxford, Miss.	.0	.0	.0	.4	12.9	48.4	37.7	99.4
20	Wilcox or Lafayette formation 4 to 16 feet below the surface 1½ miles south of Oxford, Miss.	.6	4.4	4.4	68.2	4.2	9.2	8.5	99.5
21	Purple clay from Wilcox formation at Oxford, Miss.	.0	1.0	2.5	7.6	6.0	43.6	38.3	99.0
22	Clay from Lafayette or Wilcox formation at schoolhouse, Oxford, Miss.	.0	.0	.0	.6	1.0	49.6	47.8	99.0
23	Sand from Wilcox formation 10 to 20 feet below the surface 1½ miles south of Oxford, Miss.	.0	.4	1.5	81.9	5.4	5.8	4.2	99.2
25	Sand from Wilcox formation 4 miles east of Grenada, Miss. This apparently iron-free sand is interbedded with iron-bearing sand	.0	.7	8.1	90.1	.5	.1	.0	99.5
947	Residuum 3 feet below surface near Oxford, Miss.	.2	2.4	6.0	29.0	7.0	41.7	14.6	100.9
948	Residuum 6 feet below surface near Oxford, Miss.	.0	.9	2.2	11.3	6.2	70.2	9.5	100.3
	Residuum of Cretaceous deposits.								
2	Clay balls in sand 6 feet below surface 1 mile east of Iuka, Miss.	.0	.1	2.0	12.4	6.1	39.9	39.3	99.8
3	Sand surrounding clay balls 6 feet below surface 1 mile east of Iuka, Miss.	.0	1.0	8.3	70.3	1.2	3.9	15.7	100.4
5	Sand 5 miles south of Iuka, Miss.	.1	.6	1.0	48.0	31.0	10.1	8.9	99.7
6	Sand containing small masses of white clay 4½ miles east-southeast of Iuka, Miss. (Is the clay the residuum of limestone pebbles?)	.0	.1	1.3	60.0	7.2	6.0	25.5	100.1

The pebbles of the terrace deposits are mostly of subangular chert, though well-rounded quartz pebbles are common. On the other hand, among the sand grains quartz predominates, and both quartz and chert are less well rounded. Quartzite, sandstone, and some other rocks are represented among the pebbles, but limestone seems to be lacking throughout the extent of the deposits. Many pebbles of all rocks, even quartz, are ready to fall to pieces so long have they been exposed to the weather. The chert pebbles have evidently come from the areas of Paleozoic rocks bordering the Mississippi embayment, particularly central Tennessee and Kentucky and the Ozark province, for many of them contain identifiable Paleozoic fossils. Most of the quartz pebbles may have come indirectly from the Piedmont province, which extends northeastward from northeastern Alabama, but if so they probably started long ago and in the meantime have been incorporated in one, if not several, Paleozoic and younger formations, for though very resistant they are well rounded and hence have been subjected to much wear, and no transporting agent is known to have carried material from the Piedmont province to central and northern Mississippi since middle Tertiary time. The large streams have been flowing southward across this line instead of westward along it, and if the "Lafayette" is not the product of marine invasion no shore-line transportation has been operative along this course since Miocene, if indeed since Oligocene, time.

On the whole, the lower part of each terrace deposit is more gravelly than the upper part. In many places the upper few feet is sandy clay, free from pebbles, and separated rather sharply from the underlying more gravelly portion. Generally, however, the gravel lenses become smaller, less numerous, and more sandy toward the top.

As is common with the Coastal Plain formations, the terrace deposits are more or less deeply stained with iron and are here and there cemented into sandstone and conglomerate.

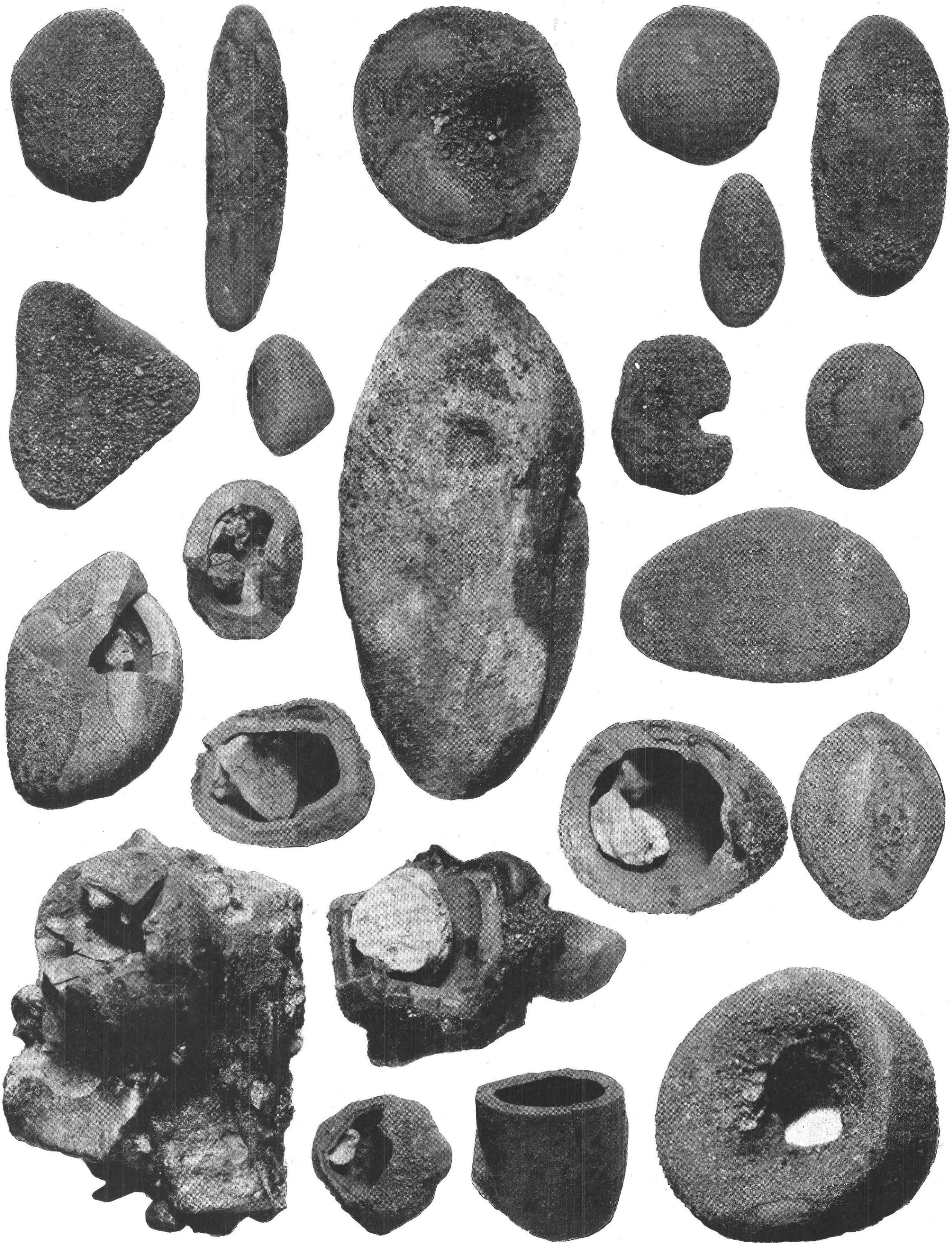
HOLLOW PEBBLES OF IRON OXIDE.

In some places—for example, near high-water mark in the bluff of the Mississippi at Natchez—iron compounds seem to have partly replaced the lime carbonate of limestone pebbles, for although here, as elsewhere in the terrace deposits, limestone pebbles are lacking, there are many hollow and fragile pebbles of iron oxide which contain a little clay. They are similar to some of the pebbles known as Klappersteine, aetites, or eagle stones. (See Pl. L.) These pebbles must have been more durable at the time of their transportation, for although they have outwardly the form of pebbles they could not have been hollow when they were formed, else the shells of individual pebbles would vary in thickness, many would be worn through, and fragments would be abundant. The clay in the interior appears to be indistinguishable from the residue of limestone after the lime carbonate has been dissolved with acid, though both materials show considerable variation.

The nature of the chemical processes involved in the replacement is not obvious. The facts (1) that in other regions layers of iron ore are common at the tops of such limestones as are overlain by marcasitic shale, (2) that in many places the contact between iron ore and limestone does not lie along a bedding plane, its position indicating that the ore is not an original bed, and (3) that fossils consisting partly of iron ore and partly of limestone are not uncommon show that the replacement of lime carbonate by some iron compound takes place rather readily under certain conditions that are common in nature. The fact that in some places the ore at such contacts is in the form of carbonate suggests that ground water saturated with iron carbonate may on reaching some lime carbonate effect replacement because of a greater solubility of the lime carbonate in water containing a moderate amount of carbon dioxide.

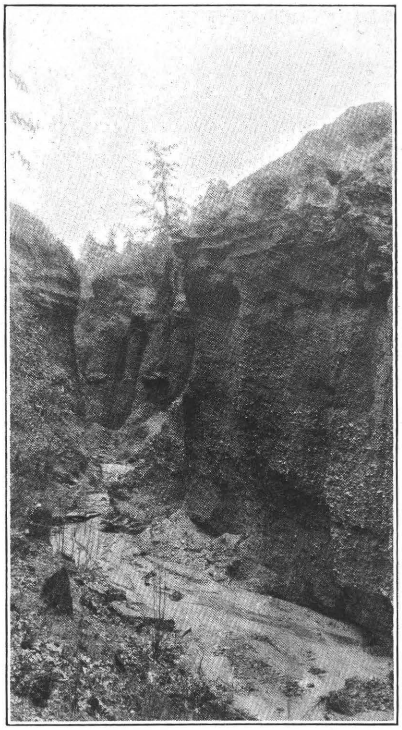
STRATIFICATION.

Although the Wilcox and other sandy Coastal Plain formations seem to show every possible variety of stratification, the terrace deposits are commonly distinguishable from them by differences in stratification alone. The strata of the terrace deposits are comparatively thick and persistent, they are commonly separated from one another by a gradation layer several inches thick, and few of them can be followed more than half a mile because, as a rule, they pinch out or become indistinct. The contrast in stratification is well shown in Plates XLVI–XLIX and LI, and its significance is believed to be that the

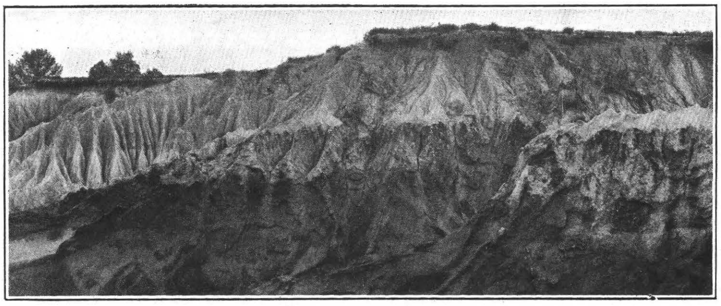


HOLLOW PEBBLES OF IRON OXIDE (KLAPPERSTEINE), POSSIBLY PRODUCED BY REPLACEMENT OF LIMESTONE PEBBLES.

Each pebble contains a little clay, and some have a little iron carbonate, suggesting that iron carbonate was the replacing compound and that it has since changed to the oxide.

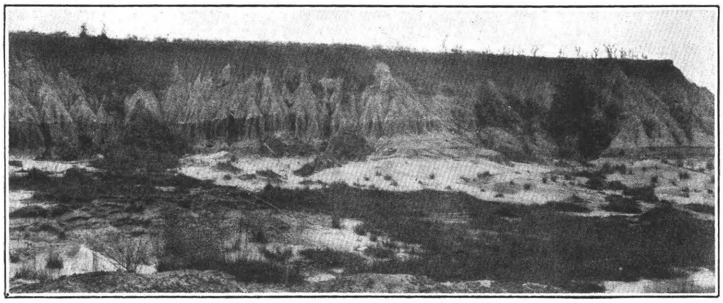


A.

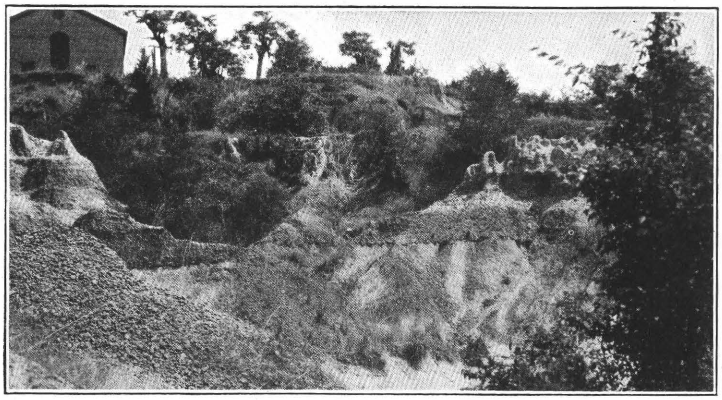


B.

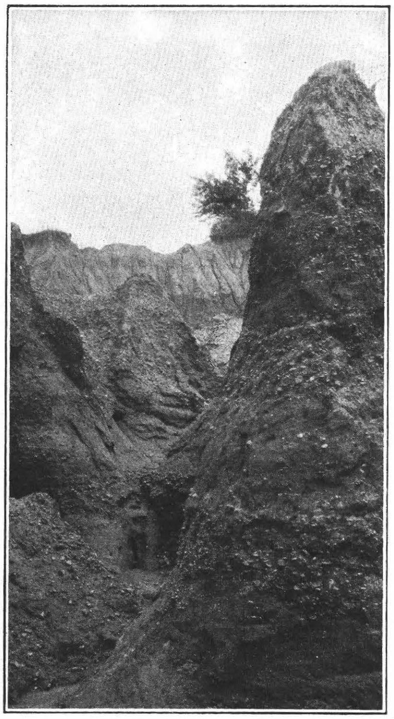
C.



D.



E.



F.

UNEVEN BEDDING AND GRAVELLY PORTIONS OF PLIOCENE TERRACE DEPOSITS.

A, Evenly stratified red gravel 2 miles north of Batesville, Miss. *B*, Uneven bedding planes 9 miles west of Holly Springs, Miss.; red (dark) material Wilcox group. *C*, Gravel in pit on campus at University, Ala. *D*, Undulating bedding plane with old soil 3 miles east of Batesville, Miss. *E*, Gravel and clay at Rocky Springs, Miss. *F*, Gravel resting upon Wilcox group 7½ miles southeast of Byhalia, Miss.

terrace deposits were made by a single large stream, whereas the Wilcox and other formations were laid down by many small streams.

STRATIGRAPHIC RELATIONS.

The terrace deposits rest unconformably on rocks ranging in age from Cretaceous to Miocene or younger. In some places where the underlying formation is sandy and the terrace deposit not pebbly, it is difficult to recognize the unconformity, but there can be no doubt of its presence. Plate XLIX, *A*, *B*, *D*, *G*, shows the common appearance of the basal contact.

The chief material overlying the terrace deposits is loess, which is thickest on the bluffs of the Mississippi and gradually thins to the east. It also varies considerably along the bluffs, being 50 to 75 feet thick at Vicksburg and Natchez and scarcely half as thick west of Grenada. The contact at the base of the loess is undoubtedly unconformable everywhere and is in places marked by an ancient soil, as shown in Plate XLIX, *E*. However, as shown in Plate XLIX, *F*, in many places one formation seems to grade into the other. Most of this gradation is believed to be due to creep. At Natchez a thin layer of terrace gravel is overlain unconformably by a heavy deposit of river sand, which is apparently of early Pleistocene age, for it contains very deeply weathered pebbles from Canada. The formation which it represents has been so severely eroded that though a somewhat careful search has been made no other remnants of it have been found.

The stratigraphic relations of the terrace deposits therefore indicate that they are considerably younger than any other Tertiary deposit of the region and considerably older than the loess and probably also than the early Pleistocene gravel at Natchez.

FOSSILS.

Diligent search for fossils that might aid in the determination of age and in the interpretation of the terrace deposits has been made by the writer and several others, but almost none have been found. Silicified shells in pebbles are common but serve only to show that the material is post-Paleozoic. Petrified wood is not at all rare, but it has been considered of little value in this study, for it might have been taken from some older formation and reburied in the terrace deposits. The writer, however, found some large logs that could scarcely have been reworked—they are not only too large but are broken into sections which retain their natural position and orientation. Thin sections of some of this petrified wood have been cut and submitted to F. H. Knowlton, who says:

> One specimen is a conifer, probably *Sequoia*, and the other a dicotyledon, perhaps *Quercus*. It is not possible to fix the age, though I think it is probably Tertiary, but beyond this I would not venture an opinion.

AGE AND CORRELATION.

The assignment of the terrace deposits to the Pliocene is based on the absence of igneous pebbles in them, their extremely weathered and dissected condition, their position topographically above the Natchez terrace, which contains pebbles of glacial origin and is believed to be of early Pleistocene age, and the fact that they may be traced almost continuously into great deposits in the southern part of the State, some of which are unquestionably Pliocene.[1] The terrace deposits are certainly younger than Oligocene, for they overlie formations of that age, and they are older than any of the loess, which is Pleistocene. Their appearance and relations indicate that they are much younger than the Oligocene formations and yet much older than the loess.

UPLAND SURFICIAL MATERIALS.

CLASSIFICATION AND TERMINOLOGY.

For some purposes it is desirable to classify the material near the surface of the earth according to the extent and nature of its modification by weathering and other erosive processes. In the region under discussion the upland surficial deposits seem to fall naturally into the principal divisions named below, from above downward. For convenience these will be called layers, though most of them have not been laid down as true strata.

1. The surface soil, about a foot thick, containing more or less organic matter and other matter that has been modified by organic agencies.

2. A discontinuous but ubiquitous layer from 1 foot to 15 feet or more in thickness, consist-

[1] Matson, G. C., op. cit.

ing of material from the outcropping edges of underlying formations which has been washed down slopes by sheet floods and small rills.

3. A layer from 1 foot to 4 or 5 feet thick, consisting of surface portions of underlying formations which have crept a few or many feet down slopes. Both Nos. 2 and 3 are as a rule scarce or altogether lacking on the crests of divides.

4. A layer of material in place, from 1 foot to 5 feet in thickness and very deeply weathered.

5. A much less but still deeply weathered layer extending from No. 4 down to the lowest dry-season position of the ground-water surface. In other words, this division includes all the material below No. 4 which is subject to alternate wetting and drying and as a consequence exhibits certain peculiarities, particularly as regards its content of iron oxide. It may be subdivided into two parts at the ordinary position of ground water and is often found at two horizons because of perched ground water.

6. Below the dry-season ground-water table the Coastal Plain strata are practically a unit as regards weathering and consist largely of unconsolidated sand and clay many hundred feet thick, resting upon a floor of hard Paleozoic rocks. This division is scarcely surficial, and yet it seems to fall under the name regolith, which was proposed for unconsolidated surficial deposits.

The terms in use for surficial materials and also those proposed but not yet current are only in part satisfactory for the materials listed above.

Layer 1 is commonly called "soil," but many writers use this word in a broader sense to include this layer, the underlying subsoil, and varying amounts of lower unconsolidated material.

For layer 2 the descriptive word "colluvial" would be used by some geologists, but this term is an adjective and it has been used for deposits of other kinds. Merrill[1] restricts it to "talus and cliff débris," a definition that would exclude layer 2. On the other hand, Hilgard[2] uses it in a much broader sense for the product of "rolling or sliding down, washing of rains, sweeping of wind, etc." He does not mention cliff débris, though he speaks of landslides and creep and says that "colluvial soils form a large portion of rolling and hilly uplands." On the whole, other authorities seem inclined to use the term in a broad sense more or less similar to Hilgard's usage, but most authors of geologic textbooks do not use it at all. The adjective "pluvial" (from pluvius, rain) has been used for such deposits, but there is no corresponding noun, and, furthermore, rain ceases to be rain after it reaches the surface of the earth.

Layer 3 is the result of a process for which the word "creep" is generally used, but there seems to be no corresponding noun for the product.

Layer 4, produced by the weathering of underlying beds in place, might be called residuum, but it is not exactly formed in place by rock decay and left as a residue after the leaching out of the more soluble products, for materials so extensively oxidized as those of most of the formations underlying uplands in Mississippi can scarcely be said to decay further, and these materials consist generally of about equally insoluble substances—mainly quartz, clay substance, and iron oxide—and hence they are subject to little change in constitution through the carrying away of more soluble parts. Furthermore, layer 5, the layer between the subsoil and the ground-water table, though differing in important respects from layer 4, is almost as truly residual. "Eluvium" also is not sufficiently definite and restricted.

The great mass of material below layer 5, comprising all the unconsolidated deposits below the dry-season water table, is somewhat peculiar to areas of Cretaceous and Tertiary deposits in this and other parts of the Coastal Plain, for in few other places does a great thickness of largely unconsolidated material perpetually saturated with water rest upon a floor of hard rock. For this material there seems to be no distinctive name. It might be called "regolith," a name proposed by Merrill[3] for the "entire mantle of unconsolidated material" resting upon "solid rock," but this term would include all the other members in the list, for though here and there the Coastal Plain strata are cemented they are on the whole comparatively unconsolidated.

Other more or less generally current terms seem still less applicable to the surficial mate-

[1] Merrill, G. P., A treatise on rocks, rock weathering, and soils, p. 319, 1897; new ed., p. 307, 1906.

[2] Hilgard, E. W., Soils, p. 12, New York, 1906.

[3] Merrill, G. P., op. cit., new ed., p. 287.

rials in Mississippi and adjoining States than those already mentioned. "Saprolite," proposed by Becker [1] for "thoroughly decomposed earthy but untransported material," would include layers 4 and 5 and perhaps also a part of layers 6 and 1. As Merrill [2] remarks, it is also objectionable on other grounds. "Geest," proposed by Deluc [3] and indorsed by Eaton, Beck, McGee,[4] and others, for decayed rock in place, as opposed to alluvium, has been used in a variety of senses, and in each it seems to include more than one of the Mississippi deposits. "Local drift"[5] and "meteoric drift"[6] would indicate layers 1 to 5 but were especially intended for residual material, for which the word "drift" seems inappropriate.

TEMPORARY DEFINITIONS.

Although most of the terms available seem objectionable on one score or another, it is undesirable to burden geologic literature with additional terms, at least until careful and somewhat extended consideration can be given to the invention of new ones. For the present report the existing terminology may perhaps be made to serve if temporary definitions are given and two terms introduced which, though new, are closely allied to two already in use.

For layer 1 the word "soil" will be used in this report, the application of the term being thus restricted to that surficial material which contains much plant and plant-modified matter. The Latin word "humus" (soil) might be used in making a technical term, such as "humulite," especially as this layer generally contains much humus.

Layers 2 and 3, which together have sometimes been called a colluvial deposit, deserve a substantive appellation, and for this purpose "colluvium," corresponding to "alluvium," seems so natural that its apparent novelty is remarkable. The writer and perhaps others have used it orally for many years. This new term will be used in a broad sense as similar as possible to that given to the adjective form by Hilgard and others. It thus becomes a generic or class name, and no doubt at a later date the two species here referred to as layers 2 and 3, and perhaps others, will be set off and named. It seems necessary even now to recognize the two species, and for these the Anglo-Saxon words "wash"[7] and "creep" will be used temporarily, though it is recognized that both words are in some respects objectionable. Layer 2 is perhaps the least well washed of all aqueous deposits, and "wash" has many other meanings. "Pluvialite" seems at present not quite satisfactory, even though the ancient Romans used "pluvialis" for "produced by rain." It would seem better to limit "pluvial" to the product of true rain, including accumulations of soil particles through the beating of rain, and to classify deposits made by little rills and other water running down hillsides as of stream origin. Not only in origin but in character such deposits are more similar to stream deposits than to material moved by rain beat. However, they should not be classed with alluvium, and Hilgard's criticism of Shaler for so doing seems well taken. The Latin word "rivulus" (a rivulet) would thus seem to furnish a better foundation than "pluvius" (rain), "pluvialis" (produced by rain), or "nimbus" (pouring rain). "Creep" has been used by several authorities for the process by which layer 3 is formed, but no name seens to have been given to the result. "Creep" is not altogether satisfactory as a noun, but it may suffice until a better term is invented—perhaps "repite," from the Latin "repo," to creep. The Latin "gravitas" (weight) may be found useful as the basis for a generic term to include both the products of slow creep and landslides which gravitate down hill slopes.

For layers 4 and 5 "upper residuum" and "lower residuum" may be used temporarily, though "residuum" is misleading except as it indicates rough homology with the untransported product of weathering in other regions, where, in the process of erosion, a mere soluble part of the rock is carried away and a less soluble part thus concentrated at the surface.

A name for layer 6 can perhaps be dispensed with in this report. One seems to be needed that will mean unweathered, except for the

[1] Becker, G. F., Reconnaissance of the gold fields of the southern Appalachians: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 3, p. 289, 1895.

[2] Merrill, G. P. op. cit., new ed., p. 287.

[3] Deluc, J. A., Abrégé géologique, p. 121, Paris, 1816.

[4] McGee, W J, The Pleistocene history of northeastern Iowa: U. S. Geol. Survey Eleventh Ann. Rept., pt. 1, p. 279, 1891.

[5] Broadhead, G. C., Missouri Geol. Survey Rept., 1873-74, p. 64, 1874.

[6] Kinahan, G. H., Irish drift, subgroup meteoric drift: Royal Geol. Soc. Ireland Jour., new ser., vol. 4, pt. 3, pp. 115-121, 1877.

[7] See, for example, Hill, R. T., and Vaughan, T. W., Geology of the Edwards Plateau and the Rio Grande Plain adjacent to Austin and San Antonio, Tex.: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, p. 254, 1898.

weathering before and during deposition, and signify that the deposits are comparatively uncemented, and another would be useful for the underlying Paleozoic rocks, which are both unweathered and cemented. It will be noticed that layers 1 to 5, inclusive, lie in the belt of weathering, a part of the zone of katamorphism[1] and those below in the belt cementation. Van Hise says: "The zone of katamorphism is divisible into two belts—(1) an upper belt of weathering and (2) a lower belt of cementation. The belts are delimited by the level of ground water."

POSSIBILITY THAT SOME RECORD OF PLIOCENE TIME MAY BE LEFT IN THE COLLUVIUM OR RESIDUUM.

If throughout the broad area of uplands occupying the central and northern parts of Mississippi east of the practically single row of counties in which the Mississippi bluffs and Pliocene terraces occur the "Lafayette" consists in reality only of the outcropping portions of several underlying formations, the sedimentary record of Pliocene time would seem to be lacking in this area, for all parts of it have been visited by geologists, and no Pliocene deposit other than the "Lafayette" has ever been found. However, in a geologic sense the Pliocene epoch was not very long ago, and the questions arise: (1) May there not have been made in this region in that epoch some deposit of which, though now mostly worn away, some remnants are left on or just below the surface? (2) Even if no Pliocene deposit was made, may not the colluvium or the residuum contain material from other formations or display some other feature due to Pliocene events?

COLLUVIUM.

GENERAL NATURE.

The material lying from 1 foot to 10 feet or so below the surface of central and northern Mississippi is generally massive reddish or buff, more or less sandy clay, having at least the general appearance of such material as would be expected to develop through the weathering of underlying more or less sandy strata. The upper part, which, especially in the western half of the region, is less sandy, has been called "the yellow loam"[2] or "the brown loam."[3] Some if not all of the lower part has been regarded as "Lafayette" or Columbia. However, several inconspicuous but nevertheless definite characteristics show that this lower part is neither residuum nor a sea or stream deposit. It is not residuum, for it contains elements not found in the immediately underlying strata, and it commonly has a sharply defined base. It is not a stream or sea deposit, for it mantles the surface at all altitudes and slopes, it is comparatively unsorted, it contains fragments of soft iron-cemented sandstone that show no wear, and it partakes from place to place of the nature of the underlying material. Its features indicate that it has been produced by rain wash, modified perhaps from time to time by climatic changes, and hence it falls under the class name colluvium. Its general features are well shown in Plates LII and LIII and its possible origin suggested in Plate LIV.

The upper part, comprising much of what has been included in the brown or yellow loam, is believed to be partly eolian and related to the loess and partly much weathered colluvium and other surficial material.

PEBBLES AND BOULDERS.

DISTRIBUTION AND LITHOLOGY.

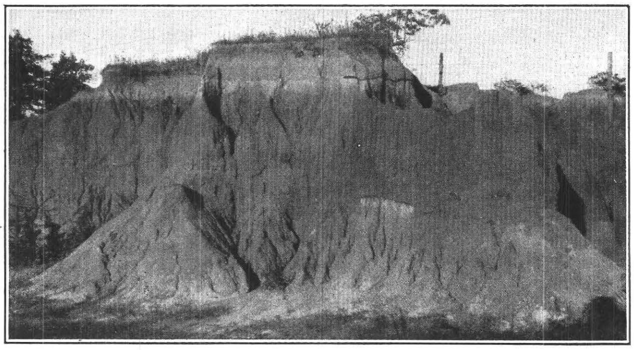
The study of the colluvium was begun at Oxford, where after a search of a few hours pebbles were found that seemed considerably larger than any occurring in the underlying Wilcox. In a few days many such pebbles were found, some being so large as to be more appropriately called boulders, whereas in the Wilcox no pebbles over half an inch in diameter were found, and few more than a quarter of an inch. On a later field trip an estimate of the average number of exotic pebbles and boulders present on a unit area in northern Mississippi indicated between 20 and 100 to the acre.

The suspicion then arose that the pebbles and boulders had come from some very high gravel deposit, practically unmodified remnants of which might be found in some part of Lafayette County or in the adjoining region. A careful search, however, was without result. Instead, more pebbles and boulders were

[1] Van Hise, C. R., A treatise on metamorphism: U. S. Geol. Survey Mon. 47, pp. 162-163, 1904.

[2] Hilgard, E. W., Geology and agriculture of Mississippi, p. 197, 1860.

[3] McGee, W J, The Lafayette formation: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, p. 393, 1891.



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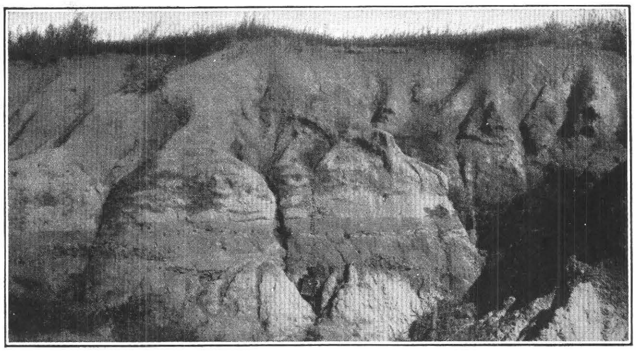

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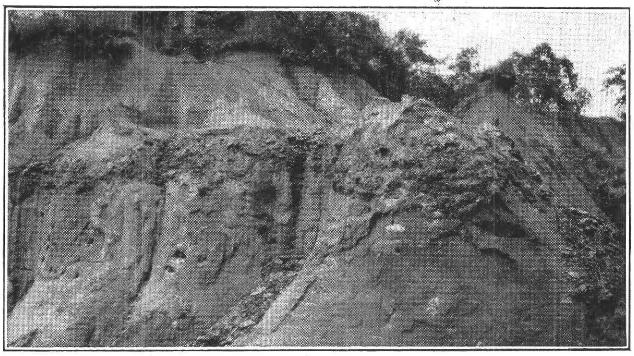

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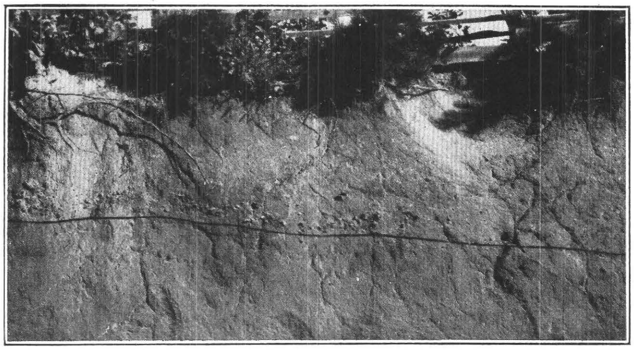

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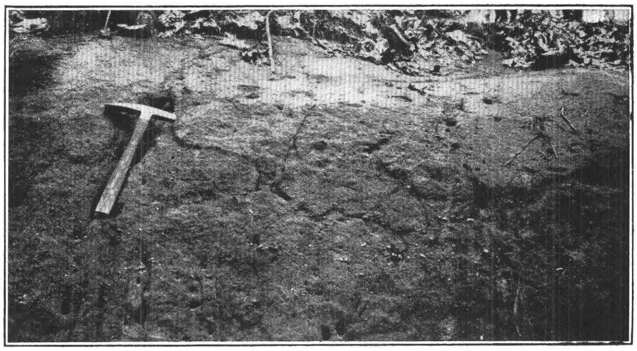

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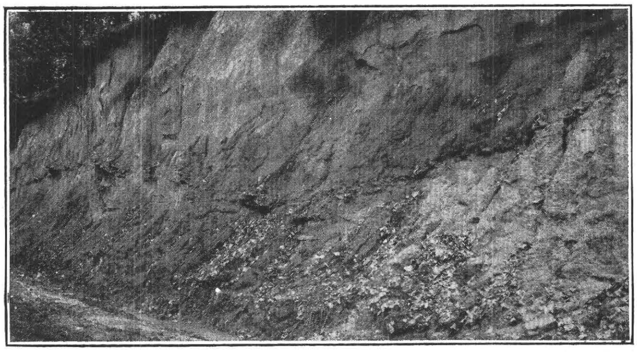
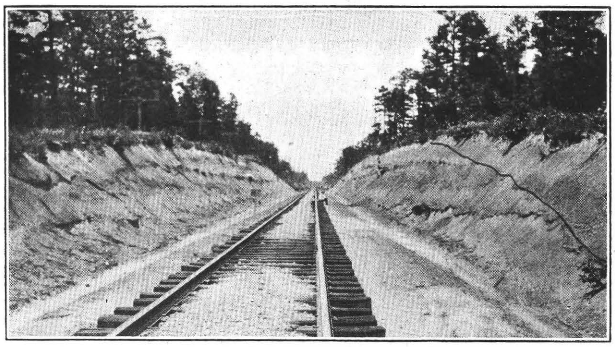


H.

TYPICAL EXPOSURES OF COLLUVIUM.

The colluvium shows little or no stratification and contains quartz pebbles and other elements commonly lacking in underlying formations, also angular fragments of iron-cemented sandstone. *A*, Colluvium about 2 feet thick, overlain by 2 feet of loess and underlain by Wilcox group, with an old soil at top, half a mile north of station at Oxford, Miss. *B*, Colluvium with fragments of iron-cemented sandstone at base, south edge of Oxford, Miss. *C*, Colluvium, from 5 to 15 feet thick, resting on Eutaw formation about 2 miles northwest of Leedy, Miss. *D*, Layer of iron-cemented sandstone fragments and concretions at base of colluvium 10 miles northwest of Holly Springs, Miss. *E*, Distribution of pebbles in subsoil 1½ miles east of Iuka, Miss. Base of colluvium indicated by black line. *F*, Distribution of pebbles in subsoil near top of Red Hill, southeast of Jackson, Miss. *G*, Colluvium resting on Citronelle formation 1 mile south of Lamberts, Ala. *H*, Colluvium, largely red sand with layer of iron-cemented sandstone fragments at base, 4 miles northeast of Holly Springs, Miss.



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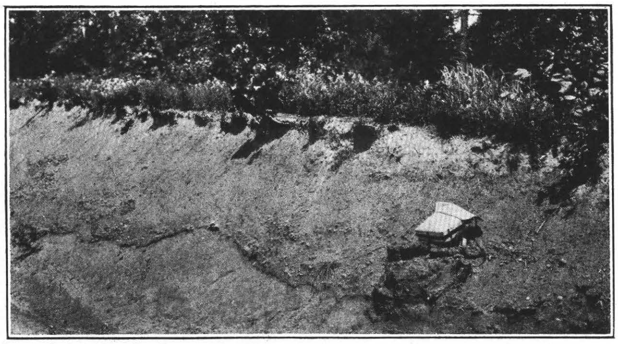

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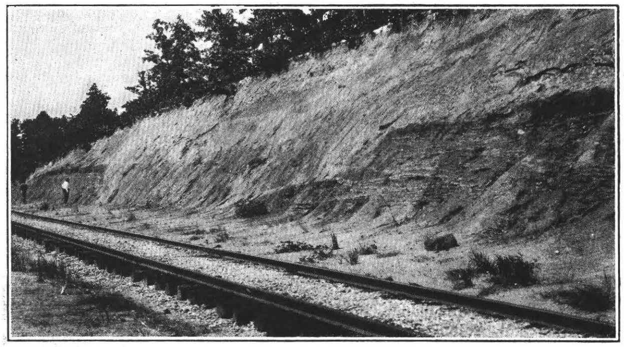

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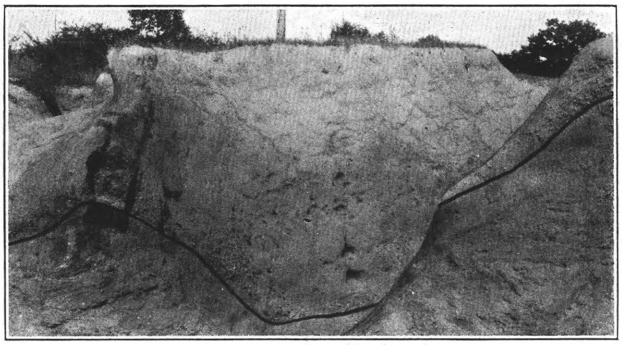

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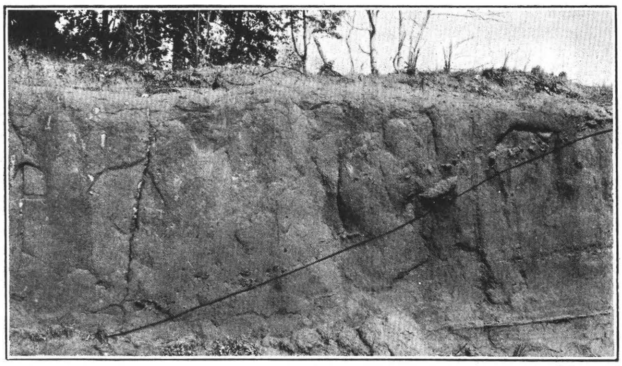

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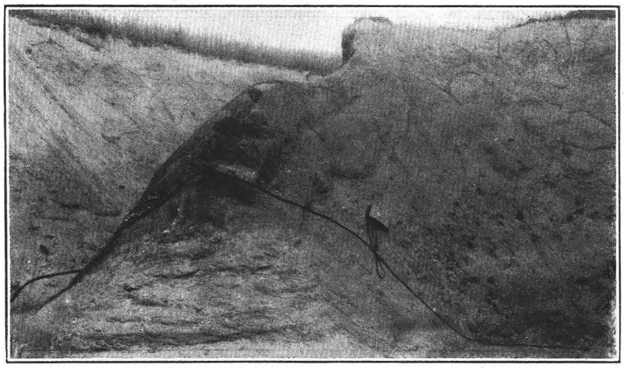

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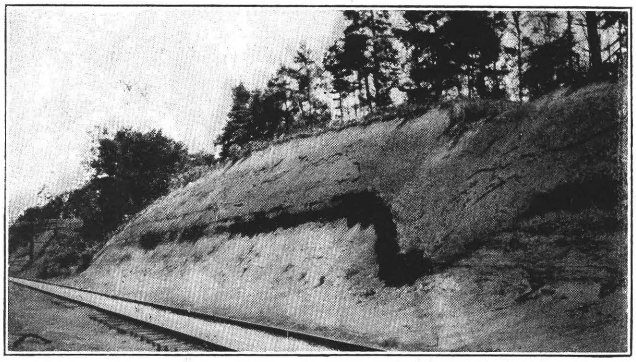

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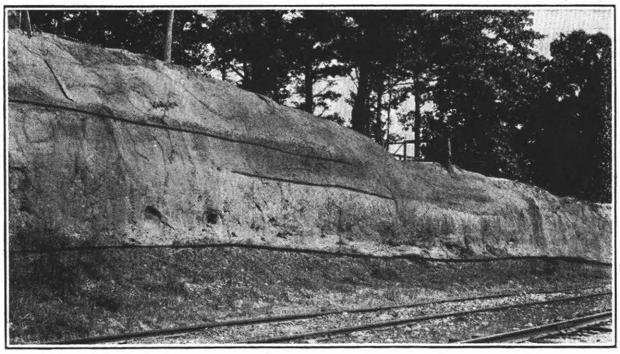
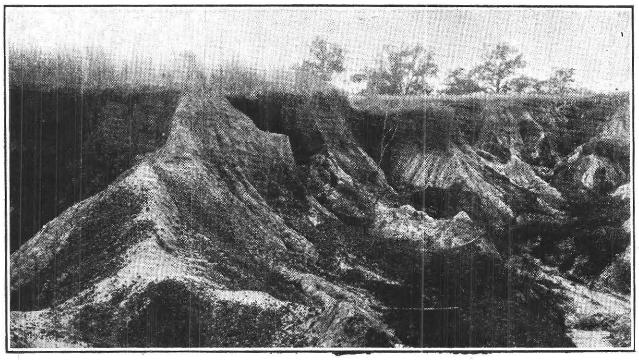


H.

EXPOSURES SUGGESTIVE OF ORIGIN OF COLLUVIUM, SHOWING PARTICULARLY THAT IT COMMONLY FILLS HOLLOWS AND IS IN SOME PLACES THOUGH RARELY DOUBLE.

Base of colluvium indicated in places by black line. *A* and *B*, Panorama of colluvium 10 miles southeast of Corinth, Miss. The concretionary mass beneath the collecting bag throws light on the origin of the surficial deposit, for it contains many Eutaw fossils, is very fragile, and has evidently been let down from the concretionary layer seen in the distance at a stratigraphic position about 10 feet higher. The concretion is of a kind characteristic of this layer. The associated pebbles, however, are not common, if indeed such pebbles occur at all in the underlying Eutaw formation, and hence the conclusion seems unavoidable that the coarser parts of overlying strata have been concentrated downward in the development of the surficial formation and that none of the material has been transported very far. *C*, Small valley filled with colluvium 8 miles southeast of Corinth. *D*, Colluvium with very uneven base 1 mile west of Iuka. *E*, Colluvium with angular fragments of iron-cemented sandstone at base, Fourmile Creek, 2 miles east of Oxford. *F*, Colluvium with uneven base half a mile west of Iuka. *G*, Gully filled with colluvium 7¼ miles southeast of Corinth. (Photograph by L. W. Stephenson.) *H*, Double (?) colluvium half a mile west of Iuka. Upper 8 or 10 feet is from railway cut; below are two layers, each several feet thick, with quartz pebbles at base.



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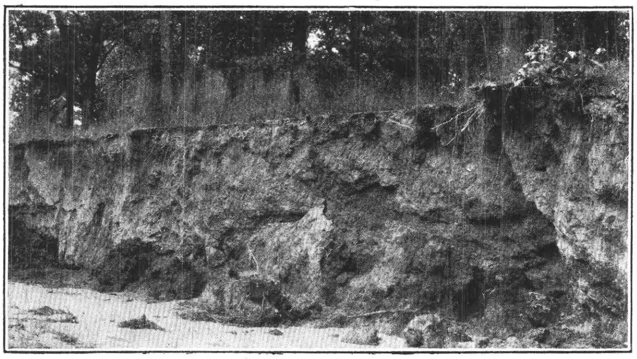

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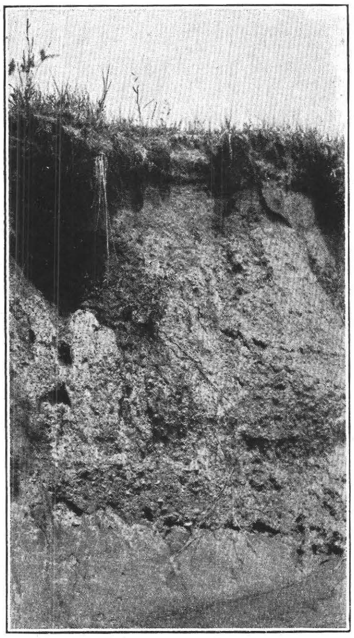

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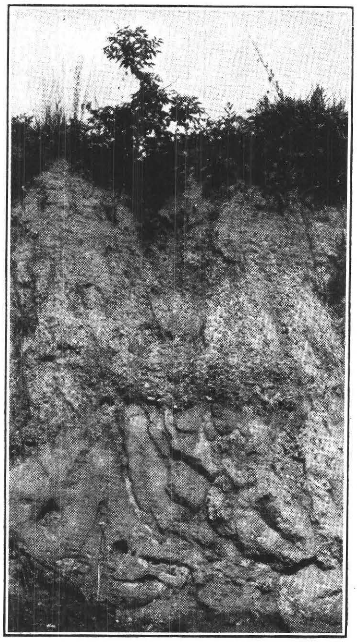

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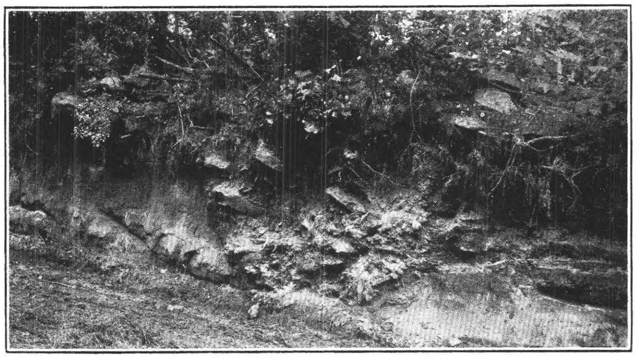

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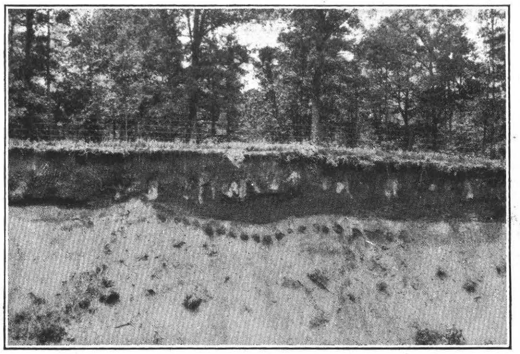
F.

RECENTLY FORMED DEPOSITS OF KNOWN ORIGIN AND HISTORY, SOMEWHAT RESEMBLING THE OLDER COLLUVIUM BUT STILL DIFFERING RATHER MARKEDLY.

A, Exposure 7 miles northeast of Canton, showing coarse material left behind in a wash; perhaps the old colluvium was formed in part by the burial of a residual accumulation of this kind. *B*, Product of creep half a mile south of Oxford. *C*, Colluvium in bank of small stream 7¼ miles southeast of Byhalia. *D*, Colluvium in bank of small stream 7¼ miles southeast of Byhalia, somewhat similar to the old colluvium. *E*, Small filled gully 5½ miles east of Grenada. *F*, Colluvium in bank of small stream 7¼ miles southeast of Byhalia.



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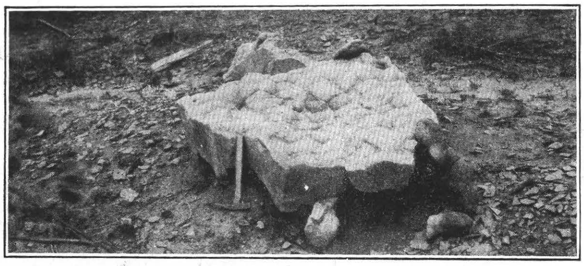

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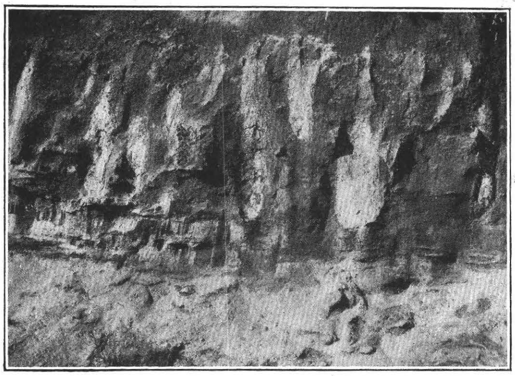

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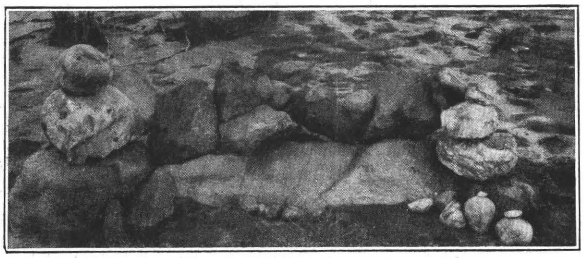

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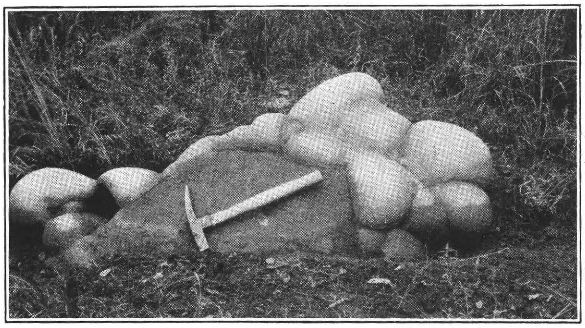

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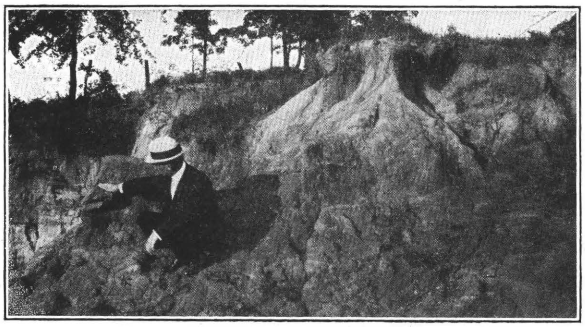

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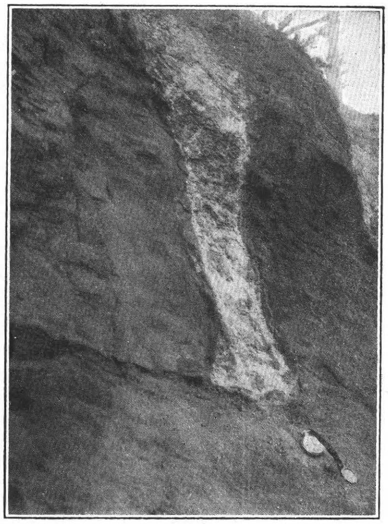


H.

REMARKABLE POCKET-LIKE FEATURES, SUGGESTING FILLED BURROWS OR POTHOLES, AND PEBBLES AND BOULDERS OF QUARTZ AND QUARTZITE FROM COLLUVIUM.

A, Filled burrows (?) extending below colluvium 3¾ miles southeast of Corinth, Miss. (Photograph by L. W. Stephenson.) *B*, Botryoidal quartzite from colluvium 5½ miles south of Oxford, Miss. *C*, Filled burrows (?) extending below colluvium 4½ miles southeast of Corinth, Miss. (Photograph by L. W. Stephenson.) *D*, Pebbles and blocks of quartz and quartzite from colluvium 1 mile northeast of Buford Mills, Miss. *E*, Filled burrow (?) extending below colluvium 1½ miles southeast of Washington, Ark. (Photograph by G. D. Harris.) *F*, Botryoidal quartzite from colluvium 5½ miles south of Oxford, Miss. *G*, Quartzite in place in colluvium three-fourths of a mile north of Oxford, Miss.; the quartzite is so much weathered that it is about to fall to pieces. *H*, Near view of one of the filled burrows (?) just northwest of Strickland, Miss. (Photograph by L, W. Stephenson.)

found, every one lying at or near the surface, without regard to altitude or physiographic relations. The pebbles and boulders not only differ from any in the underlying Wilcox, but they differ among themselves, falling naturally into several groups. Lithologically they may be classified as iron-cemented sandstone or sandy iron oxide, quartz, quartzite, and chert. All the pebbles are of very resistant materials, and yet most of them are deeply weathered. Their features are illustrated in Plate LV.

The fragments of iron-cemented sandstone show all degrees of rounding, ranging from pieces that are almost entirely angular to some that are nearly spherical, and it is generally difficult to determine whether the rounding is due to wear or to concretionary or some other cementation.

The quartz pebbles are nearly white and are well rounded, but many show more or less deep solution pits and some, particularly the larger ones, have many cracks, probably made by changes in temperature extending over a long period of time. Many of them have one or two flat faces, indicating that they have been broken by this process of insolation.

The quartzite pebbles and boulders display a wide range in form. Some look so much like the quartz pebbles that a close examination is necessary to distinguish them. On the whole they are larger, more angular, and more of a cream or brownish color. The most striking features they display are the huge size of such blocks as those 5½ miles south of Oxford, one of which is over 8 feet across, and the botryoidal form of some of the same blocks and others elsewhere, as illustrated in Plate LV, *B*, *D*, *F*. Another feature, which, though more obscure, is fully as significant with reference to the origin of some of the quartzite, is the presence of grains of certain minerals, particularly graphite, which are characteristic of the metamorphic region of northern Georgia and farther north.

Except the boulders nothing has so far been found in the residuum that promises to throw light on the Pliocene history of the region, though here and there the clay and sand portions seem to differ essentially from the underlying materials.

SOURCE.

The fact that all the pebbles and boulders are within a few feet of the surface and are much larger than any found in underlying formations indicates that they came from some other formation, and they are sufficiently numerous and observations on the size of pebbles in the underlying strata are sufficiently abundant to put this inference beyond question. The large size and angularity of such quartzite blocks as those shown in Plate LV, *B*, makes the conclusion that they are less than a mile from their place of formation practically unavoidable, but on the other hand the presence of graphite in fairly well rounded quartzite boulders 1 to 5 inches in diameter points clearly to a source in the area of metamorphic rocks 200 miles to the east. Obviously, then, the quartzite is of two varieties. Some was formed in the Coastal Plain by the cementation of sand grains with silica without the help of high temperature and pressure. Such quartzites have been found at numerous places in the Mississippi embayment, particularly in the Claiborne group, the northernmost outcrop of which is at Grenada. Being similar in certain peculiar features they may also be similar in conditions of development and perhaps also in age to the abundant quartzite blocks scattered over some parts of the Dakota plains and the region to the west. On the other hand, some of the quartzite must have been subjected to high pressure and fairly high temperature, else it would not contain delicate flakes of graphite. Such flakes could scarcely have been taken by water, wind, or any other agent from some other rock and incorporated in the sand of this rock at the time of its deposition without the delicate cleavage folia being broken up if not ground to powder or floated, because of their lightness, far out among finer deposits.

HISTORY.

Past cycles.—Although something can be determined concerning the original source of the pebbles and boulders, their history is largely problematic. The quartz and some of the quartzite pebbles and boulders evidently started in the region of metamorphic rocks 200 miles and more to the east. At many places the quartz and quartzite boulders are certainly larger than any in the formations which underlie these places, and they seem larger than those known to be in place anywhere else in the region. The large quartzite blocks and probably the iron-cemented sandstone also were formed near by, for such sandstone occurs abundantly in many formations in the region particularly near the surface and some of the quartzite blocks are too large and too angular to have been transported far. The chert pebbles had their source in a region of Paleozoic limestone; probably most of them came from central Tennessee. In any event the pebbles and boulders are evidently remnants of strata now worn away, for they are not concretions or other forms originating in their present positions. The question then arises, Did those strata belong to a single formation that covered all or practically all the region, or did they belong to several formations, some or all of which are still represented by more or less continuous deposits? It seems improbable, if not unbelievable, that they are the sole remnants of a single formation, for the removal of a formation from an area of 10,000 or 20,000 square miles would ordinarily proceed by its complete removal from some parts of the area before it had scarcely been dissected in other parts. The removal of 99.9 per cent or more from all parts of the area before all had been carried away from any part seems altogether beyond possibility, though if possible for any formation it would be so for one consisting of sand and silt containing scattered boulders. If the boulders had been let down from a single formation they should show some relation to altitude and surface features. They should be most abundant near their source and in the bottoms of washes and gullies.

The second hypothesis, that the boulders have come from several different formations, seems to accord with all known facts and principles. The original landward portion of any coastal-plain deposit, whether marine or subaerial, is likely to be coarser than the seaward portion, and as the beds off-lap one another the landward portion of each formation is exposed from the beginning of deposition, though the seaward portion is buried and protected from erosion. Hence it is not at all unlikely that the eroded landward portions of formations now present in the region once contained pebbles larger than any now found in them. If the blocks of stone too large to be moved by streams, rills, and rain wash were so numerous as to form a thick bed, they would act as a resistant stratum which in the course of erosion would come to cap the highest hills. But if they were scattered here and there in a matrix of sand and clay this finer material would be worn away from above, around, and below them, and they would be let down, with more or less lateral shifting, until by long exposure to the weather they would be broken to pieces small enough to be carried away.

Little has been determined concerning the long gaps between the times when the pebbles were integral parts of their parent rocks and the time or times when they reached their present positions, probably before the Pliocene epoch. The quartz pebbles may have passed through several cycles of weathering, transportation, and deposition. Probably they have traveled far, and to this their rounding is no doubt partly due. On the other hand, their long travel is due partly to their rounded form. Some of the quartzite may have had a similar varied history. The large, angular quartzite blocks, however, and the iron sandstones have never formed parts of any strata except those in which their cementation was accomplished and those in which they now lie. They seem to be similar in origin to the "graywethers" or "sarcen stones" of the English chalk downs, except that these are believed to be relics of formations not now present in the region. Some of the chert pebbles, particularly the smaller ones, may have been taken from their parent limestones long ago, dropped in a Coastal Plain formation, and perhaps later taken up and redeposited once or many times, but it seems probable that most of them came directly from the Appalachian province comparatively late in geologic time, during one of the more recent epochs of uplift of that province.

Present cycle.—The questions then arise, When and under what conditions were the pebbles moved from their places in the last formation of which they formed a part to their present positions, and how far did they travel? These questions are more germane to the present discussion, for it is believed that their answers afford data on the Pliocene history.

The data bearing on them are also more abundant and less inscrutable. The distribution of the pebbles, their stratigraphic relations, and certain general inferences concerning rate of erosion seem to throw light on the Pliocene history of this region.

The fact that the pebbles and boulders are nowhere concentrated into gravel beds or lenses but are widely and rather evenly scattered, particularly over the smoother middle and high portions of the surface, suggests that their lowering began, if indeed most of it did not occur, at a time when the region was lower and smoother than now, for if they had been let down by the erosion of their matrix while the country was rough they would have shown a tendency to move away from divides and down slopes, accumulating here and there in the bottoms of gullies. A similar argument indicates that their downward movement has not been great—at least not many hundred feet.

Their apparently close genetic relationship and the fact that they rest upon Coastal Plain formations ranging from middle or early Cretaceous to Oligocene indicates that they came to their present positions not longer ago than middle Tertiary time.

It seems much more likely that the pebbles came to approximately their present positions in Pliocene time than in any other epoch. If pebbles and boulders had been scattered over the surface of Mississippi in any epoch preceding the Pliocene, it seems very improbable that most of them would still remain near their original position, for in the opinion of the writer the assumption is well warranted that the uplands of central and northern Mississippi have been worn down more than 100 feet in Pliocene and Quaternary time. The present rate of erosion is probably about a foot in 10,000 years.

The pebbles and boulders have certainly been let down many feet, for they are found only in the colluvium. If they had been lowered much less than 100 feet, one might reasonably expect to find here and there remnants of the beds from which they came, but no such remnants have been found. They have not been let down many hundred feet, however, for they are somewhat evenly distributed and are almost as common on divides as anywhere else. On sharp-crested and steep-sided ridges and knobs they are scarce or lacking, but on rounded divides they seem as common as anywhere else. No beds known to be of Quaternary age have been so extensively eroded. Hence it is inferred that the beds from which the pebbles and boulders came were worn away, in part at least, in Pliocene time, and the somewhat even distribution of the pebbles and boulders suggests that the region lay lower in that epoch than it does now.

Just how the colluvium was formed is not yet clear. The distinctly greater abundance of coarse material at the base and the great extent of the deposit can apparently be explained best by climatic change, for ordinarily in the wash of soil down a slope there is little chance for such sorting. It would therefore appear that the basal coarse material was accumulated under different conditions from those which existed while the upper, finer part was being formed.

The general history of little hillside gullies in the region to-day seems to consist of (1) cutting of the gully, (2) deposition of gravelly and sandy silt in its bottom, (3) gradual obliteration of the gully by wash of fine material from above and the sides. This process being observed, the resulting deposit was carefully compared with the older colluvium, but it was found to differ markedly on the whole, though perhaps not in any single essential respect. The principal difference is that the basal coarse layer is much more irregularly developed in the present-day colluvium. This may be accounted for by the fact that owing to the activities of man in clearing forests and pasturing, etc., washing proceeds more rapidly than formerly, with results that differ not only in extent but in kind; but this seems scarcely an adequate explanation, and hence the writer is inclined to accept the hypothesis of climatic change.

On the other hand, objections may be raised to this hypothesis. The greatest climatic changes since middle Tertiary time have been those of the glacial epoch, and it might be reasonably assumed that the colluvium was produced by them, but if so it should be possible to find several deposits of colluvium of different ages and in many places one deposit superimposed upon or cutting another, whereas in only a few places, as in the railroad cut half a mile west of the depot at Iuka (see Pl. LIII, *H*), has one colluvial deposit been found above another. In any case many of the pebbles and boulders seem to date back to Pliocene time, though they may not have reached their present positions in that epoch.

Except the pebbles and their arrangement little that promises to throw light on the Pliocene history of the region has so far been found in the colluvium, though here and there the clay and sand portions seem to differ from underlying materials. One of its very remarkable features consists of forms that resemble filled burrows or potholes and extend down into underlying material. Harris [1] reproduces a photograph (see Pl. LV, *E*) showing one of these burrows, which he ascribes to a Cretaceous reptile, a Cretaceous age being assumed because the supposed burrow is in Cretaceous strata on a hillside and higher strata crop out near by. But the writer has found a great many of them, and all are connected with the colluvium. The best examples of them have been found by L. W. Stephenson in new cuts along the Illinois Central Railroad 5 to 10 miles southeast of Corinth, Miss., and pictures of some of these are shown in Plate LV. To judge by the present rate of erosion these burrows would seem to be of late Pliocene or early Pleistocene age.

RESIDUUM.

GENERAL NATURE.

Below the material which has been moved down slopes a greater or less distance by some agency, or at the surface in places where such material is lacking, lie strata of different ages that are in almost the exact position in which they were deposited and yet have been subjected to the somewhat effective weathering process of frequent wetting and drying. (See Pl. LVI.) They consist for the most part of irregularly bedded sand or clay or mixtures of the two. The upper few feet of this member, here called the upper residuum, commonly has a different appearance from the underlying part. In some places it is buffish gray or dull colored, contrasting with the brighter-hued strata below, but more generally it has red, brown, or black colors due to iron oxide, which here and there constitutes more than half of the deposit. (See Pl. LVII.) Below is a greater thickness of bright-colored and more sharply defined strata, the lower residuum, extending down to the dry-season water table.

[1] Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, pl. 15, *B*, 1910

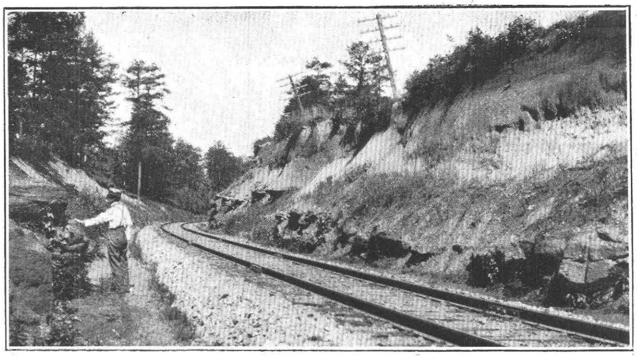
IRON CONTENT.

It seems to have been generally assumed that the iron which is so abundant or at least so conspicuous near the surface in Mississippi was deposited in one form or another along with the sediments with which it is now mingled, except for some shifting by solution and redeposition. For example, Crider [2] says: "The water passing through the Lafayette takes up iron oxide in solution and, being checked by the underlying impervious bed, deposits the iron oxide, thus cementing the sands into a compact mass." It is also assumed that the relative abundance of red color near the surface is due to some chemical change induced by exposure to the weather. Thus Berry, in the quotation given on page 130, ascribes the redness of the surficial material to dehydration of ferric oxide. Hilgard,[3] on the other hand, says that the color is due to "hydrated peroxide of iron or orange-yellow ocher." So far as the writer can determine many of the more or less reddish tints displayed may be due to either hydrous or nonhydrous iron oxide, and not only limonite and hematite may be present but perhaps turgite or other oxides and also iron compounds that are not red, such as the carbonate, sulphate, and sulphide.

If the iron has been subject to solution and redeposition and to change in constitution, it is reasonable to suspect that these processes would have been affected by any change in climate or altitude, by any burial beneath stream or sea sediments, and perhaps by faunal or floral changes. If so, the question presents itself, May not some Pliocene events have been thus recorded and the record preserved? Although the iron compounds seem to have been modified more than other portions of the residuum, perhaps other materials may also contain scraps of Pliocene history. A search has not yet brought to light any considerable record of this sort. Evidently one reason is that such records are more obscure than might be expected, and another is that the greater part of any record that was made has been effaced by erosion. The principal effect of such changes as those mentioned would have been felt within 50 feet of the surface, and the writer believes that most of the region has

[2] Crider, A. F., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, p. 46, 1906.

[3] Hilgard, E. W., op. cit., p. 7.



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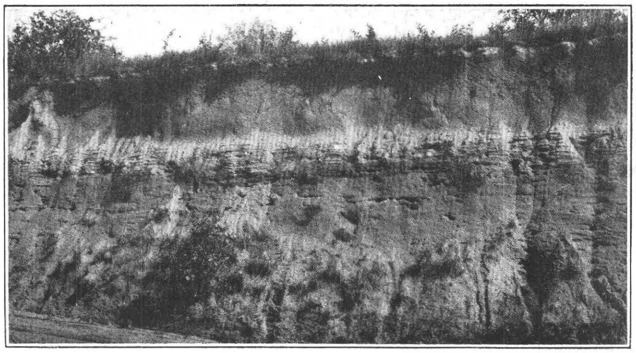

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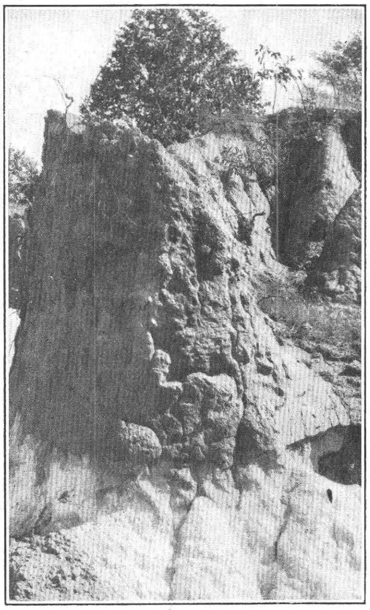

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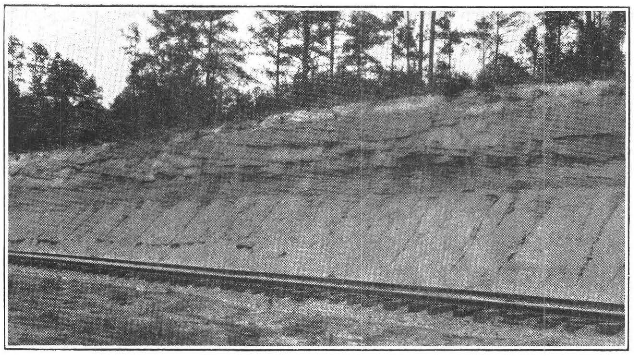

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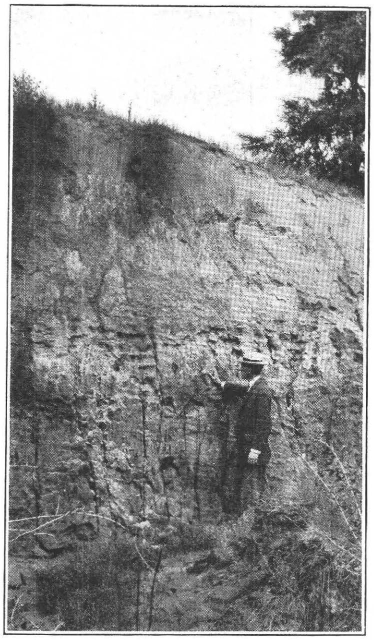

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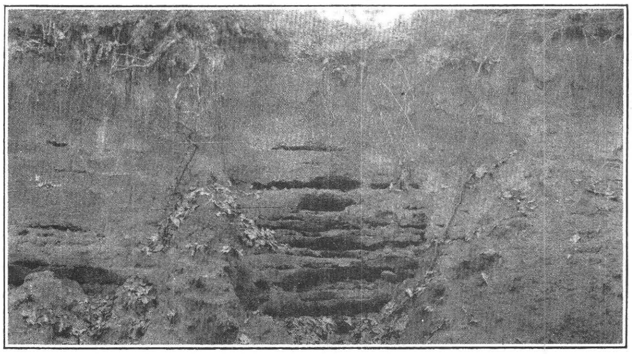
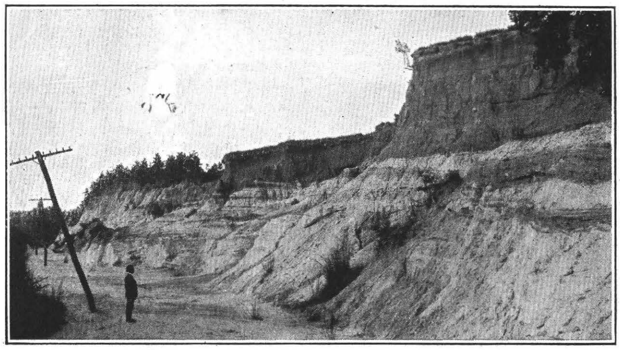


F.

RESIDUUM OR MATERIAL IN PLACE BUT MODIFIED SOMEWHAT BY WEATHERING, THOUGH LITTLE IF ANY PART HAS BEEN REMOVED.

Dr. E. A. Smith believes that much of the iron cementation shown in railway cuts has occurred since the cuts were made, but some is apparently much older, perhaps Pliocene. The residuum seems to contain material brought to it in solution and in the form of minute particles by the way of pores, from strata removed in the Pliocene and other epochs. *A*, Tuscaloosa formation 5 miles east of Tuscaloosa, Ala. *B*, Wilcox group 2 miles east of Holly Springs, Miss. *C*, Wilcox group at Oxford, Miss. *D*, Eutaw formation about 1¾ miles northwest of Leedy, Miss. *E*, Wilcox group 6½ miles east of Sardis, Miss. *F*, Wilcox group 13 miles east of Holly Springs, Miss.



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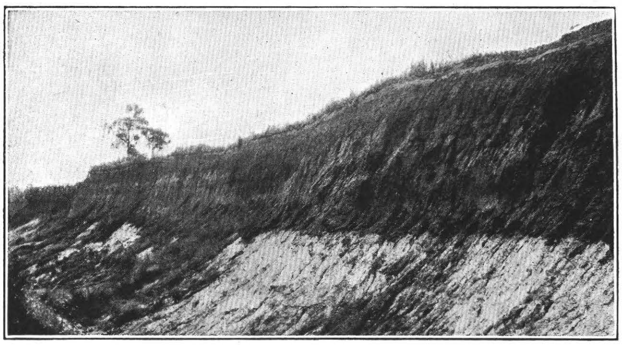

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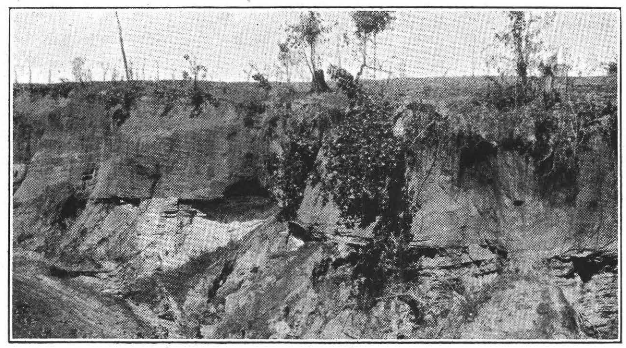

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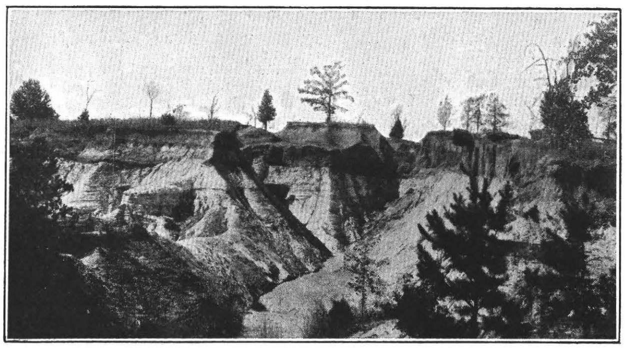

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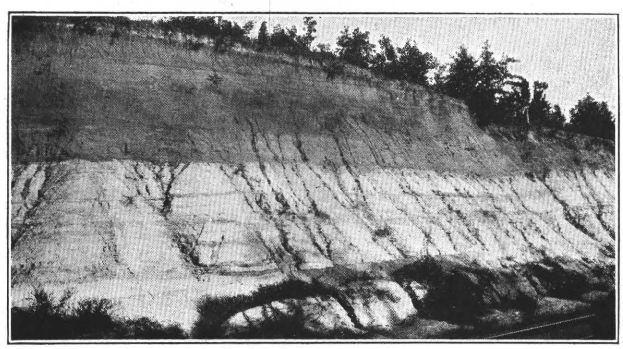

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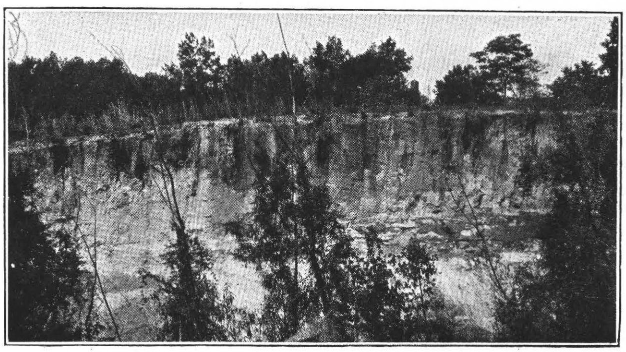

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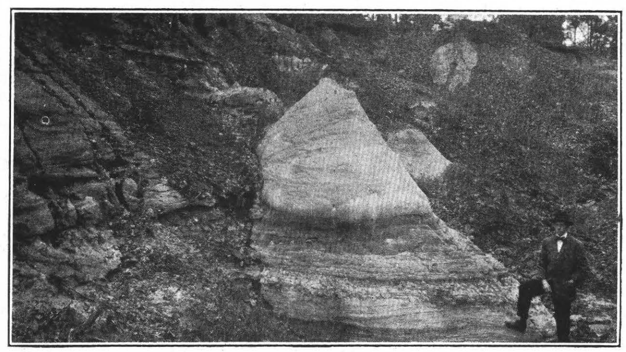


H.

VIEWS ILLUSTRATING REDDENING AND PROBABLE CONCENTRATION OF IRON COMPOUNDS NEAR THE SURFACE.

A, One mile north of station at Oxford, Miss. *B*, Gravel composed of hollow pebbles of iron oxide 1 mile north of wharf at Natchez, Miss. (See Pl. L.) *C*, Red sand with much iron oxide over impervious white clay, Grand Junction, Tenn. *D*, West side of Fourmile Creek, 2 miles east of Oxford, Miss. *E*, One mile south-southeast of Oxford, Miss.; upper part of white material is impervious clay and basal part of overlying red sand is more than half iron oxide. *F*, Three-fourths of a mile north of Oxford, Miss. *G*, Three-fourths of a mile south of Oxford, Miss. *H*, 4½ miles south of Oxford, Miss.; sand is white under clay lens showing in upper part of view but reddened to each side.

been reduced more than that amount since Pliocene time, and an additional, probably still greater, amount during Pleistocene time.

However, other facts point to the inference that the fundamental assumptions above mentioned need some modification.

It seems probable that the iron was not deposited along with the sediments where it is now found, but that it has been moved and concentrated not only through solution and redeposition but also mechanically. The basis of these inferences may be briefly stated. Much of the iron oxide is in the form of minute discrete grains, which are commonly less than a thousandth of a millimeter in diameter, and some are less than a ten-thousandth. Many of them are thus smaller than the pores of sand and other surficial material and must be carried about by percolating water. The main movement is naturally downward, for the downward movement of water after a rain is more rapid and more effective in washing than the upward and lateral movements due to capillarity and hydraulic gradient. As a result and also because the comparatively impervious bed acts as a strainer the iron is concentrated at the base of a porous layer and the top of an impervious layer.

The accumulation of iron oxide at the top of a clay layer, as illustrated by the quotation from Crider on page 146, has been ascribed to transfer in solution, but the assigned reason for precipitation of the iron seems inadequate. Only two possible causes suggest themselves, and both seem probably ineffective. First, the impervious bed is generally different in chemical constitution from the pervious bed, and something in it may cause a precipitation of the iron, but there is little reason for assuming that such a reaction occurs, particularly as the iron is concentrated only at the top of the impervious bed. Second, it is conceivable that the iron oxide is slowly being precipitated from ground water all the time, and the reason why more of it accumulates at the top of clay beds than elsewhere is that water is more nearly perpetual at such positions than elsewhere. But if this is so, it would seem that iron should accumulate at and below the water table and that the sand above should be robbed of its iron content. In many places there seems to be a concentration of iron at the top of the water table, and many iron crusts may be interpreted as marking a present or former position of the ground-water surface, but these crusts are comparatively thin instead of characterizing the saturated zone or its upper part as a whole, evidently more of the iron-rich sand is related to impervious beds than to present or former positions of the water table, and the arrangement can be much better explained by a mechanical process of downward concentration, the minute particles of iron being swept downward by rain water as it sinks into the ground and accumulating at the top of the ground water, where the rain water is stopped or its velocity greatly checked.

It should be remarked, however, that a large part of the iron oxide is very irregularly distributed, in an unaccountable manner, and much of it has evidently been affected by solution and reprecipitation, for some of it fills pores completely as a practically impervious mass and some of it coats sand grains, adhering to them closely. The iron oxide is thus found in two principal forms—as a compact mass clinging to sand grains and filling pores and as loose particles scattered through the pores. Many specimens of what seems to be deeply iron-stained red sand are easily cleaned by washing in water, and under the microscope the iron oxide is seen to consist of separate particles. The iron thus seems to be transferred both mechanically and in solution, and there is reason for believing that the dominant process is a downward mechanical concentration, followed by a slight rearrangement and compacting by solution and redeposition.

In some places, particularly where erosion is proceeding rapidly, the material most enriched with iron lies at the surface, the iron having come from material eroded away. In a railway cut half a mile south of the station at Oxford about 5 feet of colluvium overlying 10 feet of sandy Wilcox strata is exposed. A series of samples were taken at this place and submitted to Chase Palmer, of the United States Geological Survey, with the request that the percentage of total iron in each be determined. The results show a concentration of iron at the present surface and a similar concentration at the old surface which existed before the colluvium was laid down.

Percentage of metallic iron in colluvium and residuum half a mile southwest of station, Oxford, Miss.

[Chase Palmer, analyst.]

	Per cent.
Colluvium:	
1 foot below surface	3.85
2 feet below surface	3.08
3 feet below surface	2.58
4 feet below surface	2.06
Residuum:	
6 feet below surface	3.18
8 feet below surface	2.85
10 feet below surface	1.93
12 feet below surface	1.31
14 feet below surface	.89

BEARING ON PLIOCENE HISTORY OF REGION.

If the process of downward concentration of iron is now operative it has presumably been in progress for ages, though perhaps modified from time to time by climatic changes. If the surface of central and northern Mississippi has been lowered by erosion 100, 200, or 300 feet since the beginning of the Pliocene epoch, and the process of concentration has been active during this time, some iron from strata worn away in Pliocene time is probably present in the region to-day. But the search for some record of climatic and other changes in the iron deposits has thus far been fruitless. Iron-rich layers and lenses lie at many positions, which so far seem quite discordant, and much of the iron-cemented sand does not follow the bedding but cuts across it at various angles.

PHYSIOGRAPHIC RECORD.

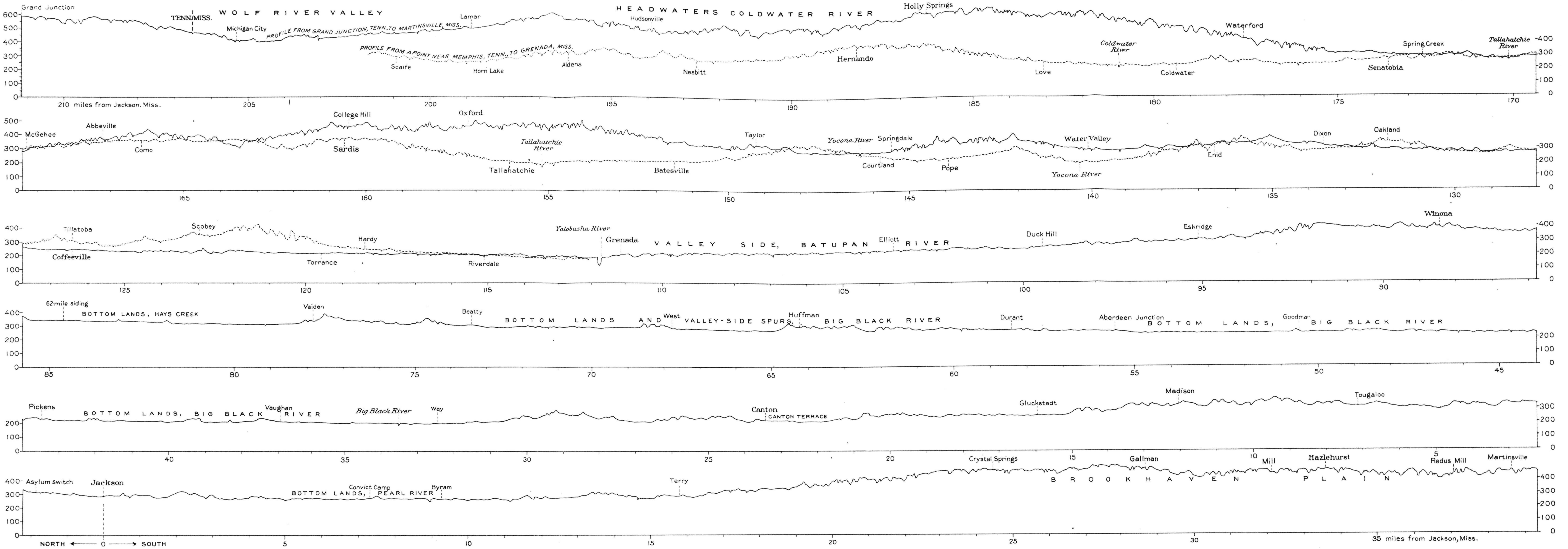
NATURE OF DATA.

In order to decipher the physiographic history of a region it is necessary first of all to have knowledge concerning areas that are approximately flat or that lie at accordant altitudes, for such features, whether large or small, may mark periods of erosion, producing extensive or incipient peneplains; of erosion and sedimentation, particularly in connection with stream terraces; or of sedimentation essentially alone, such as produces the surfaces of many sea, lake, and even stream deposits. Second, the investigator must know the arrangement of drainage lines. Third, he must know to some extent how readily the rocks underlying different parts of the region yield to erosion. Fourth, he can often use certain other facts concerning the nature of the sedimentary strata of the region and adjoining areas to which silt, sand, and gravel may have been swept from the region under study.

As detailed topographic maps have not been made for most of Mississippi, full and exact data regarding the surface features, such as are necessary for their interpretation, are comparatively meager. The literature concerning Mississippi seems to contain no descriptions of peneplains and little reference to terraces. The drainage lines are well shown on many maps of the State, but they appear in greatest detail on the General Land Office map, upon which most commercial maps are based. Information of other sorts is still comparatively scarce, though it has been considerably augmented by the present study.

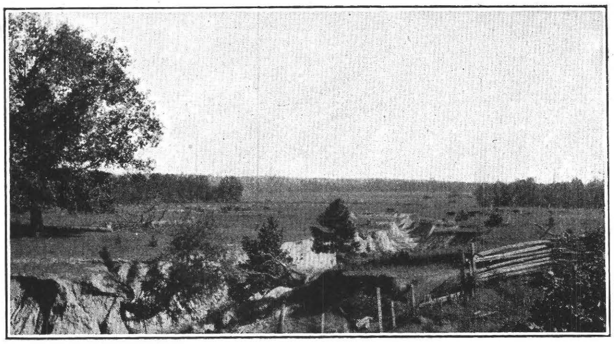
The basis of the inferences set forth in this report consists of published maps and descriptions of the region; unpublished topographic and physiographic observations of other geologists, particularly Dr. E. N. Lowe, State geologist, and members of the section of Coastal Plain investigations of the United States Geological Survey; results of spirit leveling, the profiles, generously furnished by many railroads (see Pl. LVIII), being of especial value; and notes on the appearance of the surface, made by the writer as he traveled by rail and buggy throughout the region, these notes being correlated with points of known altitude by the help of barometric readings between such points.

As good topographic maps are not available, it was necessary to use a barometer constantly, and although the readings of this instrument are subject to unknown and variable corrections, still, by using all possible means of checking, results of some value were obtained. The checks consisted of established bench marks, Weather Bureau records of air pressure for the times during which the barometer was used, the general average diurnal variation in air pressure, previous barometer readings, and occasional sights with a hand or spirit level. The appearance of the surface to the unaided eye, although scarcely usable in checking even a barometer, was nevertheless recorded, especially where appearances and barometer readings were discordant. Part of the time a barograph was used to record the air pressure for the day at a single point, generally in a hotel, and the barometer readings were modified to accord with those of the barograph.



PROFILES ALONG ILLINOIS CENTRAL RAILROAD FROM GRAND JUNCTION, TENN., THROUGH JACKSON TO MARTINSVILLE, MISS., AND FROM A POINT NEAR MEMPHIS, TENN., TO GRENADA, MISS.

Profiles show surface features before cuts and fills were made.
Figures along bottoms of profiles show distances north and south from Jackson, Miss.
Vertical scale exaggerated about 20 times.



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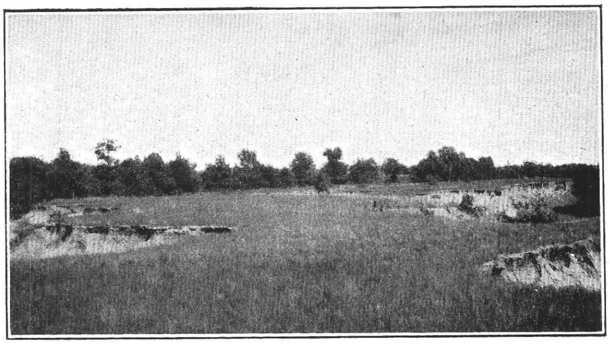

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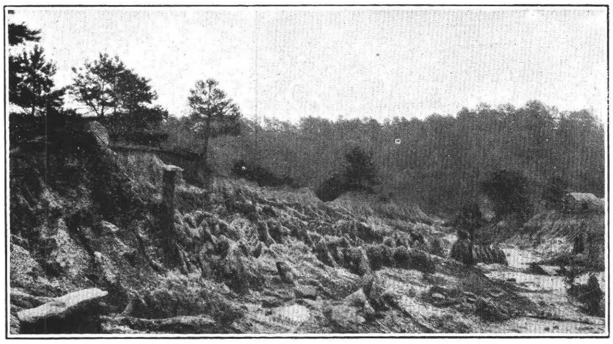

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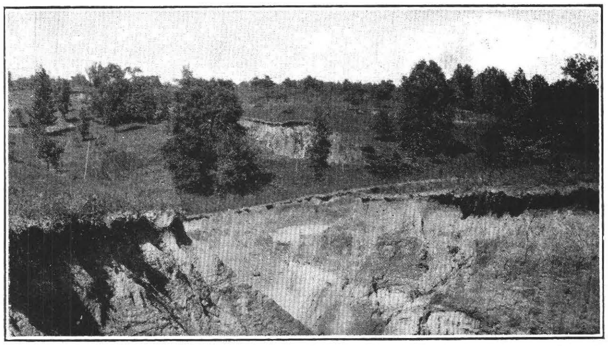

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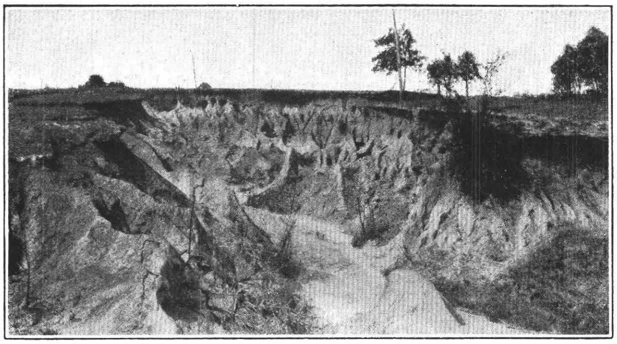

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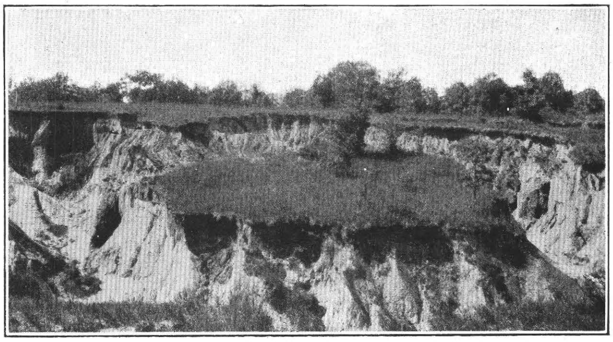

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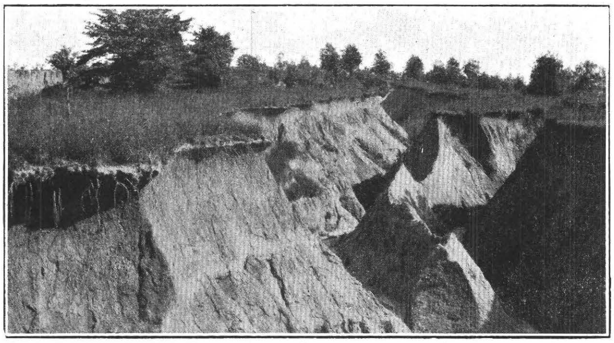

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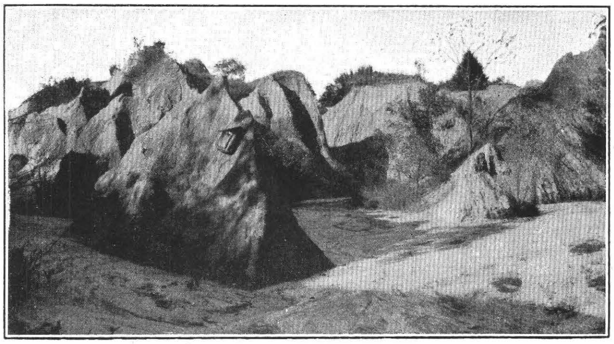
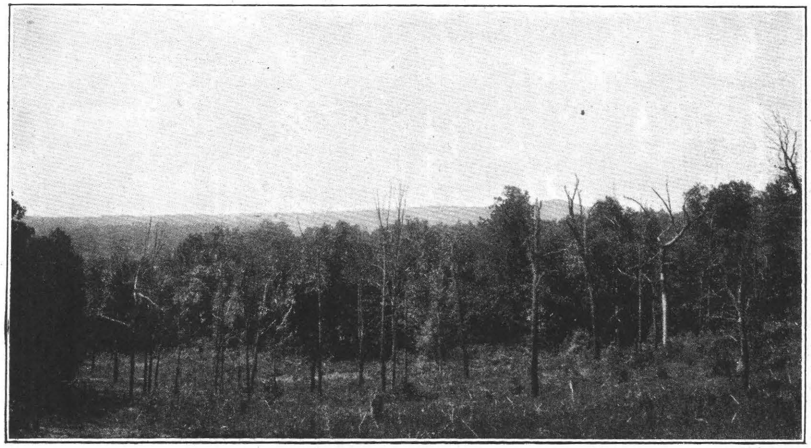


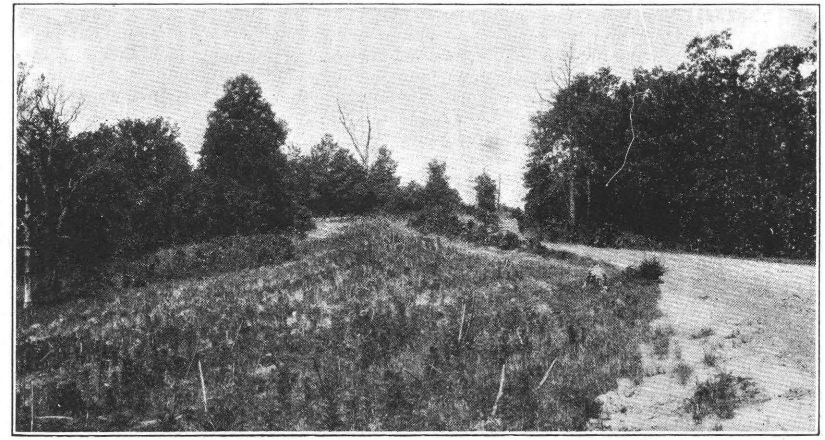
H.

VIEWS ILLUSTRATING OCCURRENCE AND MODE OF DEVELOPMENT AND THE EXCELLENT EXPOSURES AFFORDED BY OLD FIELD GULLIES.

Such gullies may have played an important part in the Pliocene erosion of the region, though they were no doubt much less numerous than to-day. The part played by the sod in resisting erosion is well shown. Many of the gullies have rounded instead of V-shaped heads and evidently grow neither through erosion by water flowing into their heads nor through softening of materials by underground water issuing as a seepage, but only because of the fact that the rain which falls into them finds erosion easier than that which falls on sodded areas. *A*, Recent colluvium on border of flood plain 1¼ miles south of Delay. *B*, 8 miles south-southeast of Yazoo City. *C*, 5 miles west of Grenada. *D*, 12 miles east of Batesville. *E*, 7 miles west of Oxford. *F*, 12 miles west of Oxford. *G*, 15 miles east of Batesville. *H*, At Oxford; shows filling after deep erosion.



A.



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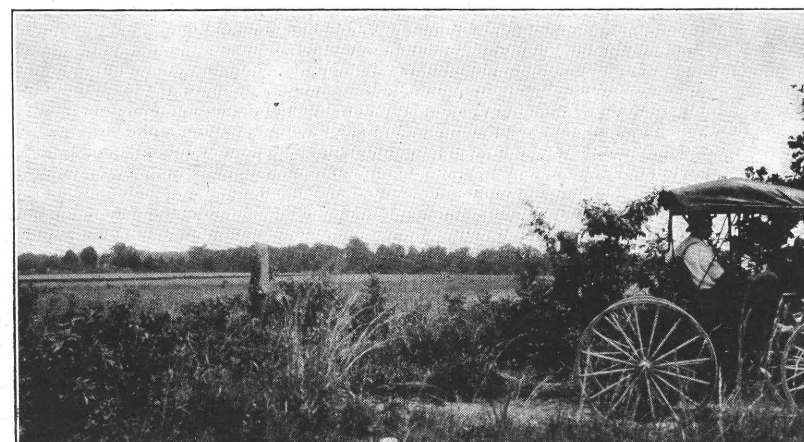

D.

VIEWS ILLUSTRATING PENEPLAINS AND MONADNOCKS.

A and *B*, Peneplain with monadnock in distance 6 miles east of Holly Springs; the road on the right follows an even-crested divide, whose top was once a part of the peneplain. *C*, Thackers Mountain, a monadnock, from a point 5½ miles south of Oxford. *D*, Flat plain at altitude of 600 feet (barometric) on Ripley road, 11 miles east of Holly Springs.

GENERAL SURFACE CONFIGURATION OF THE REGION.

The surface features of northern and central Mississippi are those of comparatively rough elevated coastal plain, sculptured for the most part in only slightly consolidated sand and clay, the layers of which are nearly flat but lenticular and commonly ill defined. The altitude ranges from about 800 feet above sea level at the tops of some of the higher hills in the northeastern part of the State to about 100 feet on Mississippi River at Vicksburg, in the southwest corner of the area here discussed. The profile in Plate LVIII shows some of these features.

The areas underlain by sand are mostly rough, and some of them are almost rugged. The areas of clay and limestone are less extensive and smoother; some parts, as for example the uplands north of West Point, being strikingly flat and prairie-like. A part of the flat country around West Point, however, is made up of terrace tops. The principal areas of clay and limestone are along the east and south sides of the region. The divides in these areas are lower than in the sand areas; on the other hand, the valley bottoms seem somewhat higher. Old field gullies are common in most parts of the State, and their general form is illustrated in Plate LIX.

The physiographic record of Pliocene time in Mississippi seems to fall into three principal divisions. One is found in the upland surface forms, another in high terraces along Mississippi River, and a third in the arrangement of drainage lines.

UPLANDS.

MONADNOCKS.

Several more or less distinct stages in erosion are recorded in the surface features. The most striking and most legible part of this record consists of isolated monadnock-like hills which rise above the general upland where the underlying material is sand, for sand seems to be much more favorable to their preservation than limestone or clay. Several of these hills are to be seen in the vicinity of Iuka; one is 3 miles southwest of the town and another 5 miles northwest. Blue Mountain, south of Ripley, and parts of the Pontotoc Ridge also belong in this class. A striking isolated hill known as Thackers Mountain stands on the west side of the Illinois Central Railroad 5 miles southwest of Oxford, and another, somewhat lower, known as Summerville Mountain, is 9 miles west-northwest of Oxford. These hills are not capped with gravel or other material differing from the country rock, though as a rule each one has a layer of sand firmly cemented by iron at or near its top.

The question then arises whether any or all of these striking isolated hills have been formed in one and the same cycle of erosion. Apparently the two in Lafayette County were not formed in the same cycle, for one, Thackers Mountain, rises above a high divide, whereas the other, Summerville Mountain, is on the side of the broad valley of Toby Tuby Creek, and its crest is scarcely so high as the divide between this stream and Clear Creek, the next stream to the southwest. According to barometer readings, it is also considerably lower than the divide between Tallahatchie River and Yocona River, the major drainage lines to the northwest and southeast.

Most of the isolated hills, however, stand on high uplands and their tops show more or less concordance in height. Those in the northeast corner of the State reach about 800 feet above the sea; those in the Pontotoc Ridge country, east of New Albany, about 700 feet; and Thackers Mountain about 600 feet. In Choctaw County hills that are perhaps similar in history have crests at about 650 feet, suggesting that if they are of the same age the area including Choctaw County has been uplifted, for it is no more favorably situated with reference to drainage lines than the area to the north. The similarity in height of these isolated hills is not very close, however, the high hills in any county commonly showing a discordance of 100 feet or more.

The fact that no such large masses of hard rock seem to be present anywhere in the region, except on the tops of scattered hills, suggests that their formation was started by conditions different from those of to-day. If other such masses were present in the earth and were sharply defined and not close together, no doubt in the progress of a single cycle of erosion they would come to cap isolated hills, but unless the strata were horizontal and the hard masses occurred in only one layer the hills would be discordant in height. As a matter of fact, strata belonging at the horizons of the iron-cemented hill caps are well exposed at many places and are within reach of wells in extensive areas, but no, such large, hard, and sharply defined masses have been found except on hilltops. Hence it must apparently be inferred that the formation of the hard masses began on a peneplain now marked by the tops of most of these hills and that instead of disintegrating with exposure to the weather the masses that now cap the hills have become more and more consolidated. The processes of underground mechanical concentration of iron oxide outlined on page 147 seem in accord with this inference. It seems possible if not probable that the hard masses began to develop in little hollows on a smoothish surface and then after uplift and during dissection the hard masses caused hills to develop where there had been hollows. Had there been no peneplain there might have been no such isolated hills.

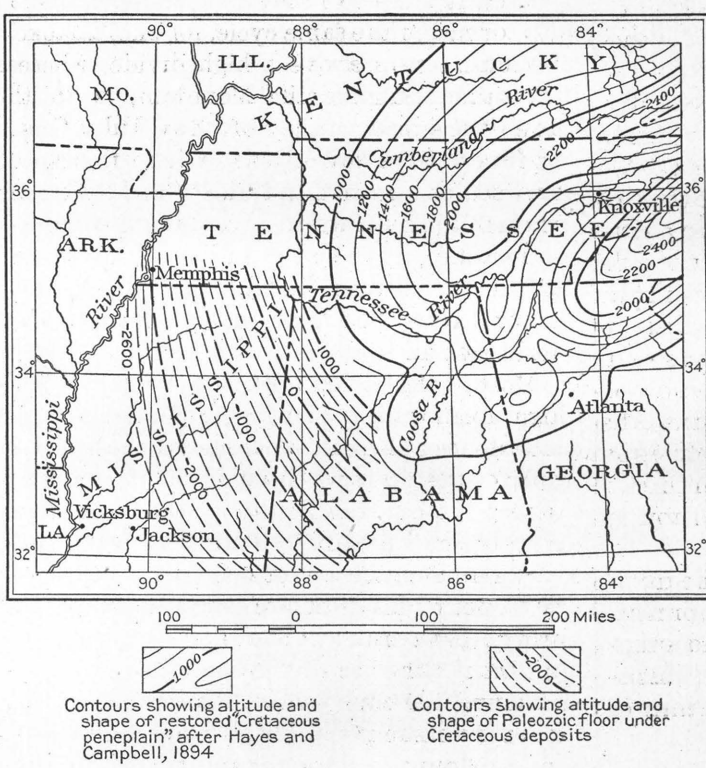

FIGURE 22.—Diagram showing the slope of the Cretaceous peneplain, according to Hayes and Campbell, and the slope of the Paleozoic floor beneath the Cretaceous deposits of Mississippi, which has been considered as being equivalent to this peneplain. The contours showing the Cretaceous surface are copied directly from an illustration in the pioneer description of peneplains of the southern Appalachians, which may be regarded as a first approximation and a representation of a hypothesis of the authors. Some believe that no peneplain of the Appalachians would, if restored, have the form of that here represented, but there is general agreement (1) that peneplains are represented in the Appalachian province, (2) that they slope outward from a central region at an angle no greater than that represented here, and (3) that in a belt around the margin of the province the slope decreases outward.

In any case their rough accordance of summits suggests a peneplain. On the other hand, the hard caps are not being softened by weather and even seem to be due in part to the forms of the hills, as well as the forms of the hills to the hard caps.

EVENNESS AND CONCORDANCE IN HEIGHT OF LOWER CRESTS.

Throughout a large part of the region the divide crests are so nearly even that more and better wagon roads are to be found on them than at any other topographic position. This is well shown in Plate LX, which shows also in the distance two low monadnocks. The evenness, however, though commonly a striking feature, is throughout most of the region only relative.

Generally the divides in any area are not only even crested but somewhat similar in height, the differences in altitude being as a rule only 50 to 100 feet. At many places, however, the average altitude of the divid seeems to increase rather abruptly by 50 or 100 feet, and the increase can scarcely be explained by the presence of harder rock. In some places the rise is so abrupt as to be unquestionable, but more commonly there is room for doubt as to the existence of any significant boundary of a physiographic feature.

The scarcity of exact data as to altitude, the uncertainties of the barometer, and the common lack of definition of the surface features make the unraveling of the upland erosional record very difficult. At hundreds of places it is evident that more of the upland surface lies at one, two, three, or even four altitudes than at any intervening positions, and that the difference is not due altogether to differences in hardness of rock nor to a combination of such differences and some other cause. But satisactory proof that any particular feature records a change in the rate or nature of erosion is difficult to obtain, and the correlation of features that probably record stages of erosion is fully as difficult.

However, after several months of study the writer has become convinced that several stages of erosion are recorded in the uplands and that these stages can be proved when detailed topographic maps are made. The data collected suggest that surfaces of concordant height stand at four different main positions. One position is represented by the tops of most of the monadnock-like hills. A second is represented by the comparatively even-crested high divides of the Pontotoc Ridge and some other less conspicuous features, particularly in a belt extending north-northeastward from the headwaters of Pearl River to Tishomingo County. A third, which is at present by far the most extensively represented, is that of most of the divides of the region. A fourth is represented by the tops of innumerable shoulders or benches, which are broadest near Mississippi River and on the more yielding formations.

Shoulders on spurs and benches on hillsides which are accordant in altitude but not sufficiently so to be terrace remnants and which bear no terrace deposits are common at still lower positions, but they are even more difficult of correlation and interpretation. Any single one might be due to a resistant bed or to some unknown cause. However, after traversing many valleys the writer has become convinced that below the four upland flats referred to above, two or more changes in rate and nature of erosion are recorded in features that are not stream or sea-cut terraces.

RELATION OF PHYSIOGRAPHIC FEATURES TO THOSE OF THE APPALACHIAN PROVINCE.

GENERAL CHARACTER OF SURFACE ALONG BORDER.

In the northeast corner of Mississippi and adjoining parts of Tennessee and Alabama opportunity is afforded for tracing the peneplains of the Coastal Plain northeastward into the Appalachian province, where three peneplains have been mapped and described and have become widely known. Fortunately several quadrangles in this critical border area have been mapped topographically.

According to Hayes,[1] the region lying northeast of the northeast corner of Mississippi, including much of central Tennessee and northeastern Alabama, belongs in the Highland Rim portion of the Interior Lowlands division of the southern Appalachian province. (See figs. 22 and 23.) Later studies have not led to any essential revision of this classification. Hayes and Campbell[2] describe two peneplains in this region. The older and higher or "Cretaceous peneplain" slopes westward and southwestward from 2,000 feet above sea level in Warren County, Tenn., 60 miles southeast of Nashville, to 1,000 feet above sea level within 100 miles, or at the rate of about 10 feet to the mile. The second or Tertiary peneplain is represented on Plate VI of the report cited, reproduced in part in figure 22,

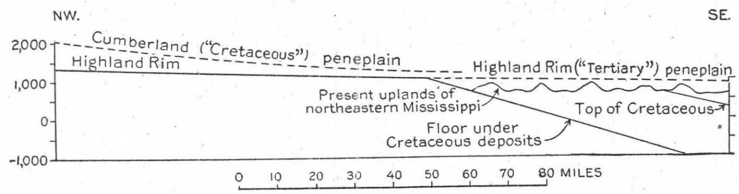

FIGURE 23.—Diagrammatic profile to show relations of upland surface features of Mississippi to the peneplains in a portion of Tennessee to the northeast, described in the text. This profile indicates that the peneplains of the Appalachian province are much younger than the floor beneath the Cretaceous sediments, and apparently the older of the two plains represented is younger than the floor under the Tertiary. This representation of the Appalachian peneplains seems subject to amendment of two principal sorts. First, the restored Cumberland peneplain may be warped up over the Nashville uplift, which falls in the left center of the figure; and, if so, the apparent discordance between it and the floor under the Cretaceous would be reduced. Second, there is strong indication that more than two peneplains are represented in this region, and each has a general slope less than those represented, and, if so, the discordance would be increased.

as having a westward and southwestward slope in the same region from 800 to 600 feet in 60 miles, or $3\frac{1}{3}$ feet to the mile. Hayes[3] a little later described three peneplains under the names Cumberland, Highland Rim, and Coosa, of which the first two apparently correspond to the Cretaceous and Tertiary, though he does not say so explicitly. The conclusions concerning these peneplains have received wide acceptance, and it would be out of place to discuss their status in a report on Mississippi.

In the vicinity of Iuka, in the northeast corner of Mississippi, the divide tops average perhaps 650 feet above the sea and are thus

[1] Hayes, C. W., Physiography of the Chattanooga district: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 2, pl. 2, 1899.

[2] Hayes, C. W., and Campbell, M. R., Geomorphology of the southern Appalachians: Nat. Geog. Mag., vol. 6, pls. 5, 6, May, 1894.

[3] Hayes, C. W., op. cit.

not far from alignment with the slope of the Tertiary peneplain above referred to. As a matter of fact, however, between 10 and 25 miles to the northeast the divides of to-day rise somewhat abruptly to 1,050 feet, and farther northeast the rise is again very slight. Thus the divides in south-central Tennessee fail to accord with the described slope of the Tertiary or Highland Rim peneplain. To the west they hold their altitude or decline very gently to 600 feet at the border of the somewhat lower area of Mississippi River terraces 25 miles east of Memphis. To the south they decline 350 feet within 80 miles, the altitude of those near West Point being only about 300 feet. The decline is not regular but is relatively steep to the belt underlain by the nonresistant Selma chalk. For example, the divide on which Guntown, 35 miles southwest of Iuka, is built has an altitude of about 350 feet. This same belt of weak rocks is, however, over 500 feet high west of Iuka, suggesting two stages of erosion. South-southwest of Iuka, along the main divide between Mississippi and Tombigbee rivers, and southward to the latitude of Natchez, or fully 250 miles, the surface ranges from 450 to 600 feet in altitude, showing from place to place a response to varying rock hardness and perhaps recording substages in erosion and slight warping. In other words, the uplands of Mississippi seem to show remnants of several plains, all of which are nearly horizontal and lie below the uplands of the adjoining Interior Lowlands subdivision of the Appalachian province and most of which, at least, have not sufficient northeastward rise to meet the "Tertiary peneplain" of Tennessee, unless they have undergone a somewhat sharp upwarp, so as to rise 400 feet in 25 miles.

HIGHLAND RIM PENEPLAIN.

Not only would the upwarp first referred to be called for if the general uplands of Mississippi are to be correlated with the Tertiary peneplain, as described, or with the Highland Rim, as it exists to-day, but also a downwarp a little farther to the northeast, for the slope of the "Tertiary peneplain" is only one-third as great as this rise, and the crests of the present divides in the vicinity of Waynesboro, Tenn., 40 miles northeast of Iuka, Miss., are still more nearly horizontal and 400 feet higher than most of the divides of northeastern Mississippi. Hence the assumption that the uplands of Mississippi are not of the same age as those of the adjoining portion of the Appalachian province seems warranted, and this assumption is verified by the fact that the divides near Waynesboro show some degree of accordance with the tops of the monadnocks near Iuka, suggesting that these two groups of features may be equivalent in age and may owe their difference in size and form to the difference in underlying materials.

East and south of Waynesboro, Tenn., there are some rather large and flat upland areas that are no doubt remnants of the plain which Hayes called the Highland Rim peneplain, and apparently considered identical with the Tertiary peneplain that he and Campbell had described three years before. One remnant is a flattish divide area of about 40 square miles, from 1 to 5 miles wide and about 22 miles long, all of which is between 1,000 and 1,080 feet above sea level. The crest of the north end of this divide averages about 1,065 feet above sea level and that of the south end about 1,005 feet; in other words, the divide slopes southwestward at the rate of about 3 feet to the mile for 20 miles.

In Mississippi, 45 miles southwest of this area, is a monadnock whose top is almost 800 feet above the sea. If the divide south of Waynesboro, with its slope of 3 feet to the mile, were extended to this hill it would lie 870 feet above the sea. As, if other considerations balance, the smaller the remnant of a peneplain the lower is its altitude, it may be that the two crests are to be correlated, and this possibility is strengthened by one or two remnants of intermediate height—for example, one 3 miles southeast of Riverton, Ala., whose top is 850 feet above the sea. It is also only natural that the peneplain should be found to slope continuously in a southwesterly direction toward the sea and the master drainage line.

In view of the presence of a large stream (the Tennessee) in this region, it is remarkable that the distance between the remnants described is not greater. They are so close together and so similar in altitude that it must be inferred either that they are all remnants of the same surface or that the larger and relatively higher ones near Waynesboro belong to a somewhat older surface.

If a broader area is considered it is found that the flat near Waynesboro extends interruptedly northeastward 40 miles, or nearly to Columbia, holding the same altitude of a little over 1,000 feet; indeed, it may be carried to Duck River Ridge, 10 or 12 miles north of Columbia, whose crest is also between 1,000 and 1,050 feet above the sea. East of this ridge the surface rises gradually for at least 15 miles, to a point where it reaches 1,150 feet, and it seems to have a general eastward rise beyond that point. However, in the Hollow Springs quadrangle, 40 miles east of Columbia, where it is well developed and preserved, it has a southeastward slope from 1,200 or 1,300 feet to about 1,100 feet within 15 miles. To the north the old flat is interrupted by the Nashville Basin, the bottom of which Hayes [1] correlated with a peneplain in Georgia that he called the Coosa.

From these facts it is evident that the Highland Rim is so high and so nearly horizontal that if projected south-southwestward it would intersect nothing in northeastern Mississippi but would lie slightly above the tops of the monadnocks in that region. If extended still farther it would likewise lie just above the tops of the highest hills in Union and other counties, and at Thackers Mountain (600 feet), 70 miles southwest of the 800-foot hill near Iuka, it would lie at 660 feet. Other intermediate hills, however, suggest that the slope of 3 feet to the mile is slightly reduced in Mississippi, so that at Thackers Mountain the position of the old plain is perhaps 700 feet above the sea, this hill, like others of the monadnocks, having been worn down 100 feet or so more than the larger remnants in Tennessee.

Still farther south the old plain seems to be traceable in the tops of the highest hills as far as the latitude of Jackson, a short distance south of which it is apparently covered by strata of Pliocene age, at an altitude of about 470 feet. However, as the Pliocene overlaps somewhat it is possible that this old surface lies below the Miocene. The tracing is a little uncertain because of the lack of topographic maps, the poor preservation of the features representing the old plain, and the comparatively slight difference in height between this plain and younger and lower upland plains; but two features relieve a large part of the uncertainty. One is the comparatively strong contrast in form between the monadnock-like remnants of the old surface and the much broader remnants of younger plains, and the other is the apparently uniform response to erosion by the numerous ferruginous sand members of several formations. If no error has been made in tracing, the average slope of the old surface in Mississippi is 2 feet to the mile for 200 miles. Owing to warping, however, the slope is not regular but apparently ranges from 3 feet to the mile to horizontality, or even a slight reversed slope here and there.

COOSA PENEPLAIN.

If the old surface represented by the tops of monadnocks in Mississippi is the Highland Rim peneplain, one would expect to find remnants of the younger Coosa peneplain in some of the lower hilltops. Correlation is somewhat uncertain, because the distance from the Mississippi region to known remnants of this surface is greater than to the type region of the Highland Rim peneplain. It seems possible that the Coosa plain is compound and that its members are equivalent to the two or three upland plains of Mississippi that lie lower than the tops of the monadnocks.

According to Hayes [2] peneplains may be correlated by continuous tracing, by noting similarities in degree of dissection, by observing coincidence of projected plains, and by determining recent drainage changes. To this list may be added observations of relation to other peneplains. Apparently the Coosa peneplain can not be traced continuously into Mississippi. Its degree of dissection would presumably be different in the region under consideration from that in the type locality, because the underlying materials are very different and also because of a different arrangement of principal drainage lines. The regions are too far apart to use coincidence of projected plains as a criterion, and no recent drainage changes seem to help in correlation.

In Mississippi the next to the oldest peneplain of which remnants are preserved lies about 100 feet below the tops of the widely spaced monadnocks, and if they have been worn down 100 feet more than larger remnants its position is about 200 feet lower than that of the Highland Rim. On the other hand, it lies from 100 to several hundred feet above the present valley bottoms, which have ap-

[1] Hayes, C. W., op. cit., pl. 2.

[2] Hayes, C. W., op. cit., p. 25.

proximately adjusted gradients, and it is maturely dissected. It thus resembles the Coosa peneplain in being next below the Highland Rim peneplain, in lying considerably above present graded valley floors, in being much dissected, and in being the principal if not the only peneplain between the Highland Rim and the present valley floors. It differs from the Coosa plain in being somewhat more dissected and in being apparently one of about three that are younger than the Highland Rim. The greater dissection may be explained by more yielding materials. The Coosa plain is decidedly undulating if not rough, and it seems possible if not probable that it will be found to be compound. If so, its divisions may correspond with plains later than the Highland Rim lying lower than the tops of monadnocks in northern Mississippi.

Thus it seems possible to determine the probable age of certain peneplains in Mississippi from evidence found within the State, and this forms a basis for revising and clarifying ideas concerning the age of Appalachian peneplains. It is recognized, however, that the data are not conclusive.

WARPING OF PENEPLAINS.

The peneplains of northern and central Mississippi lie nearly horizontal, and yet all of them have suffered some warping; originally each had no doubt a slight general inclination in some direction between west and south. Their present slopes are in the same quadrant, but the directions of slope of some have apparently been shifted a little, and the amount of slope of some has been increased and of some diminished. In general, the younger the plain the gentler is its present inclination, and a considerable part of the deformation seems to have taken place in Pliocene time.

The Paleozoic floor slopes about 30 feet to the mile; the plain at the base of the Tertiary about 20 feet to the mile; the slope of one at the top of the Eocene and others buried in the Eocene is no doubt considerably less than 20 feet to the mile. Thus the slope of successive buried plains gradually decreases toward the top of the geologic time scale. The slope of the top of the Oligocene averages only about 2 feet to the mile, and still younger peneplains seem to have average slopes of less than 2 feet to the mile.

Next to the general southwestward tilting of the plains and the fact that the older the plain the greater the slope, the most striking feature of their warped form consists in the decidedly steeper average slope of the older plains south of a belt of counties in the latitude of Vicksburg. The downward bend does not follow a sharp line but is irregularly developed. On the whole, its course trends east-southeastward from Jackson. For the older plains it inclines more to the southeast, and for the younger plains to the east. The slopes of the plains continue to increase southward, and at the present coast even some of the Pliocene buried plains are tilted as much as 25 feet to the mile.

Not only do the plains slope steeply in the south end of the State, but in the central part they seem to have been warped in the opposite direction, so that north of Jackson their original gentle seaward and riverward slope has been reduced to zero or a reversed slope. So far it has not been possible to determine the details of the warping. Some features suggest that a principal axis of uplift runs from Natchez to the northeast corner of the State, and another from Mobile northeastward, and other features suggest an east-west axis through Vicksburg and another through Natchez. Perhaps the warping has followed all these lines at the same time or at different times. Determination must await the preparation of topographic maps. In any case the evidence that some of this warping occurred in Pliocene time seems convincing, for both peneplains and quasipeneplains, including those which slope down into Pliocene deposits, seem to be warped upward around Jackson, and features of terraces and the drainage confirm the inference.

TERRACES.

GENERAL FEATURES.

The presence of several ancient and high gravel terraces, principally along the Mississippi, the deep erosion of these terraces, and some other reasons for regarding them as Pliocene have been referred to under "Sedimentary record." Apparently there are four main Pliocene terraces. All of them are now discontinuous, but on account of the facts that the terrace remnants are parts of ancient valley floors which were evenly graded, and that they have not since suffered very great deformation, they can be classified and correlated roughly, and if topographic maps were available they could no doubt be traced with a good degree of certainty.

The scattered remnants of the terraces were followed southward from Illinois through Tennessee, Kentucky, and western Mississippi to Vicksburg, where they were found to broaden and swing abruptly to the east across the State and continue into Alabama. After a conference with G. C. Matson,[1] who had been working on the late Tertiary deposits of the Gulf coast, it was decided to name the four main terraces as described below and illustrated in figure 24.

BROOKHAVEN TERRACE.

The Brookhaven terrace is broad and well preserved around Brookhaven, where it now lies nearly 500 feet above the sea. On the north it rises gradually for 35 miles to the southern parts of Hinds and Rankin counties, where, notwithstanding the fact that it has been severely eroded, its scattered remnants still reach 550 feet above the sea. That this terrace or some similar gravel-formed surface must have once extended 20 or 30 miles still farther north is indicated by the gravelly soil and subsoil of the higher knobs in that belt. These knobs are all lower than the remnants of the terrace south of Jackson, apparently for two reasons—the easy erodibility of the Vicksburg and Jackson formations, which underlie this district, and the fact that the horizon of the original surface of the terrace is lower because of warping than in the vicinity of Star and other places south of Jackson. The warping is inferred from the position of several plains and terraces but particularly from that of the younger terraces, which are fairly well preserved west and northwest of Jackson.

[1] Matson, G. C., op. cit., pp. 180-186.

Thus the Brookhaven terrace, or plain, as Matson has called its seaward portion, is fully 60 miles wide and rises northward from about 450 feet to more than 550 feet, perhaps to 600 feet, and then declines to some unknown altitude greater than 450 but probably not more than 500 feet. It has been so severely deformed and eroded that present information is not sufficient to justify a statement that it is not compound. Relative to lower terraces, it is much broader in the east-west coast belt than along the Mississippi in the central and northern parts of the State, and this may be due simply to a difference in resistance of underlying materials, but differences in the process of development may also have played a part, and differences in destructive processes have almost certainly had a notable effect.

North of Vicksburg and Jackson, for the width of a county or two, no remnants of the Brookhaven terrace are now known, though pebbles let down from the deposit forming it are numerous in many places. North of Yazoo County, however, where the underlying formations are the more sandy and resistant Claiborne and Wilcox, scattered remnants of the Brookhaven terrace are found as far north as Memphis. They seem to decline very gradually to the north, or upstream, from about 460 to about 430 feet above sea level.

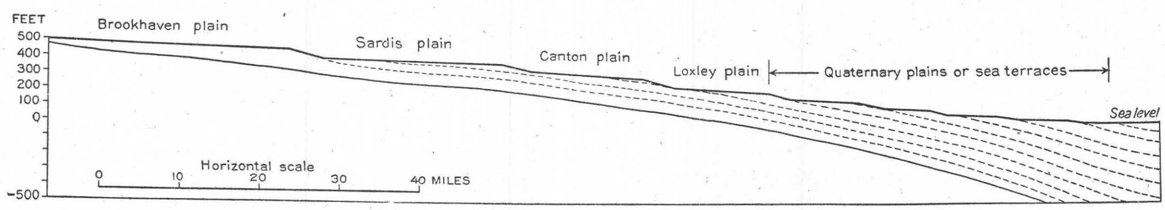

FIGURE 24.—Diagrammatic cross section of Pliocene deposits and profile of Pliocene terraces in the south end of Mississippi.

SARDIS TERRACE.

The Sardis terrace is somewhat better preserved than the Brookhaven but is still so badly eroded that in the lack of exact topographic data the identification of many of the supposed remnants is somewhat doubtful. It seems to be practically horizontal and from 2 to 10 miles wide from Sardis, where it lies nearly 400 feet above the sea, to Durant. Between Durant and Vicksburg, where no part of the Brookhaven terrace remains, there are a few remnants of the Sardis terrace. A few miles southeast of Vicksburg the terrace lies a little more than 400 feet above the sea, and east of Natchez it reaches nearly 450 feet, is 30 to 40 miles wide, and is fairly well preserved. To the east it becomes narrower and slopes to the east and south.

CANTON TERRACE.

In the vicinity of Canton, Miss., there are some very broad, rather flat, upland areas, underlain by sandy clay with gravel here and there, at an altitude of somewhat less than 300 feet above the sea, evidently remnants of a terrace. To the north the terrace seems to be nearly horizontal or to rise very gently to the Tennessee line. To the south the remnants rise to an altitude of about 370 to 380 feet at a point east of Natchez. Along the Mississippi this terrace ranges generally from 1 mile to 10 miles in width, though here and there it seems to have been cut away by the lateral swing of the river. Unlike the older terraces, it seems to be fairly well developed along some of the larger tributaries, particularly the Big Black.

LOXLEY TERRACE.

The Loxley terrace lies generally 40 to 80 feet below the Canton terrace, and its general slope is slightly greater, or more nearly like that of the present flood plains of the Mississippi and other large rivers. In the northern part of the State it lies 275 to 300 feet above the sea, or 100 feet above the present flood plain. To the south it declines gradually at about the same rate as the present flood plain to Yazoo City, where its surface buried under the loess is about 250 feet above the sea. From Yazoo City to Vicksburg it seems to be about horizontal and thus its distance above the present stream increases. Farther south its altitude increases somewhat rapidly downstream to more than 300 feet at a point east of Natchez. Apparently a terrace equivalent in age was well developed and is fairly well preserved on Pearl, Big Black, Yalobusha, and Tallahatchie rivers and on the Tombigbee, in the eastern part of the State. The terrace rises up each one of these streams, though its height above the present flood plain gradually decreases upstream—in other words, on these streams the terrace has a downstream slope which is more gentle than that of the present flood plain. However, the divergence of the two is not uniform.

WARPING OF TERRACES.

Although many of the terrace tops are undoubtedly parts of ancient flood plains, most of them differ in gradient from the present flood plains of the same streams. On the whole they have a more gentle slope, but in some parts of the State they seem to slope upstream instead of down, and these upstream slopes can be accounted for only by deformation.

The Brookhaven terrace seems to be warped upward as much as 200 feet just south of Jackson, where its position reaches 550 feet. Indeed, it seems to slope away from this district in all directions, but most steeply to the west and south. Fifty miles to the northeast it is 60 or 70 feet lower. To the east, near the Alabama line, it is over 100 feet lower, and according to Matson [1] this slope continues across Alabama. Apparently, however, another and smaller upwarp is located north of Mobile. Fifty miles south of Jackson the terrace is more than 75 feet lower. To the west also it declines to about 380 feet in Louisiana.

The site of maximum uplift of the later terraces seems to be successively farther and farther southwest toward Natchez, and the amount of uplift less and less. Perhaps, however, the actual amounts of uplift of each terrace did not differ greatly, but, the effect being cumulative, the oldest terrace now shows the greatest deformation. The resulting slopes have been still further modified by an uplift of the earliest Pleistocene terrace in the vicinity of Natchez.[2]

DRAINAGE MODIFICATIONS.

MISSISSIPPI RIVER.

During Pliocene time the Mississippi or some other large stream followed the general course of the present Mississippi, in the region under discussion, as can be inferred from the remnants of its old deposits and valley floors which are preserved in the form of terraces. Nevertheless the stream differed in several noteworthy respects from the Mississippi of to-day.

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[1] Matson, G. C., op. cit., p. 180.

[2] Shaw, E. W., The mud lumps at the mouths of the Mississippi: U. S. Geol. Survey Prof. Paper 85, p. 18, 1914.

In early Pliocene time its mouth was far above the site of its present mouths—probably farther north than Natchez, which is 375 miles by water above the mouths—for (1) the general effect of bringing so huge a load of sediment as it carries to the sea is to build the coast forward, whether or not moderate warping is in progress, though in case of rapid downwarping the coast might migrate landward; (2) no Pliocene river deposit is known south of the southwest corner of Mississippi; and (3) a Mississippi River terrace deposit believed to be early Pliocene spreads eastward across the State 100 miles north of Natchez, indicating either a seashore at this latitude or the northern boundary of a great and continuous area of land sedimentation, for the deposit caps the highest divides, and its landward edge, though now much frayed, was apparently once straight or gently sinuous.

The volume of the Mississippi was evidently much smaller in the Pliocene epoch than now, for an extensive area is known to have been added to the northern part of its basin by the glaciers of Pleistocene time, and certain topographic features in the upper half of its basin including the youthful form of its valley, seem to indicate that this added area is considerably larger than has generally been supposed. The coarseness of the Pliocene deposits of the river may also be an indication of lesser volume. If its volume was less its gradient was presumably steeper, as the coarse deposits also suggest; and if the gradient was steeper the inferred deformation which has brought the deposits in places to a horizontal attitude or even given them an upstream slope was greater than if the slope had been as gentle as at present. However, the gradient of the lower half of the Mississippi is not extremely gentle to-day, for the lower Amazon, the lower Nile, and even the lower Ohio have gradients as slight or slighter.

The breadth of the Mississippi Valley was apparently not so great in Pliocene time as to-day, for the terrace remnants of its Pliocene valley floor are small and have evidently been severely worn by lateral swings of the river. In very few places are all four of the main Pliocene terraces represented, and in some places all have been worn away.

In one or several parts of the Pleistocene epoch the Mississippi flowed on the west side of its valley, at times whipping against the bluff at Little Rock, and the Ohio joined it at some point below Helena, Ark., perhaps south of Greenville, Miss., Crowleys Ridge being the divide between the two rivers. It appears probable that a similar arrangement existed in Pliocene time, but direct evidence is lacking.

PEARL RIVER.

The course of Pearl River lies for the most part in the region of the coastal Pliocene deposits, and although precise data concerning the form of the valley and the profile of the stream are scant it is evident that some anomalous features are displayed in the vicinity of Jackson. These features seem to be explained by the upwarps at Jackson and to the southwest. In the first place its course has a peculiar westward bend at Jackson and its main tributaries come from the east, suggesting that one or more of its main western tributaries have been captured and diverted by the Big Black. Second, the smaller southern tributaries of the Big Black are pushing the divide close over to the Pearl, whose channel is from 50 to 100 feet higher than that of the Big Black. Third, in the vicinity of Jackson the Pearl has a low gradient, a very meandering channel, and a swampy flood plain, whereas the Big Black and also sections of the Pearl above and below this part have a higher gradient, a more direct course, and a less swampy flood plain. In the vicinity of Jackson the Pearl has the appearance of an aggrading stream, which is disproportionately small compared with its valley, yet it is 250 to 300 feet above sea level and the distance that its water has to travel in getting to the sea is 100 miles shorter than that traveled by the water of the Big Black.

These facts suggest that the headwaters of the Big Black were once the western headwaters of the Pearl. Whether the diversion took place near Canton or at some place farther upstream has not been ascertained. The remarkable width of the Canton terrace and the much lower general altitude and more subdued surface features around Canton, compared with the region around Jackson, shown on the Jackson topographic map, suggests that the stream capture may have occurred in that vicinity, and that the time was late Pliocene or later.

BIG BLACK RIVER.

In addition to the apparent enlargement of its drainage basin one other feature of the Big Black seems worthy of mention in a paper on the Pliocene history of the region. The divide between the Tennessee and the headwaters of Big Black, Yalobusha, Yocona, and Tallahatchie rivers is well over toward the Tennessee, the middle and upper portions of which are much more nearly in line with one of these Mississippi rivers than with the lower course of the Tennessee. On account of this and other considerations Hayes and Campbell[1] have inferred, and many geologists have accepted the inference, that the Tennessee once had a southwesterly course across Mississippi. They believe that "at the close of the Cretaceous cycle of erosion" a small river flowed westward across northern Alabama and emptied into the sea in the northeast corner of Mississippi; that one or more of the head branches of this stream then captured some eastern Tennessee drainage that had been going to Mobile Bay; that upon the withdrawal of the sea this stream followed the course of the Big Black to the Mississippi. The northward diversion of the Tennessee in the northeast corner of Mississippi is described as having occurred in the early part of "the present cycle," after "the Lafayette depression," which "occupied the closing epoch of the Tertiary cycle."[2]

Although many details of the history of the Tennessee as set forth by Hayes and Campbell appear to need modification, numerous facts seem to support the more essential parts of their postulate. The Tennessee surely did not flow down the course of the Big Black in Pliocene time, for no high terraces seem to be left along the Big Black as a record, and there is no abandoned valley between the two streams. Certainly the Tennessee did not flow near Iuka and Tupelo, as shown in their figures. For similar reasons it seems also certain the Tennessee did not flow down the Yalobusha, Yocona, or Tallahatchie valleys in the Pliocene epoch.

That it did not flow down the Tombigbee, however, or even that it did not follow one of the other valleys mentioned, in some earlier epoch, is not clear. The Eocene deposits of Mississippi seem to be largely stream laid and to indicate that when they were laid down many small streams (or distributaries of a few large ones) with shifting channels flowed in general southwesterly courses across Mississippi. Presumably the Eocene sediments of Mississippi came from the adjoining portion of the Appalachian province, which includes the middle and upper parts of the present basin of the Tennessee and adjacent territory. There is hence reason for assuming that the drainage of most of the Tennessee basin in Eocene time, and perhaps also in Oligocene time, went southwestward across western Alabama and Mississippi. However, the Oligocene Vicksburg limestone and some of the Eocene Jackson marl indirectly indicate that at the time of their deposition sand and silt from the southern part of the Appalachian province was not being deposited in the region of their occurrence (Mississippi and farther east).

TOMBIGBEE RIVER.

Along the Tombigbee there are somewhat extensive high terraces, particularly in the vicinity of West Point, Miss., and to the southeast in Alabama; Bear Creek, a tributary of the Tennessee in the northeast corner of Mississippi, has a strikingly gentle gradient and a broad valley; the divide around the headwaters of the Tombigbee, in the northeast corner of the State, is only 15 or 20 miles from the Tennessee; and northeast of Iuka the Tennessee flows over a rocky shoal in a very narrow valley. These facts suggest that the Tennessee may have emptied down the Tombigbee Valley in Pliocene time, but if so some parts of the old course of the stream have not been found. It seems rather unlikely that Bear Creek occupies a part of the old course, for its valley, though wide, is scarcely wide enough for the Tennessee, and if it was cut by a large stream that is now diverted the diversion must have occurred in Quaternary time, for the valley is broad to its bottom. As Lowe[3] has pointed out, however, the higher part of the divide between the major streams is in some places "a narrow ridge" a few hundred yards wide and perhaps 50 feet high, and it is probable that at a point 4 miles below Paden Mackeys Creek, a tributary of the Tombigbee, is as low as the Tennessee at the

[1] Hayes, C. W., and Campbell, M. R., op. cit.
[2] Idem., p. 119.

[3] Lowe, E. N., A diversion scheme to prevent overflows of the Mississippi and to establish a navigable waterway from Mobile Bay to the Ohio River, p. 5, 1912.

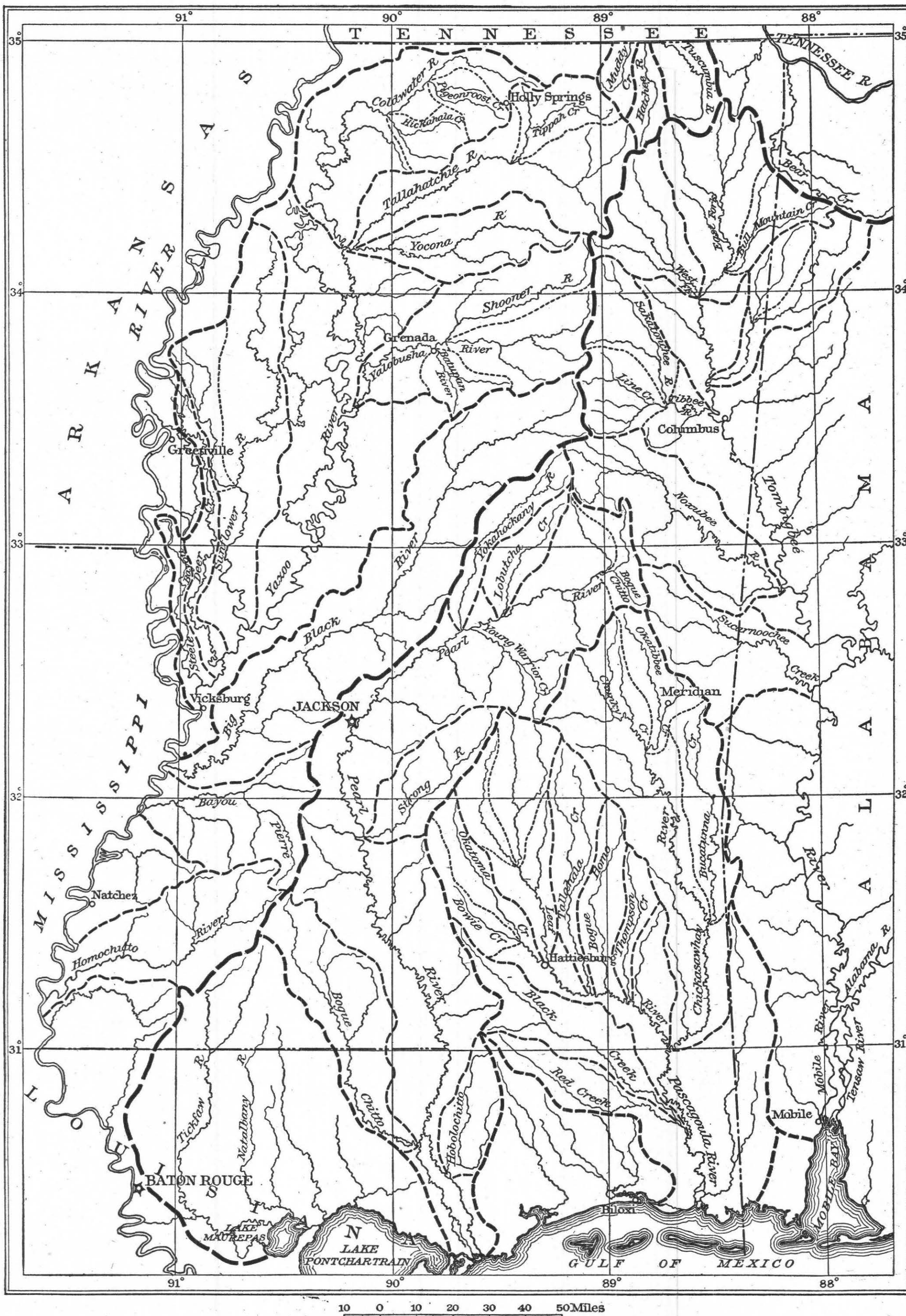

FIGURE 25.—Sketch map showing shapes of drainage basins in Mississippi. Note particularly that the divide between Mississippi and Tennessee rivers is located far to the east, and that the form of the drainage basin of the Pearl strongly suggests that the upper and middle parts of the Big Black basin formerly drained into it.

north boundary of the State. Lowe states that "the total distance * * * from the Tennessee River to an equal elevation on Mackeys Creek is 29 miles," and the crest of the divide is only about 200 feet above low water on the Tennessee and considerably less above high water.

The general shape of the drainage basins of Mississippi, which seems to have been largely acquired in Pliocene time, is indicated in figure 25.

STRUCTURAL RECORD.

What is known of the structural record of Pliocene time in northern and central Mississippi has been largely outlined in the discussion of warped physiographic features. It consists of evidence of uplifts in the southwestern part of the State and perhaps also along a belt extending northeastward to the northeast corner and possibly another uplift whose axis lies in southwestern Alabama, affecting the southeast corner of the State. Stephenson [1] has found evidence of an uplift at Starkville, on the axis that is thought to run northeastward from Jackson, and such an uplift may have occurred, as there seem to have been other movements along this axis in Pliocene time.

The Pliocene uplift along the Memphis-Charleston axis suggested by Shaler,[2] described by McGee,[3] and accepted by Hayes and Campbell,[4] does not seem to have affected either the surface features or the deposits of Mississippi, though it is described as crossing the northern part of the State.

That a surprisingly large amount of deformation of the strata of Mississippi probably occurred in Pliocene or early Pleistocene time is shown by the comparatively much disturbed attitudes of the Pliocene deposits and the surface features that are buried in them or for other reasons are believed to date from the Pliocene epoch.

Hilgard [5] and Crider [6] call attention to a northward dip of Eocene and Oligocene strata between Jackson and Canton. Veatch[7] describes a fault with a downthrow on the north of about 600 feet that extends from Texas through southern Arkansas and northern Louisiana to a point 15 or 20 miles north of Vicksburg and forms a continuation of one in Texas called by Hill [8] the Red River fault and described as having a similar displacement; but later work by Stephenson [9] throws doubt on the existence of this fault in at least a part of its course. Another structural feature, "the Angeline-Caldwell monoclinal flexure," is described by Veatch as extending southwestward from the same point north of Vicksburg.

However, on account of the fact that an uplift of the southwestern part of Mississippi is implied by the physiographic features, the writer recommended that an area around Vicksburg be examined with reference to its possibilities of yielding oil and gas. A survey [10] was made and the hard rocks were found to be bent upward, thus confirming the inferences drawn from surface features. The map showing the structure of the hard rocks gives somewhat more detail than can be inferred from the surface features in the lack of topographic maps, but still it shows less accurately the movements that have affected the rocks, because it includes the effects of pre-Pliocene warping and also those of all later movements together, whereas from the surface features something may be inferred as to the time, place, and effect of each movement.

CONCLUSIONS.

INTERPRETATION OF THE "LAFAYETTE FORMATION."

In the opinion of the writer, the material called "Lafayette formation" in Mississippi is the product neither of Pleistocene icy floods from the north nor of a marine invasion; it is not a Pliocene blanket of waste from the Appalachians gradually spread over the State by streams; and it does not consist altogether

[1] Stephenson, L. W., unpublished notes.

[2] Shaler, N. S., On the causes which have led to the production of Cape Hatteras: Boston Soc. Nat. Hist. Proc., vol. 14, pp. 110-121, 1871.

[3] McGee, W J, The Lafayette formation: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, p. 403, 1891.

[4] Hayes, C. W., and Campbell, M. R., op. cit., p. 81.

[5] Hilgard, E. W., Geology and agriculture of Mississippi, p. 128, 1860.

[6] Crider, A. F., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, p. 34, 1906.

[7] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46: p. 68, pls. 36, 37, 41, 1906.

[8] Hill, R. T., Geography and geology of the Black and Grand prairies, Tex.; U. S. Geol. Survey Twenty-first Ann. Rept., pt. 7, p. 384, 1901.

[9] Stephenson, L. W., unpublished notes.

[10] Hopkins, O. B., Structure of the Vicksburg-Jackson area, Miss.: U. S. Geol. Survey Bull. 641, pp. 93-120, 1916 (Bull. 641-D).

of parts of pre-Pliocene formations, with their surface residuum. It is believed to be made up of unrelated or distantly related materials that have been erroneously grouped together and to consist in the main of more or less modified parts of the underlying formations, including some residuum and colluvium, and of terrace deposits of Pliocene and Quaternary age.

DIASTROPHISM.

Position of surface at beginning of epoch.—The facts that the buried portion of the Pliocene surface is of gentle relief and that the tops of monadnocks and other remnants of plains are somewhat concordant in altitude suggest that at the beginning of the Pliocene epoch the surface of Mississippi was smoother than it is to-day. The coarseness of the stream deposits and the nature of the warping of the plains and formations suggest that at that time the surface of central and northern Mississippi, though possibly lower than at present, had a considerable and somewhat regular westward and southward slope toward Mississippi River and the Gulf. However, this surface, though perhaps lower with reference to sea level, was higher with reference to the underlying rocks and possibly with reference to the earth's center; for it has not only suffered local upheaval but has been worn down by erosion and perhaps has sunk a little, owing to general earth shrinkage.

Deformation.—The triangular area of which Jackson, Vicksburg, and Natchez form the corners has certainly been elevated in and perhaps after Pliocene time, and the place of maximum upwarp seems to have shifted southwestward during the epoch, for the deposits and plains are not only warped upward, but the earliest ones are uplifted most and the center of uplift is different for different plains and deposits. In addition there appear to have been a general east-west and a northeast-southwest belt of uplift through Jackson and another region of uplift just east of the southeast corner of the State. The maximum amount of uplift seems to have been at least 200 feet, for a terrace seems to rise in a downstream direction to that extent between Yazoo City and Star. The uplift seems to have been intermittent and to have occurred in four principal stages. The great breadth of the earliest Pliocene terrace and its height compared with the bordering divides suggest that the low relief of the beginning of Pliocene time lasted through perhaps a third or a half of the epoch before the first of the four uplifts occurred. The most pronounced result of all the movements is a great steepening of the seaward slope of strata and plains of all ages in the southern third of the State. Other than the depression of the coast region involved in this steepening, no downwarps are known to have occurred.

EROSION.

Weathering and local transportation.—The work of meteoric waters and of vegetation during the Pliocene epoch was evidently manifold. In addition to the main processes involved in the production of soil rains and consequent rills washed much of the incoherent underlying sand and clay down slopes and dissolved and carried away much mineral matter, both above and below ground; gravity through the aid of wetting and drying and other agencies, including perhaps freezing and thawing, pulled surface material downhill; wetting, aeration, and chemical processes weathered the material lying above ground water and transported iron oxide and other substances, both by solution and mechanically, a greater or less distance; and apparently much iron oxide that lies near the surface to-day has been concentrated downward from strata that were worn away in Pliocene time.

Through transportation and corrasion.—Aside from the probably small amount of mineral matter that has been carried to the sea underground the removal of such matter from Mississippi has evidently been accomplished largely by streams, though no doubt some material has been swept out of the State by wind. The general work of erosion has been the gradual deepening of valleys, though apparently this work has been in places, particularly on the Mississippi, subjected to interruptions during which considerable deposits were laid down. Not only were valleys deepened, however, but divides were reduced both by mechanical and by chemical agencies. To judge by processes now active the amount of material carried away in solution was fully as great as that in suspension if not greater. Hence it must be assumed that all parts of the region that have been exposed since Miocene time have been subjected to a continuous and vigorous process of reduction, perhaps to an extent of 100 tons to the square mile each year.[1] It seems reasonable to assume, therefore, that the surface at the beginning of Pliocene time was at least 100 feet above the highest hills remaining to-day, and that much of it was lowered more than 200 feet in the Pliocene epoch.

At apparently four different times the nature of the erosive processes was so modified that plains began to be formed, though the earliest one or two of these times may have been in the Miocene epoch. It seems possible that the deepening of valleys in Mississippi was checked at times when it was accelerated in adjoining provinces, for at such times in Mississippi through streams would probably be overloaded with material from their upper courses. In any case erosion developed striking monadnock-like hills in certain sandy areas and cemented their tops with iron oxide.

In the northeast corner of Mississippi an opportunity is afforded for tracing the peneplains of the Appalachain province southwestward into the Coastal Plain. A careful study of the surface features in and near this part of the State suggests that the Highland Rim peneplain, so well developed in the adjoining portion of the Appalachain province, is less ancient than has generally been supposed. It does not seem to be older than the beginning of the Pliocene but may be as old as early Miocene. A pre-Cretaceous peneplain, however, is apparently represented by hilltops in and near the northeast corner of Mississippi, but this plain is preserved because for a large part of its existence it was buried beneath the Coastal Plain sediments and has only recently been exposed. There is also indication that a peneplain emerges from between the Cretaceous and Tertiary systems in Mississippi and passes upward toward the northeast but slopes less steeply than the pre-Cretaceous plain, with the result that the two intersect. Both plains no doubt suffered considerable denudation in Pliocene time. The Miocene (?) plain at the tops of the isolated hills rises even more gently to the northeast and intersects the other two plains. The still lower and younger plains are not yet satisfactorily differentiated, but they are nearly horizontal and, like the older ones, rise to the northeast, each successive one more gently than the preceding and each intersecting all the older plains.

If the old surface represented by the tops of monadnocks is not the Highland Rim peneplain, it must be slightly younger, and if so that peneplain must cross it and slope down under slightly older sediments. The lack of any indication of such a relation lends support to the interpretation that the monadnocks are really somewhat reduced remnants of the Highland Rim peneplain. Moreover, if the seaward portion of this peneplain passes under Pliocene sediments, it must have been formed just before Pliocene time, and one part was buried and another carved into monadnocks during Pliocene time.

It seems evident that the present divides, which show a comparatively abrupt rise 10 to 25 miles northeast of Iuka, do not belong to a surface of uniform age and origin, but that the surface farther northeast is the remnant of a plain which was mainly developed upon resistant cherty limestone of Mississippian (St. Louis and Fort Payne) age and which now has a gentle southwesterly slope to a line lying about 25 miles northeast of Iuka. Along this line the Highland Rim peneplain intersects a more steeply sloping and older planed surface which dips under Cretaceous deposits that reach sea level 15 or 20 miles west of Iuka. The accordant crests of Mississippi, with the possible exception of the monadnock tops, evidently belong neither to the Highland Rim peneplain nor to the peneplain finished just before Upper Cretaceous time. However, the surface of the region when it became partly submerged in the Upper Cretaceous sea may have been little or no smoother than it has been at many times before and since.

Drainage modifications.—The drainage modifications seem to have been continuous and very gradual rather than sudden. A portion of the Pearl seems to have been captured by the Big Black; but the other changes seem to have consisted in a gradual shifting of divides, which is suggested by drainage patterns but can not be demonstrated because of lack of topographic data. Perhaps the most striking feature of this class is the short distance between Tennessee River and the divide on the southwest side of its basin in Mississippi.

[1] See particularly data on the Pearl at Jackson given in U. S. Geol. Survey Water-Supply Paper 234, p. 87, 1909.

SEDIMENTATION.

Sedimentation in valleys.—Not only did the streams of Mississippi considerably deepen their valleys in the Pliocene epoch, but at the same time, though not at a uniform rate, they deposited much sand and gravel in their valley bottoms. Apparently, at four stages in particular, the Mississippi received more sand and gravel than it could carry perhaps because of uplifts of the Appalachian or Ozark mountains, and as a consequence it meandered widely, undercutting its valley sides and spreading sand and gravel over its flood plain. Somewhat extensive though much dissected remnants of these deposits are to be found to-day here and there along the valley side. The overloaded condition did not last long, for the deposits do not seem to have been much thicker than the ordinary alluvium along large rivers. Perhaps the four terrace deposits correspond to the four peneplains that are possibly represented in the divides; but it may be that at only two or three times of valley filling were plains perceptibly developed and that the older one or two peneplains are Miocene.

Coastal sedimentation.—Whether at the beginning of Pliocene time the coast was at the northern limit of the Pliocene deposits or whether part or all of these sediments are land deposits are problems that have not been solved, though the balance of evidence seems to favor land deposition. The facts that the northern boundary seems to have been a somewhat regular line, that the deposits cross interstream areas, that they are fairly uniform in composition and extent and resemble the terrace deposits of the Mississippi much more than those of other streams, and that the surface features consist of about four terraces parallel to the coast suggesting in some respects the surfaces of uplifted compound deltas seem to suggest marine conditions. On the other hand, the facts that the terrace fronts are not well-defined escarpments, that sea cliffs and beaches seem to be lacking, that Pliocene land plants grew at least as near the present coast as Perdido Bay, Ala., and perhaps considerably farther south than the present coast, that the stratification and sorting seem to point to stream rather than ocean action, and that nowhere in these deposits do there seem to be marine fossils strongly suggest land deposition.

CLIMATE AND LIFE OF THE EPOCH.

What is known of the plants and animals that lived in Mississippi in Pliocene time is largely set forth in recent papers by Matson and Berry.[1] The only additional organic remains worthy of mention are petrified logs, such as are fairly common in the high terrace deposits of the Mississippi. The climate also seems to have left little record except the products of weathering, which seem to be indistinguishable from those of to-day. Perhaps some of the erosion features were produced by changes in climate, but they seem more reasonably accounted for by deformation.

[1] Matson, G. C., The Pliocene Citronelle formation of the Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 98, pp. 167–192, 1916. Berry, E. W., The flora of the Citronelle formation: Idem, pp. 193–208.

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