THE PLIOCENE CITRONELLE FORMATION OF THE GULF COASTAL PLAIN.

By George Charlton Matson.

PRESENT INVESTIGATION.

In the spring of 1910 the writer, working under the direction of T. Wayland Vaughan, geologist in charge of Coastal Plain investigations, undertook a study of the later Tertiary formations of the Gulf Coastal Plain. According to the plans outlined before the work was begun, the beds that had formerly been grouped under the names Lafayette formation and Grand Gulf formation were to be studied with a view to their possible separation into more satisfactory stratigraphic units that might be correlated with other formations which, on the basis of their fossils, had been assigned to their proper positions in the geologic time scale. The original plan included a study of the post-Vicksburgian Tertiary deposits from western Florida to Mississippi River and correlations with formations previously recognized in Florida, southern Alabama, and Louisiana. This plan was subsequently modified to extend the investigation as far west as Sabine River. The field work was interrupted and the office work was delayed by calls for geologic work in other areas, so that the preparation of the reports could not be begun until the spring of 1914.

SCOPE OF THIS REPORT.

In this paper it is proposed to discuss the general character and relations of beds of Pliocene age and to leave for subsequent publications the details of lithologic character and distribution of the Pliocene beds recognized. Although not abundantly fossiliferous, these Pliocene deposits contain some fossil plants, and at two localities—near Lamberts, north of Mobile, and at Red Bluff, on Perdido Bay—it was possible to obtain collections adequate for correlation. The fossil plants from these places are described elsewhere in this report by Mr. Berry, who also discusses their geologic age.

EARLY INVESTIGATIONS.

The area considered in this report has been studied by a number of geologists, though few of them had adequate opportunity to examine the formations in detail. The major portion of the time at their command was naturally devoted to the fossiliferous formations, and the nonfossiliferous beds were assigned to groups that by some investigators were probably regarded as separable into formations provided enough time could be given to their study. The result of this method of classification was to group together beds differing in age and having very extensive geographic distribution. The beds of each of these groups were composed of materials of similar lithologic character that appeared to be nonfossiliferous. The lithologic character of the materials naturally depended on two factors—the source of the material and the processes to which the sediments had been subjected since their removal from their original position. The sediments of the Coastal Plain were transported to approximately their present position by streams that existed when deposition began, and in any broad drainage basin the material for the different formations from the older to the younger was derived either wholly or in part from the older lands to the north, even though shore currents shifted some sediments from one place to another and eroded and redeposited materials along the strand line. In some places, however, no terrigenous deposits were laid down and the formations are made up either wholly or in part of organic or chemically precipitated material.

As the detrital deposits came from a common source, they vary only in accordance with the character of the changes to which they have been subjected since they were eroded from the older land surface. The processes of weathering that have affected the formations of the

Coastal Plain since their deposition have been comparatively uniform, and for this reason the sediments of different ages in the Coastal Plain that are now available for examination are very similar. In the later part of Tertiary time, except in Florida, there was a general absence of strictly marine conditions, and organic deposits of that age are either thin or entirely lacking. The Coastal Plain formations in general are composed of clays and sands derived from the older land, transported to their present position by the streams and in places by marine currents and waves and subjected since their deposition to similar processes of weathering. As a result the deposits are so similar that they can be divided into distinct formations only by laborious investigation with careful attention to detail. Such studies were beyond the reach of early investigators, both because of lack of time and because of lack of funds for their prosecution.

FORMATION NAME.

The name Citronelle formation is applied to sediments of Pliocene age, chiefly nonmarine, that occur near the seaward margin of the Gulf Coastal Plain, extending from a short distance east of the western boundary of Florida westward to Texas. (See fig. 15.) Citronelle, a town on the Mobile & Ohio Railroad, in the northern part of Mobile County, Ala., was chosen as the type locality because of the excellent exposures of the formation in its vicinity, especially to the north along the railroad for a distance of 3 or 4 miles. The best collection of fossils was obtained from a clay bed a few miles south of the type locality, near a station called Lamberts, where a flora sufficiently

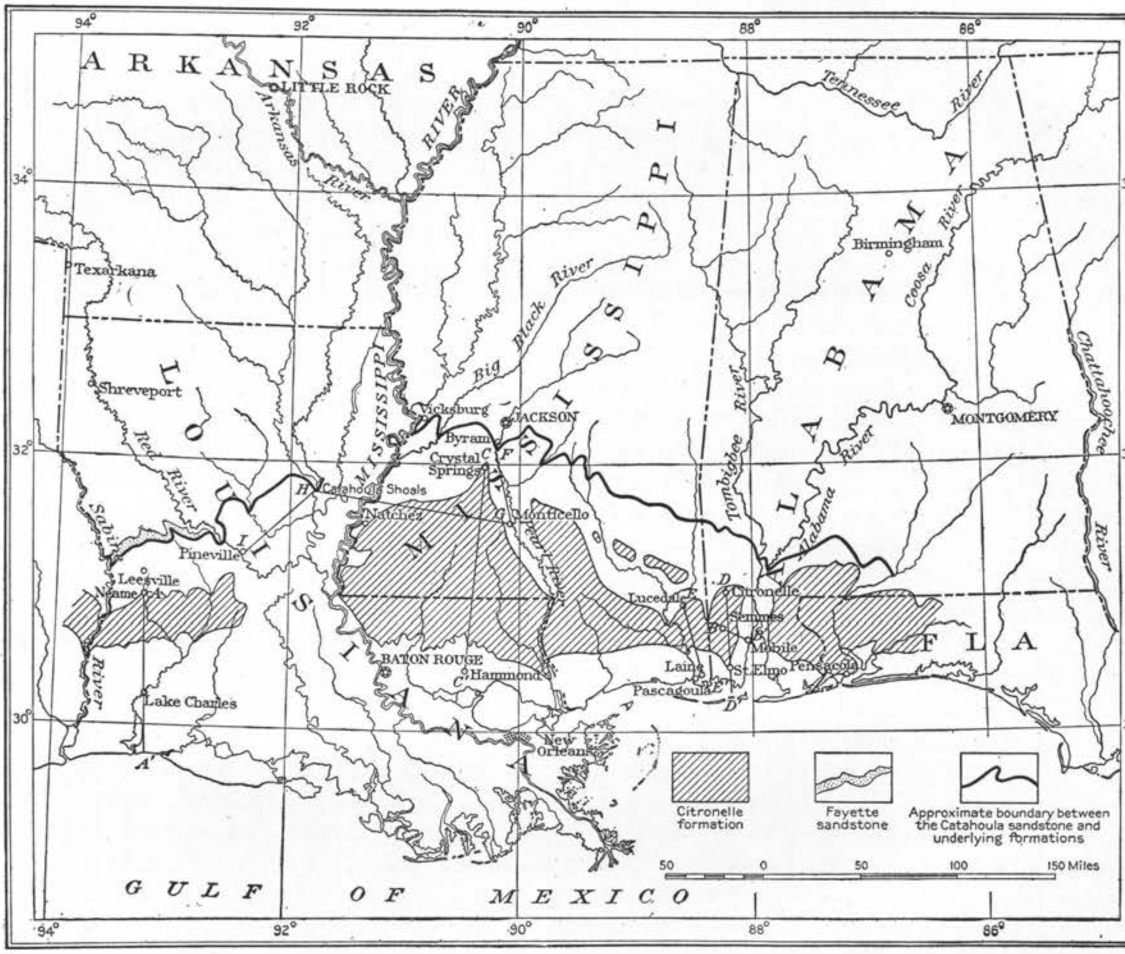


FIGURE 15.—Map of Louisiana, Mississippi, and Alabama showing approximately areas covered by Citronelle formation and Fayette sandstone and boundary between Catahoula sandstone and underlying formations. Sections along lines *A–A′*, *B–B′*, *C–C′*, *D–D′*, *E–E′* are given in Plate XXXII; sections along lines *F–G*, *G–H*, and *H–I* in figure 20 (p. 219).

well preserved to permit correlation of the beds with the Pliocene was found.

SYNONYMY.

The Citronelle formation is the equivalent of a portion of the deposits formerly classified as "Drift," "Orange sand," and "Lafayette." The name can not be regarded as a synonym for any of the older terms because in all the earlier descriptions the old names were made to include not only the Citronelle formation, but overlying alluvial and colluvial sands and gravels and extensive areas of sand and gravel lying farther inland and belonging to a number of different terranes. In addition, the earlier applications of the old names were such as to include beds of Pleistocene age, forming a fringe between the Pliocene beds and the coast and extending into the river valleys. The development and use of the different names will be mentioned briefly in discussing the earlier publications.

The Lafayette of some writers may have included not only the Citronelle but portions of the older formations, together with the alluvial material forming the flood plains and terraces along the streams and the colluvial sands, gravels, and clays distributed on the slopes. In some places portions of the unweathered Miocene and Oligocene beds were called Lafayette, though in most localities only the weathered portions were included. The use of the term "Lafayette" was so elastic that exposures on the valley slopes might all have been included in the formation, even though the outcrops of the older beds were unweathered, or the unaltered beds might have been called "Grand Gulf," the weathered deposits "Lafayette," and the relations of the deposits explained by assuming that the contact between the "Lafayette" and "Grand Gulf" was irregular.

PREVIOUS DESCRIPTIONS.

One of the earliest reports on the geology of the Gulf Coastal Plain contains a description of what is called "Diluvium or northern drift." [1] The areal distribution of the materials described indicates that the gravels of glacial origin bordering the Mississippi are included under that term, together with the alluvial deposits on some of the smaller streams and also, it is thought, some of the beds of Pliocene age. The siliceous pebbles mentioned in this report, especially the fossiliferous cherts, are similar to those found in some of the gravels of the Citronelle formation, though this can hardly be regarded as conclusive evidence for correlating these deposits with the Citronelle, because such materials may be expected in other formations derived from the same sources. The occurrence of the porphyry mentioned by Wailes would probably be limited to gravels of glacial origin, because it is unlikely that such materials would be derived from the sedimentary formations occurring in the drainage basin of the Mississippi and its tributaries.

In a report by Harper,[1] published three years after that of Wailes, the name "Orange sand" is used to designate materials that had been called "Diluvium" in the earlier publication. This name, which was taken from a report by Safford,[2] continued in use for many years, though it was necessary to redefine it in order to harmonize the application by different writers. It is clear from the following quotation that Harper [3] intended to apply this term to a part of the deposits herein named Citronelle formation:

> This cover is thickest where the Eocene meets the Miocene. It decreases southward towards the seacoast and the State of Louisiana; but nevertheless hills of the Orange sand, with the characteristic pebble stratum, are found here and there even very near the seacoast.

The application of the terms Eocene and Miocene by this writer is so unusual and so different from the present usage that for the benefit of those who may not have access to Harper's geologic map, it seems advisable to say that he included in the Eocene the entire area south of the outcrop of the Jackson formation. It is in this area that his Orange sand includes the Citronelle formation. A discussion of the other beds classed as Orange sand by Harper may be omitted because they lie outside of the area included in this report.

The reports cited above were based on brief reconnaissances in which observations were made at widely separated localities. Although some of the later investigations were of similar character, a tendency toward more detailed study is shown in the character of the reports. The deposits included in the Citronelle forma-

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

[1] Harper, L., Preliminary report on the geology and agriculture of the State of Mississippi, p. 162, Mississippi Geol. Survey, 1857.

[2] Safford, J. M., Geological reconnaissance of Tennessee, pp. 148, 162, 1856.

[3] Harper, L., op. cit., p. 162.

tion were first systematically discussed on the basis of extensive field investigations by Hilgard,[1] who included beds belonging to the Citronelle formation in the "Orange sand." He said:

> But the formation which gives character to the surface conformation of the State—whose presence is the rule, and whose absence the exception requiring special mention; which forms the main body of most ridges and, to a very great extent, their surface also—is that which has been very appropriately designated by Prof Safford, the State geologist of Tennessee, as the Orange sand formation.

The term "Orange sand," as used by Hilgard, includes some of the deposits herein named Citronelle formation and also portions of older and younger deposits correlated with them on the basis of lithologic character.

In a discussion of the "Orange sand" Hopkins[2] correlated some of the materials in Louisiana with the Orange sand of Hilgard. In his section across the State the name "Prairie diluvium" includes the beds now called the Citronelle formation, as well as both older and younger beds. A subsequent report by Hopkins[3] contains a more comprehensive discussion of the "drift," in which he included a large amount of material varying in age from the oldest beds exposed in Louisiana to the Pleistocene. Among these beds are the deposits here named Citronelle formation, which Hopkins mentioned in connection with the distribution of the drift in some of the parishes south of the outcrop of the beds later designated Catahoula sandstone. The geologic map accompanying Hopkins's report shows the area occupied by the Citronelle formation as covered by what he calls "drift." A third publication by this author discussed the "drift" in more detail, giving special attention to its constitution and origin.[4] The identifiable fossils occurring in pebbles are listed, but unfortunately some of the localities where these pebbles were collected were not given, though Hopkins stated the age of the geologic formations that supplied these pebbles and the possible geographic distribution of the localities from which they are derived. The report contains some speculation as to the means of transportation of these pebbles to their present positions.

[1] Hilgard, E. W., Report on the geology and agriculture of the State of Mississippi, pp. 4-29, Mississippi Geol. Survey, 1860.

[2] Hopkins, F. V., Louisiana Geol. Survey First Ann. Rept., for 1869 (included in the annual report of the Louisiana State Seminary of Learning and Military Academy), p. 78, 1870.

[3] Hopkins, F. V., Louisiana Geol. Survey Second Ann. Rept., pp. 21-26, 1871.

[4] Hopkins, F. V., Louisiana Geol. Survey Third Ann. Rept. (included in annual report of D. F. Boyd, superintendent Louisiana State University, for 1871), pp. 190-203, 1872.

After the publication of the papers cited there was a revision of the nomenclature because of the confusion resulting from the differences of usage in different areas. The necessity for this revision was emphasized when McGee[1] correlated his Appomattox formation with "at least a part of the Orange sand of Hilgard and other southern geologists."

In 1891 the name "Orange sand" was replaced by "Lafayette formation," the type locality for the new name being in Lafayette County, Miss.,[2] where, according to Berry,[3] the "Orange sand" is of Eocene (Wilcox) age. This change was made at a conference in which Hilgard, McGee, LeConte, and Loughridge participated, and the decision reached by them was subsequently indorsed by Safford.[4] McGee was the first geologist to apply the term Lafayette to deposits distributed over the entire area of the Coastal Plain and extending across the edges of the older formations between Washington and the Rio Grande.[5] Although he regarded his Lafayette as somewhat more restricted than Hilgard's Orange sand, it is clear that he included in the Lafayette the beds now known as the Citronelle formation. This is shown by numerous references to the localities where this formation is at the surface, by the maps accompanying the report, and by numerous diagrams showing the relations of the formations exposed on the Gulf Coastal Plain. The accompanying sections (figs. 16 and 17) illustrate the relations of the "Lafayette" to older and to younger formations, and if the thickened portion of the "Lafayette" as represented in these sections is separated from a portion of the thin layer on the upland it will represent approximately the Citronelle formation. As the present report does not deal with the major portion of the deposits coating the surface of the upland, it has seemed best to omit them from the discussion.

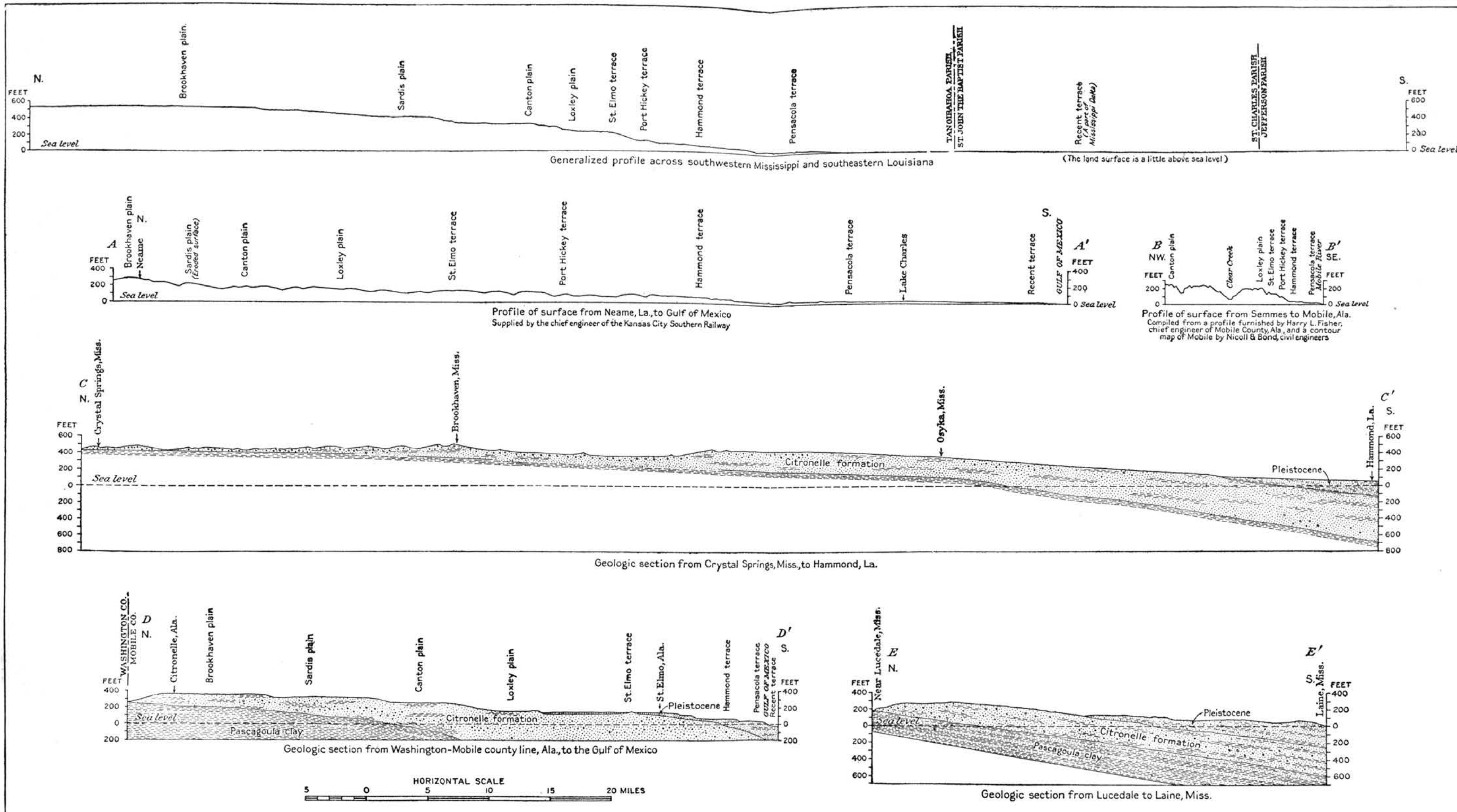
[1] McGee, W J, Three formations of the middle Atlantic slope: Am. Jour. Sci., 3d ser., vol. 35, p. 330, 1888.

[2] Hilgard, E. W., Orange sand, Lagrange, and Appomattox: Am. Geologist, vol. 8, pp. 129-131, 1891.

[3] Berry, E. W., The Lafayette formation: Jour. Geology, vol. 19, pp. 249-256, 1911.

[4] Hilgard, E. W., op. cit., p. 131.

[5] McGee, W J, The Lafayette formation: U. S. Geol. Survey Twelfth Ann. Rept., pt. 1, pp. 430-501, 1891.



SECTIONS OF THE CITRONELLE FORMATION AND PROFILES OF THE TERRACES.

After the appearance of the report by McGee the name "Lafayette" was adopted by writers on Coastal Plain geology and soon came into general use, in an area extending from Maryland to Rio Grande. The present report, however, is restricted to the area from western Florida to eastern Texas and does not deal with the Atlantic border of the Coastal Plain though some of the superficial materials on the older Tertiary and the Cretaceous formations are not included in the Citronelle. In dealing with the thin coatings of weathered sand or clay resting on the older beds it is in many places difficult to obtain enough physiographic evidence to warrant correlations, because of the lack of topographic maps.

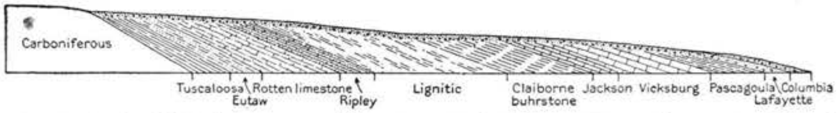


FIGURE 16.—Section through the Coastal Plain in western Alabama; generalized in part from sections constructed and described by E. A. Smith and L. C. Johnson. (After McGee.)

or with the major portion of the region west of Sabine River.

Clendennin [1] discussed the "Lafayette formation" as developed in Louisiana, and the geographic distribution as he described it is much the same as that of the Citronelle, but this author followed McGee by including older materials also.

A paper by Dall and Stanley-Brown [1] gives details of a number of sections along Apalachicola River in Florida and notes on exposures at Bainbridge and Macon in Georgia. In this paper the upper member of each of the sections on Apalachicola River is called Lafayette, and these beds are correlated with the exposures farther north. If any of these exposures are to

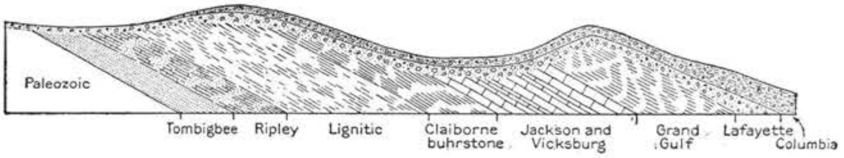


FIGURE 17.—Section through the Coastal Plain in the Mississippi embayment; generalized in part from sections constructed and described by E. W. Hilgard and L. C. Johnson. (After McGee.)

The "Lafayette" in Alabama was described by Smith,[2] who summarized its distribution as follows:

> While the materials of the Lafayette formation are to be found as a superficial covering over the entire Coastal Plain of the State; that is, over all the Tertiary and Cretaceous strata, lapping in places even far over upon the edges of the Carboniferous and other Paleozoic terranes—it is only in the two Gulf-bordering counties, Mobile and Baldwin, that we find it forming one of the structural units, intercalated between the Biloxi and Second Bottom deposits above and the fossiliferous clayey sands of the Pascagoula horizon below.

The portion of the "Lafayette" which this author called a structural unit belongs to the Citronelle formation, and some portions of what lies above the older formations to the north may be outliers of this formation, be classed with the Citronelle formation it is the upper part of the section at Alum Bluff, though from their conformity with the clays resting on the Miocene the fine sands and clays forming the upper portion of the bluff are believed to be older than Pliocene.

The Citronelle formation in Louisiana is included in the beds called "Lafayette formation" by Harris,[2] who made special reference to the occurrence of this formation on the east side of Mississippi River and in the "Florida parishes." A large part of the information in this report seems to have been gleaned from the earlier publications by former geologists of Louisiana and from the comprehensive paper by McGee. The information concerning the territory covered by this formation west of the

[1] Clendennin, W. W., The Florida Parishes of east Louisiana and the bluff, prairie, and hill lands of southwest Louisiana: Louisiana Geol. Survey, pt. 3, pp. 187-192, 1892.

[2] Smith, E. A., Johnson, L. C., and Langdon, D. W., jr., Report on the geology of the Coastal Plain of Alabama, p. 66, Alabama Geol. Survey, 1894.

[1] Dall, W. H., and Stanley-Brown, Joseph, Cenozoic geology along the Apalachicola River: Geol. Soc. America Bull., vol. 5, pp. 169-170, 1894.

[2] Harris, G. D., Geology and agriculture of Louisiana: Louisiana Geol. Survey, pt. 5, pp. 99-107, 1899.

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Mississippi is somewhat less complete than that about the area east of the river, but special mention is made of the gravel pit in the southern part of Rapides Parish. Another paper by the same author was published in one of the subsequent reports of the Louisiana Geological Survey.[1] This paper is devoted very largely to a discussion of the theories of the origin of the "Lafayette formation," with some mention of the distribution of the beds referred to it. The localities noted in the area covered by the Citronelle formation are Neame, where the beds are over 275 feet above sea level; Sulphur, where the same deposits are reported to occur in a well extending to a depth of more than 400 feet below sea level; and Morgan City, where they extend to a depth of more than 500 feet. The relations of these deposits are shown graphically in a diagram of the country from a point north of Jackson, Miss., southward through Tangipahoa, Amite, and Hammond to the Gulf.

The reports by Crider[2] afford little additional information concerning the Citronelle deposits. This author included in the "Lafayette formation" the beds in the southern part of Mississippi belonging to the Citronelle formation and stated that they were reported to attain a thickness of over 200 feet.

Veatch[3] dealt in considerable detail with the "Lafayette formation" in Louisiana, including in this formation beds belonging to the Citronelle, as shown by his diagram and by his statement of the detailed distribution of the formation. He said:

> South of the Catahoula and Fleming formations these sands and gravels form the surface for miles and then pass southward beneath the more recent clays of the Quaternary, forming there the water-bearing beds which furnish a portion of the waters used in the irrigation of that region.

It is possible that in addition to the beds described in this quotation some of the deposits classed as Lafayette lying north of the area described are outliers of the Citronelle formation.

[1] Harris, G. D., Geology and agriculture of Louisiana: Louisiana Geol. Survey, pt. 6, pp. 32-36, 1902.

[2] Crider, A. F., and Johnson, L. C., Summary of the underground-water resources of Mississippi: U. S. Geol. Survey Water-Supply Paper 159, pp. 12-13, 1906. Crider, A. F., Geology and mineral resources of Mississippi: U. S. Geol. Survey Bull. 283, pp. 44-46, 1906.

[3] Veatch, A. C., Geology and underground water resources of northern Louisiana: Louisiana Geol. Survey Bull. 4, pp. 43-45, 1906.

In 1907 Smith[1] discussed the "Lafayette formation," which he made to include the area underlain by the Citronelle formation. The term "Lafayette formation" as used in this report is not synonymous with Citronelle formation, but some of the beds covering a portion of the "Grand Gulf" and lying south of the northern margin of that formation may belong to the Citronelle.

Matson and Clapp[2] discuss the "Lafayette formation" in Florida in a general way. The Citronelle formation comprises only a minor part of the area assigned to the "Lafayette" in Florida and is not included in any of the detailed sections given. In this report the name "Lafayette" is used for the weathered portions of deposits of Oligocene, Miocene, and Pliocene age and for surface deposits of various ages.

STRATIGRAPHIC RELATIONS.

The Citronelle formation rests upon the Pascagoula clay (Miocene) and overlaps the Oligocene formations. Wherever the contact with the underlying formations has been observed it is marked by an unconformity, the older formations having been eroded before the deposition of the Citronelle formation. (See Pl. XXXII.) The seaward margin of the Citronelle formation is overlain by beds of Pleistocene age, and contacts between the Pliocene and younger beds can be seen at many places. They show a marked unconformity, the Citronelle formation having been eroded and the materials derived from it having been incorporated with materials from other sources to form the deposits of Pleistocene age. (See Pl. XXXIII.) The unconformity may also be inferred from the fact that the Pleistocene deposits form terraces along the seaward margin of the Citronelle formation and extend into the valleys of the major streams, reaching entirely across the Citronelle and resting upon the still older formations. The relation of the Citronelle to the other formations of the Gulf Coastal Plain is shown in the accompanying table.

The Citronelle formation differs from both the older and the younger formations in being

[1] Smith, E. A., The underground water resources of Alabama, pp. 24-25, 302-316, Alabama Geol. Survey, 1907.

[2] Matson, G. C., and Clapp, F. G., A preliminary report on the geology of Florida, with special reference to the stratigraphy: Florida Geol. Survey Second Ann. Rept., pp. 141-145, 1909.

Pleistocene and Tertiary formations of the Gulf Coastal Plain.

Age.	Eastern Texas.	Louisiana.	Mississippi.	Alabama.		Florida. Western.	Florida. Peninsular.
Pleistocene.	Pensacola terrace. Hammond terrace. Port Hickey terrace. St. Elmo terrace.	Pensacola terrace. Hammond terrace. Port Hickey terrace. St. Elmo terrace.	Pensacola terrace. Hammond terrace. Port Hickey terrace. St. Elmo terrace.	Pensacola terrace. Hammond terrace. Port Hickey terrace. St. Elmo terrace.		Pensacola terrace. Tsala Apopka terrace. Newberry terrace.	
Unconformity							
Pliocene.	Citronelle formation. Nonmarine chiefly, including high-level terraces. Yellow and red sands and clay, locally gray where unweathered. Gravel near the landward margin. Thickness, 50–250 feet.	Citronelle formation. Nonmarine chiefly, including high-level terraces. Yellow and red sands and clays, locally gray where unweathered. Much gravel near the landward margin, especially in the valley of Red River. Thickness, 50–400 feet.	Citronelle formation. Nonmarine chiefly, including high-level terraces. Yellow and red sands and clays, locally gray where unweathered. Much gravel near the landward margin and in the valleys of the principal streams. Thickness, 50–400 feet.	Citronelle formation. Nonmarine chiefly, including high-level terraces, marine fossiliferous equivalents in wells. Yellow and red sands and clays; locally gray where unweathered. Gravel near the landward margins contains fossil plants. Thickness, 50–340 feet.		Citronelle formation. Nonmarine chiefly, including high-level terraces; marine fossiliferous equivalents in wells. Yellow and red sands and clays, some gravel. Thickness, 50–150 feet.	Caloosahatchie and Nashua marls. Marine.
Unconformity							
Miocene.	Pascagoula clay. Marine in part. Blue, green, and gray clay, locally calcareous and fossiliferous. Some large calcareous concretions and many small nodules. Some layers of sand and sandstone. Thickness, 250–300 feet.	Pascagoula clay. Marine in part. Blue, green, and gray clays, locally calcareous and fossiliferous. Some layers of sand; locally a sandstone near the top. Many nodules of calcium carbonate in some layers of the clay. Thickness, 250–450 feet.	Pascagoula clay. Marine in part. Blue and gray clays and sands; some thin beds of sandstone; locally gravels and conglomerates at the base. Fossiliferous marls in places and some clays with nodules of calcium carbonate. Thickness, 50–400 feet.	Pascagoula clay. Marine in part. Blue and gray clays and sands. Thickness, 250 feet.		Choctawhatchee marl. Marine.	Jacksonville formation. Marine.
Unconformity							
Oligocene.	Hattiesburg clay. Nonmarine. Blue and gray clay; some layers calcareous. Thin layers of sand and sandstone. Thickness, 300–350 feet.	Hattiesburg clay. Nonmarine. Blue and gray clay; some beds calcareous. Thin layers of sand and sandstone. Thickness, 300–350 feet.	Hattiesburg clay. Nonmarine. Blue and gray clay with thin beds of sand and sandstone. Thickness, 350–450 feet.	Hattiesburg clay. Nonmarine.[a] Blue and gray clay with thin beds of sand and sandstone. Thickness, 300 feet.	Alum Bluff formation. Marine.	Apalachicola group. Alum Bluff formation. Marine.	
	Catahoula sandstone. Nonmarine. Gray sands, sandstones, fine conglomerates, quartzites, and clays. Thickness, about 475 feet.	Catahoula sandstone. Nonmarine. Gray sands, sandstones, fine conglomerates, quartzites, and clays. Thickness, 600–800 feet.	Catahoula sandstone. Gray sands, sandstones, fine conglomerates, quartzites, and green clays. Thickness, 200–550 feet.	Catahoula sandstone. Gray sands, sandstones and green clay. Thickness (maximum), about 200 feet.	Chattahoochee formation. Marine.	Apalachicola group. Chattahoochee formation. Marine.	
		Vicksburg limestone.	Vicksburg limestone. Marine.	St. Stephens limestone. Marine.		Marianna limestone. Marine.	
Eocene.	Fayette sandstone. Marine. Gray sands, sandstones, quartzites, and dark, calcareous clays. Thickness, 100–160 feet.		Jackson formation. Marine.			Ocala limestone.[b] Marine.	
	Jackson formation. Marine. Fossiliferous marls, clays, and some thin beds of sandstone. Traceable into typical Jackson of Mississippi. Thickness, 50 feet.	Jackson formation. Marine. Gray sands, sandstones, and dark calcareous clays. Thickness, 100–160 feet.					

[a] Redefined.

[b] According to C. W. Cooke.

predominantly sandy, with many lenses and scattered pebbles of chert gravel. To understand fully the application of the name it is necessary to know the mode of deposition of the formation. After the Miocene strata had been laid down the Coastal Plain was eroded into broad, shallow valleys having approximately the same positions as those of the present streams. These valleys were filled by the deposition of Pliocene alluvial sands and gravels, and near the coast the deposits were extended across the interstream areas. This filling formed a broad plain, which was later partly eroded, while at the same time the margin of the formation was pushed farther seaward and three successively lower plains were built, their sediments resting on the older deposits. The original deposit formed a seaward-sloping plain, and each successive addition formed a new plain, which was represented also in the stream valleys. (See Pl. XXXII.) Some portions of the deposits were doubtless reworked by the waves, especially in the interstream areas, and this accounts for the more complete rounding of the pebbles in portions of the seaward areas of the formation than in the stream valleys and the development of flat plains with shallow ponds in the interstream areas. The closing stage of the deposition of the successive plains is marked by the fine sandy silts laid down at flood stages while the streams were eroding their beds to lower levels. The deposition was pushed far seaward in some places, as shown by sands with Pliocene fossils at Pensacola and Mobile and by a leaf-bearing clay at Red Bluff, on Perdido Bay, Ala.

The sediments included in the Citronelle formation have sometimes been referred to the Pleistocene because of their physiographic resemblance to the terraced deposits of Pleistocene age. They differ from the Pleistocene deposits of the Gulf coast, however, by being more sandy and containing more gravel. The evidence of their greater age is shown by their mature dissection, which in general exceeds that of the coast Pleistocene and glacial deposits, and by the weathered condition of the pebbles, many of which are composed of chert so completely decomposed as to break or even crumble easily in the hand. The Pliocene age is further shown by the presence of the Pliocene fossil plants, those at Red Bluff showing that the deposition was originally extended some distance beyond the southern margin of the general area shown in figure 15 (p. 168), and that the Pleistocene material was later deposited upon the eroded surface of the Citronelle. The line between the Pliocene and Pleistocene plains is drawn between the 150-foot and 200-foot terraces. The Pleistocene age of the plains at lower levels is shown by their slight dissection and by the presence of crystalline pebbles in the fluviatile portion of the 150-foot terrace at Natchez, Miss.

The 150-foot terrace rises gradually landward to 170 feet or more, and its representatives in the river valleys are still higher, attaining elevations of somewhat more than 200 feet a short distance from the coast. Deposits of this terrace contain the pebbles of crystalline rocks at Natchez—the Natchez formation.

The Pliocene plains are more eroded than the Pleistocene plains and when compared in the same area they may be distinguished by this difference. The Pliocene material was considerably eroded before the formation of the uppermost Pleistocene terrace, and relatively wide valleys were developed even on some of the small streams. The formation of the Pleistocene terraces was begun by a submergence that affected the drainage some distance from the coast and resulted in the formation of flat, swampy areas along most of the streams. These readjustments in drainage conditions are still marked by swamps in many of the small stream valleys in southern Alabama, Mississippi, Louisiana, and southeastern Texas, the flat-bottomed valleys being overgrown by swamp vegetation through which the streams meander in very poorly defined channels.

LITHOLOGY.

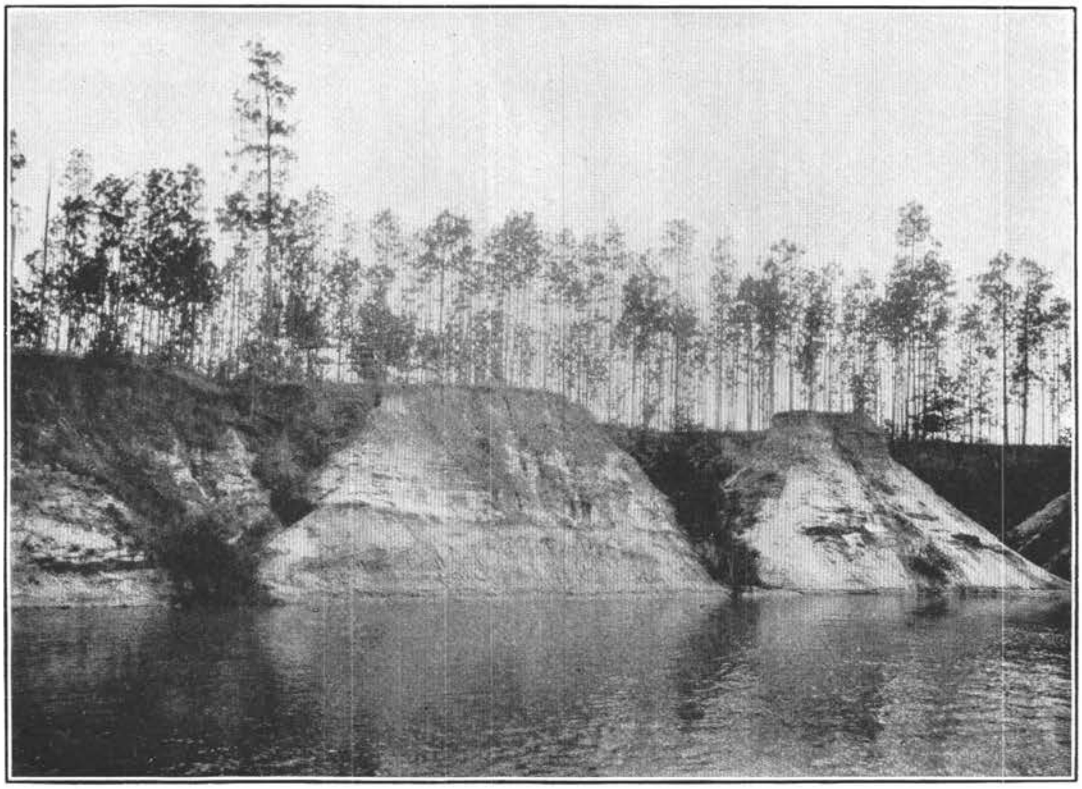
The Citronelle formation is predominantly sandy but contains varying amounts of clay in the form of thin layers or lenses. (See Pl. XXXIV.) The relative proportion of materials of different kinds varies from place to place, and in any one section it varies from top to bottom, though in general sand is everywhere abundant (see Pls. XXXV and XXXVI), and at many places there is some gravel. The proportion of sand is greatest near the base, and the formation contains more sandy material in the vicinity of the principal drainage lines than in the interstream spaces. There is also a larger percentage of sand and gravel near the landward than the seaward margin of the formation (see Pls. XXXVII and XXXVIII), though in making comparisons it is necessary to consider large masses and to choose localities bearing about the same relations to the principal lines of drainage, because more sand and gravel will be found in the vicinity of large streams near the coast than on some of the interstream spaces farther inland.

The sands of the Citronelle formation are sufficiently rounded to indicate that they have been subjected to extensive attrition. The pebbles vary greatly in degree of rounding; many of them are much waterworn and resemble pebbles found on the beach, others are only slightly rounded, and still others are subangular. The sand is predominantly quartz, and the pebbles in the Mississippi embayment are mostly chert, with a somewhat smaller percentage of crystalline quartz and quartzite. Many of the chert pebbles contain cavities lined with chalcedony in the form of agates or geodes, and a large number of them are fossiliferous, containing fragments of corals, crinoid stem, and other organic remains such as are common in the Paleozoic limestones and chert. In Alabama there are many pebbles of quartz, with a subordinate percentage of quartzite, but in some places chert pebbles are numerous. In western Louisiana the pebbles are mostly quartz with some admixture of chert.

Certain peculiarities in the distribution of materials in the Citronelle formation are worthy of mention. In Mississippi the outliers are in general composed of coarse subangular chert gravel, with a varying percentage of small, well-rounded quartz pebbles. In Louisiana and Alabama quartz gravel is common. The coarse pebbles have in a measure the same composition and evidently came from a common source, and the same is true of the fine pebbles. The coarse subangular fragments are mostly chert and have been subjected to fluviatile wear with very little subsequent rounding by waves, but many of the finer, well-rounded pebbles are quartz and have doubtless been shaped by prolonged subaqueous erosion. Probably the subangular material was brought directly from its original source, and the fine, well-rounded material was subjected to wave erosion by being deposited in some one or more of the older formations of the Coastal Plain, from which it was obtained by Pliocene streams. This conclusion seems warranted because the gravel is a poorly assorted aggregate of material of all sizes from sand to pebbles an inch or two in diameter. (See Pls. XXXIX, XL, and XLI.) If the gravel had been subjected to wave action during Pliocene time it would have been assorted, and it is therefore inferred that the perfect rounding of the small pebbles was accomplished by wave action during earlier geologic periods.

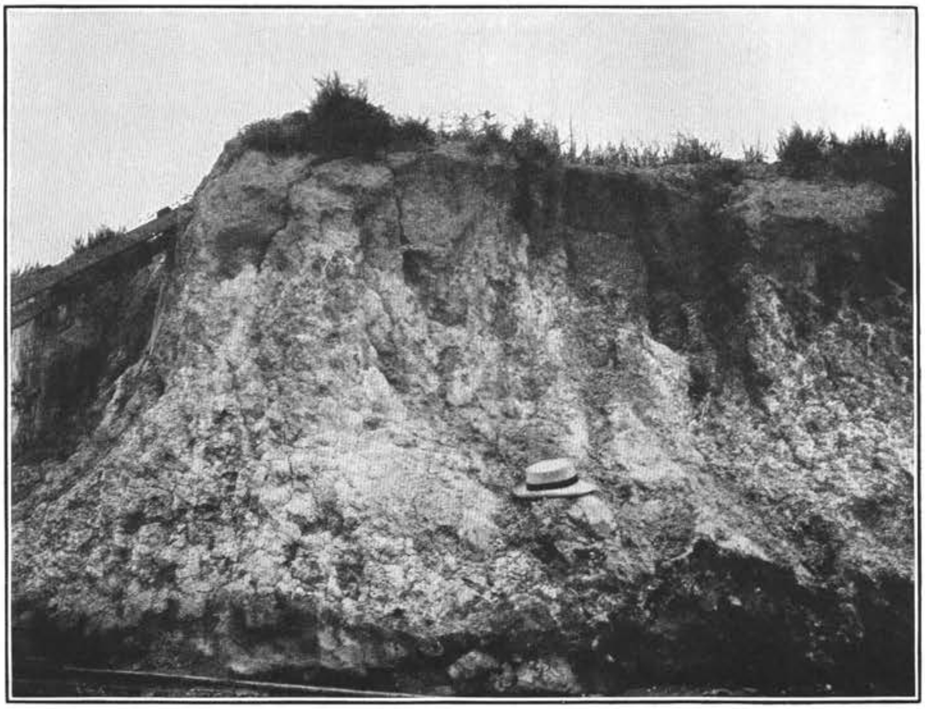
The clays vary greatly in character, some of the beds being relatively pure and others distinctly sandy. On the whole the sandy clays predominate, and in many places thin layers of sand are found in the clay beds.

The Citronelle formation has a very wide range in color. Doubtless when fresh some of the materials included in the formation were either blue or gray with small percentages of red and yellow, but nearly all the exposures available for observation at the present time have been subjected to so much weathering that the original colors have been partly or wholly obliterated. The sands in most of the sections are either orange or red, though near the surface some of them are yellow. This predominance of the orange and red colors on weathered surfaces led to the designation of the materials in this formation, either wholly or in part, as "Orange sand." The clays vary in color according to the degree of weathering to which they have been subjected, beds that have been buried to sufficient depth to protect them from the oxidizing effect of the atmosphere or surface water being either pale blue or gray. Where the oxidation has been slight they are mottled, the first change producing spots or blotches of a light-red or peculiar purplish color. As the process of weathering continues the purple color disappears and a deep-red color predominates, and still further weathering changes the red color to pale yellow. The iron in the clay, which presumably causes the coloring, changes during the process of oxidation to hydrous oxide, and on complete weathering of the clay to a yellow color the iron becomes more or less aggregated into nodules of varying sizes. Somewhat similar aggregations of iron hydroxide occur in the sands in the form of concretions and geodes,

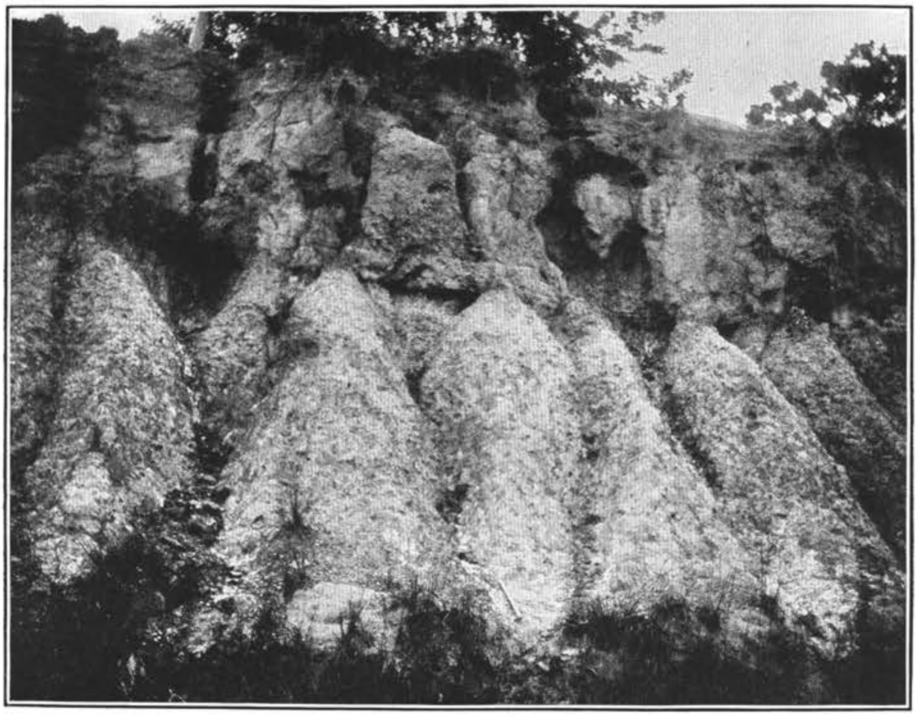


A. CITRONELLE FORMATION (?) OVERLAIN BY PLEISTOCENE SAND AND LOAM ON THE WEST BANK OF ESCAMBIA RIVER SOUTH OF MOLINO, FLA.

B. ANOTHER VIEW NEAR THE SAME LOCALITY, SHOWING UNCONFORMABLE CONTACT.



A. CLAY PIT OF THE SOUTHERN BRICK CO., 1 MILE NORTH OF GOULDING, FLA.



B. SANDSTONE AND CLAY, PIT OF THE SOUTHERN BRICK CO., 1 MILE NORTH OF GOULDING, FLA.

or as shells inclosing cores of clay. In other places the iron accumulates in the form of plates cementing thin layers of sand or as a filling for more or less definite cracks that cross the strata at high angles. Where the iron hydroxide is disseminated among the sand grains or pebbles it transforms the bed into a sandstone or conglomerate. This cementation apparently takes place near the surface and as a rule does not extend for any great distance along a bed, so that in most places the sandstone and conglomerate are in the form of blocks of varying sizes. (See Pl. XXXVIII, *A*.) The irregularity in size and shape of these blocks usually prevents them from being utilized in construction, even where they are firmly cemented, but south of Citronelle, at the 28-mile siding on the Mobile & Ohio Railroad, a hard sandstone belonging to this formation has been quarried to a depth of over 5 feet, and the rock obtained at this locality has been used in the construction of a church.

The texture of the formation in any particular locality depends entirely on the arrangement and relative percentages of the different kinds of materials. In general, the sands form more or less continuous beds containing lenses of pebbles or clay that in some places have considerable horizontal extent and in others are limited to only a few feet. Many clay lenses are only a few feet to a few rods in extent, though in places they interlock with other lenses lying above and below them, and in that way present the appearance of a continuous bed, unless it is possible to examine the section in detail. In the sands cross-bedding and cross lamination are the rule rather than the exception, the layers of clay and pebbles in many places being inclined at high angles. Smooth, even bedding is comparatively rare except in the clay lenses.

In this formation, as in many others, pebbles of clay are common, occurring at many stratigraphic horizons and having a wide geographic distribution. Most of them are more or less perfectly rounded balls of clay embedded in sand in such a way as to form a lenticular clay conglomerate. In places there are more or less rounded blocks of clay in which the original lamination is still preserved. Here and there this lamination coincides in direction with that of the sands, but as a rule it differs. Doubtless many of the pebbles were eroded from the subjacent clay by the currents that transported the sand. Some of the pebbles and probably most of the angular fragments were derived from the undercutting of small cliffs developed by waves or currents. (See Pl. XLII.) This explanation for blocks of clay embedded in sand was first suggested by T. Wayland Vaughan[1] to account for similar clay fragments found in some of the sands of the Wilcox formation, but it is also applicable to such clay fragments in the Citronelle formation.

STRUCTURE.

In the Citronelle formation the arrangement of the sediments in lenticular beds makes it impossible to determine the structure by observations on the elevation of beds (see Pls. XXXIX, *A*, and XL, *B*) except at a few localities where the conditions are unusually favorable. The prevalence of cross lamination and cross-bedding renders determinations of dip with a clinometer valueless because the inclinations observed may not agree in direction with the dip of the beds, and they may vary in direction or be in opposite directions in a single section. Under such unfavorable conditions the recognition of local structural features is everywhere difficult and in most places impossible.

The inclination of the base of the formation can be measured in many places, especially near the landward margin. The results of such measurements show that the dip is not uniform, and in addition to irregularities resulting from deposition on an uneven surface there is a general increase in the rate of inclination of the base of the formation toward the coast. These facts are well shown by the section across southwestern Mississippi and eastern Louisiana, where the contact of the Citronelle with the older formations descends at an average rate of a little less than 6 feet to the mile from a point 6 miles north of Wesson to Osyka, Miss., and at a much higher rate from Osyka, Miss., to Hammond, La. (See Pl. XXXII.) Other sections show steeper inclinations, but they are based on less accurate and less detailed information. The base of the Citronelle formation near the coast is drawn at the transition

[1] Unpublished notes.

from sands, sandy clays, and gravel to finer-grained sediments, chiefly clays, containing characteristic fossils of the Pascagoula clay, and the correlations are probably approximately correct, though there may be errors of a few feet in the position of the contact because of slight inaccuracies in the well logs used for the purpose of obtaining measurements of depths to the base of the Citronelle formation. Where the computations of the rate of dip of the base of the formation are made on a line several miles in length, the amount of error in the rate per mile is minimized.

The actual dip of any portion of the formation may be less than the inclination of the base, because deposition probably began near the coast and was gradually extended inland. This is suggested by the fact that the coarse gravels that form outliers along the landward margin of the formation rest on finer deposits belonging to the Citronelle farther south. For example, the coarse gravel rests on the Pascagoula clay near Wesson, but at Brookhaven it overlies about 130 feet of red sand with interbedded clay that is included in the Citronelle. The gravels are covered near Summit by still younger sediments that are more argillaceous than those below.

Near the coast the upper portion of the formation was laid down on the seaward slope of the earlier deposits, and in this portion the actual dip is probably greater than the dip of the base of the formation. In the absence of reliable data to use in computing the true dip, however, it seems best to give the inclination of the base. The exact dip of the base of the formation is not easy to determine, because near the coast there are no exposures that reach the contact with the Pascagoula formation and it is difficult to interpret the information supplied by some of the logs of wells. Such computations as have been made give discordant results that are probably not entirely due to the incomplete information but are partly explained by local variations in the rate of dip.

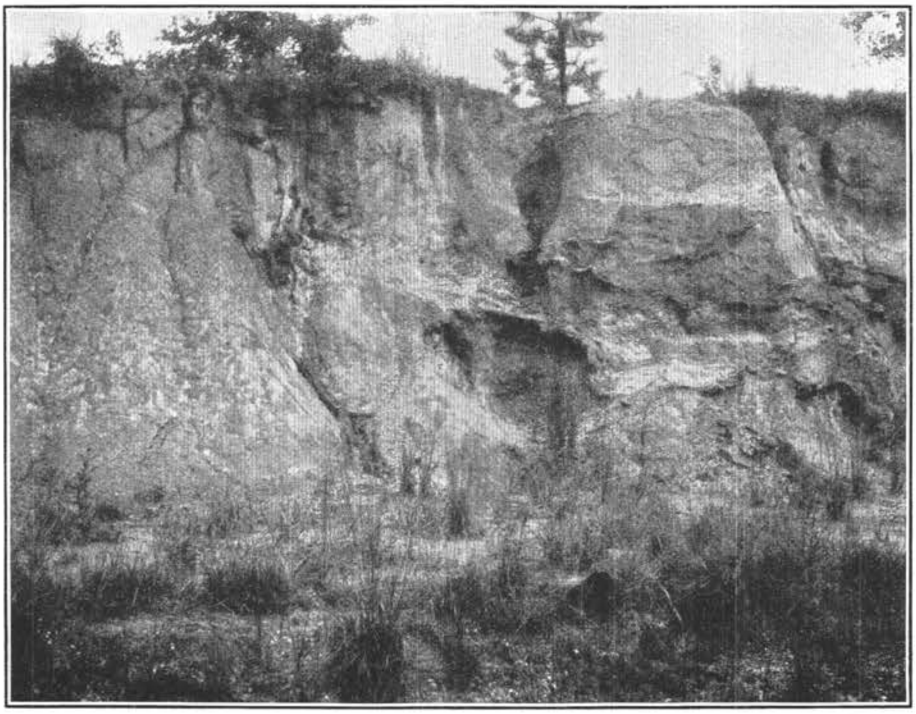
In the northern part of Mobile County, Ala., the base of the Citronelle formation is about 240 feet above sea level, and at Citronelle, 4 miles south of the county line, the contact with the underlying Pascagoula clay is at 220 feet above sea level, giving an average inclination of about 5 feet to the mile. From Citronelle southward to Semmes the contact descends from 220 feet above sea level to 92 feet below sea level, or at the rate of about 16 feet to the mile.

At Laine, Miss., where the surface is about 10 feet above sea level, characteristic fossils of the Pascagoula formation were obtained from the De Lamorton well at a depth of 615 feet (?), and the base of the gravel beds was reached at 605 feet. This well is 53 miles S. 28° W. from the place in Mobile County, Ala., where the elevation of the base of the formation was determined, indicating a dip of nearly 16 feet to the mile, provided the gravel reached in the well is at the base of the Citronelle formation; but as the gravel may be somewhat above the contact the dip thus determined should be regarded as the minimum inclination of the base of the formation rather than the exact amount.

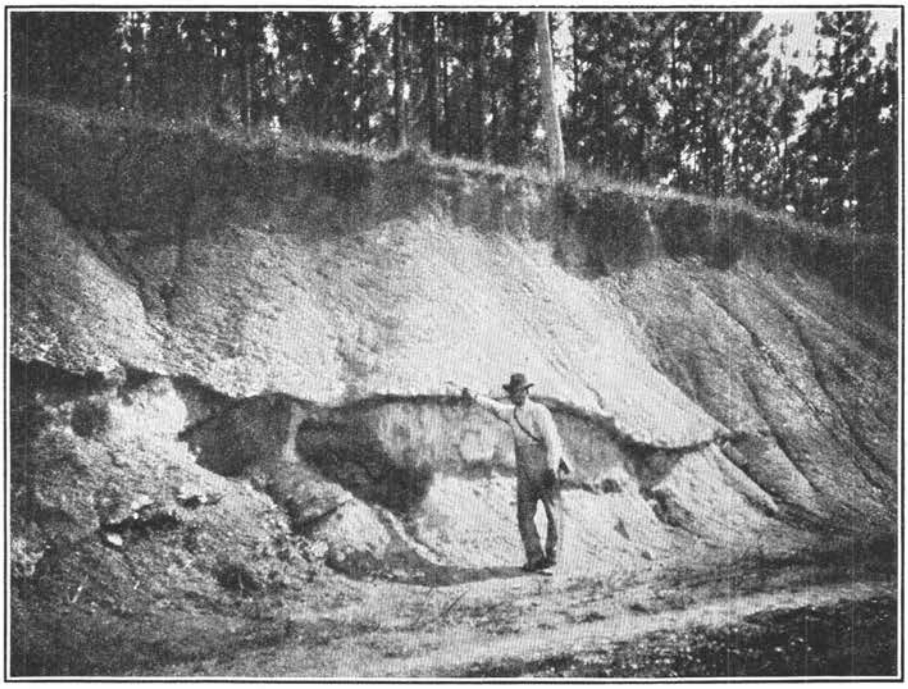
Near Maxie the base of the Citronelle formation is about 215 feet above sea level, and at Bond, 6 miles S. 20° E., a well reached the contact of this formation with the clays of the Pascagoula at an elevation of 115 feet. The steep dip between these two points, nearly 17 feet to the mile, is explained by the fact that the formation was deposited on an uneven surface. Computations of the rate of dip between Maxie and Laine give about 14 feet to the mile, and the direction is about S. 45° E. At Fontainebleau,[1] about 20 feet above sea level, fossils belonging to the Pascagoula clay were obtained in a well at a depth of 500 feet. These fossils probably came from beds near the top of the Pascagoula, and they show that the dip of the Citronelle formation between Maxie and Fontainebleau is between 14 and 15 feet to the mile in a direction S. 35° E.

In western Mississippi measurements of the dip of the Citronelle formation have been made farther inland than in eastern Mississippi and in Alabama. (See Pl. XXXII.) Six miles north of Wesson the base of the formation is 435 feet above sea level, and just east of Brookhaven it is 330 feet above sea level. Here the contact of the Citronelle with the older formations descends about 115 feet in 15 miles, or at the rate of nearly 8 feet to the mile. From Brookhaven to Osyka the contact descends from 330 to 100

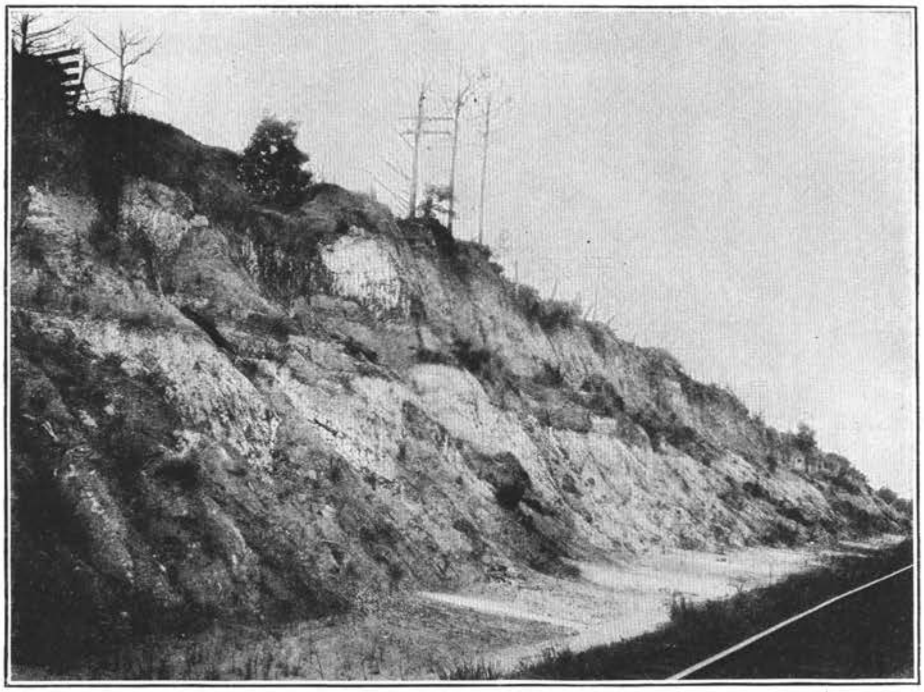
[1] Crider, A. F., and Johnson, L. C., Summary of the underground water resources of Mississippi: U. S. Geol. Survey Water-Supply Paper 159, p. 32, 1906.



A. SANDS AND SANDY CLAYS WITH PLATES OF LIMONITE-CEMENTED SANDSTONE, NORTHERN ESCAMBIA COUNTY, FLA.



B. SAND CONTAINING A LENS OF CLAY, WITH A PLATE OF SANDSTONE CEMENTED WITH LIMONITE AT THE CONTACT OF THE SAND AND CLAY, NORTHERN ESCAMBIA COUNTY, FLA.



A. SAND AND CLAY, FLOMATON, ALA.

B. SAND AND GRAVEL, FLOMATON, ALA.

feet above sea level, or 230 feet in about 39 miles, which is at the rate of 6 feet to the mile. From Osyka southward the dip is difficult to determine because of meager information, but it apparently becomes steeper, amounting to approximately 810 feet between Osyka and Hammond, a distance of 35 miles, which would be at an average rate of about 23 feet to the mile. These determinations are all made along a line extending nearly north and south.

In Louisiana many wells have been drilled south of the margin of the Citronelle formation, but the materials penetrated in most of them are not described in the records with sufficient exactness to permit correlations. Between Centerville, Miss., and Bass, La., the rate of dip of the base of the formation is about 19 feet to the mile, and it must increase rapidly toward the south, as is shown by the great thickness of the overlying Pleistocene deposits at New Orleans. Between Osyka, Miss., and Bass, La., the rate of descent is about 10 feet to the mile and the direction about southwest. This is less than the slope from Centerville to Bass and probably indicates that there was a delta in the Mississippi Valley during this epoch rather than an embayment. West of the Mississippi few data that can be used in computing the dips of the formation have been obtained. About a mile north of the Jennings oil field, where the strata are undisturbed and the surface is only about 25 feet above sea level, Miocene fossils were found at a depth of 1,960 feet.[1] The base of the Citronelle formation near Woodworth, about 70 miles north of the Jennings oil field, is approximately 140 feet above sea level. This would give a dip of nearly 30 feet to the mile, provided the fauna found near Jennings came from the top of the Pascagoula clay. This dip represents a maximum, and the actual rate of descent between the two points is probably not so great.

The figures given in the foregoing discussion should be regarded as only approximate measures of the rate of inclination of the base of the formation. The general dip of the deposits beneath the Pleistocene along the southern margin of the formation is shown in Plate XXXII and amounts to less than 20 feet to the mile. The general dip is toward the south, though there are doubtless many local variations in direction. Dips determined from the elevations of the bases of outliers and from logs of wells drilled where the Citronelle formation is at the surface are much lower than 20 feet to the mile, and the rate is variable because the formation was deposited on a surface that was uneven and had a steep slope near the Pliocene strand line. This steep slope accounts for the fact that near the coast the dip becomes steeper, probably exceeding 20 feet to the mile. In the vicinity of New Orleans the original slope near the Pliocene strand line may have been increased by subsidence during Pleistocene time, as shown by the great thickness of Pleistocene beds (2,443 feet) overlying the Tertiary formations.[1]

The thickness of the Pleistocene beds at Fort Morgan, Ala., suggests a steep descent of the Pliocene Citronelle formation. The log of the well at that place, shown in Plate XLIII, in pocket, was made from a series of samples of drillings, and the subjoined list of fossils was furnished by Mr. Dall.

	Depth (feet).
Fragments of echinoderms and two Recent shells, *Donax variabilis* Say and *Paramya subovata* Conrad	30–32
Dentalium acus Dall, *Nassa acuta* Say, Ervilia sp. junior, Ostrea, and echinoid fragments, all Recent	30–40
Recent shells, *Mulinia lateralis* Say, *Donax variabilis* Say, *Arca transversa* Say, etc	32–87
Recent species, *Abra æqualis* Say, *Arca transversa* Say, *Strigilla carnaria* Linné, *Mulinia lateralis* Say, Leda, Pecten, and Dolium fragments	100–112
Strigilla carnaria Linné, Recent	169–175
Ostrea fragments	175–256
Recent species, Ervilia cf. *E. nitens* Montgomery, *Phacoides crenella* Dall, *Mulinia lateralis* Say, Diplodonta sp., *Modiolus demissus* fragments, Cadulus and Cymatium fragments	217–321
Fragments of Phacoides, Mulinia, Ostrea, and Marginella sp.; probably Recent	322–337
Divaricella cf. *D. dentata* Wood, fragments; Mulinia cf. *M. lateralis* Say; Cadulus fragments; and Phacoides sp., young; probably all Recent	523–570
Nassa acuta Say, upper Miocene to Recent	1,076–1,089
Ostrea fragments	1,089–1,121
Conus pealei Green, Recent	1,244–1,290
Mulinia lateralis Say, Recent to Miocene	1,290–1,330
Chione sp., fragments	1,350–1,370
Ostrea fragments, Anachis cf. *A. avara* Say, and a fragment of Turritella sp	1,378–1,573

The material above 1,290 feet is nearly all Quaternary; that below may possibly be Pliocene.

[1] Harris, G. D., Oil and gas in Louisiana: U. S. Geol. Survey Bull. 429, p. 58, 1910.

[1] Harris, G. D., op. cit., p. 170.

This well is 35 miles S. 35° E. from St. Elmo, where the Pliocene reaches an elevation of 130 feet above sea level. The surface of the Citronelle formation descends about 1,220 feet between these two points, or at the rate of more than 35 feet to the mile, but the original inclination may have been much less, because although the Pliocene has been eroded at both localities the amount of post-Pliocene erosion was greater at Fort Morgan, which is near the axis of Mobile Bay.

Near Pensacola the available information suggests a somewhat lower dip for the top of the Citronelle formation. At Pine Orchard, nearly 7½ miles north of Pensacola, the top of the formation is about 160 feet above sea level, and about 4½ miles south of Pensacola the shells obtained at a depth of 256 to 276 feet below sea level were tentatively referred to the Pliocene by Mr. Dall. This indicates a maximum dip of 416 feet in a distance of about 12 miles, or at the rate of about 35 feet to the mile, approximately toward the south.

From the foregoing statements it seems evident that there is a rapid increase in the rate of inclination of the top of the Pliocene near the coast at Pensacola and Mobile and north of New Orleans, and similar conditions doubtless prevail along the entire shore line. This apparent steeper dip at Pensacola and Mobile is, however, partly explained by the fact that in the wells cited the seaward equivalent of the Citronelle formation may have been reached some distance above the level of the fossil-bearing beds. Still, even after liberal allowances have been made for inaccuracies due to this cause, it is obvious that the top of the Citronelle formation must originally have had a steep seaward slope near the coast.

THICKNESS.

The thickness of the Citronelle formation is variable, ranging from a few feet near the landward margin of the formation to several hundred feet near the coast. Exact determination of the thickness near the coast is difficult because it is necessary to rely in part on logs of wells for data, and the information obtained from this source is not entirely satisfactory. The uncertainty is increased by the fact that the overlying Pleistocene beds consist of sands and clays resembling those belonging to the Citronelle formation.

In southern Alabama the Citronelle formation forms a high upland reaching nearly 350 feet above sea level, and in the adjacent valleys the older formations are not exposed in the valleys where the elevation is less than 100 feet. Thus the formation may have a thickness of more than 250 feet. The log of a well drilled about 12 miles west of Mobile shows sand and gravel to a depth of 245 feet and an additional thickness of pink sand and clay amounting to 95 feet. This gives a minimum thickness of 245 feet and a maximum of 340 feet.

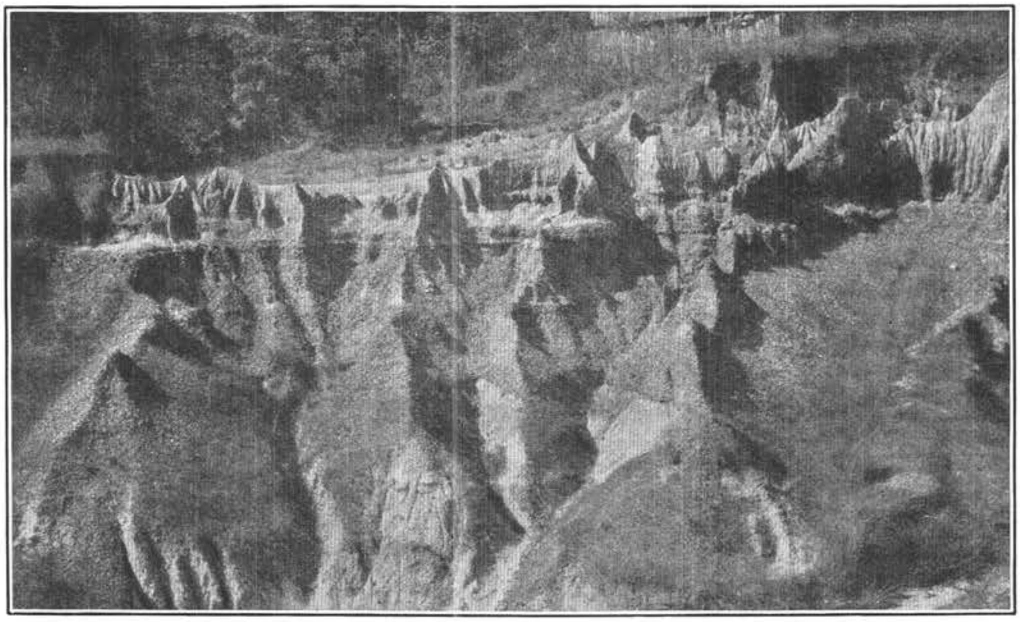
In Mississippi the thickness of the outliers of the Citronelle formation as a rule does not exceed 20 to 30 feet. At Bond a well penetrated 90 feet of sands and gravel belonging to this formation before encountering the underlying Pascagoula. The De Lamorton well at Laine passed through sand containing some tree trunks at a depth of 141 to 153 feet. The materials beneath this sand are described as sand, shale, and gumbo to a depth of 615 feet, where Pascagoula fossils were obtained. These materials included a gravel bed with its base at 605 feet, and if this is at the base of the Citronelle the thickness of the formation at that place may be as great as 452 feet. At Fontainebleau the Pascagoula clay was reached at a depth of 500 feet,[1] and as the Pleistocene beds are probably as thick there as at Laine, the thickness of the Citronelle formation at Fontainebleau is estimated to be about 350 feet.

A well at Osyka passed through 150 feet of sand and gravel belonging to the Citronelle formation, and the formation has an additional thickness of about 50 feet beneath the upland. Farther south, at Hammond, the thickness may amount to several hundred feet, though the formation is not readily separable from the Pleistocene, and accurate determination of thickness is impossible. Near Brookhaven the Citronelle formation has a thickness of about 130 feet, but it thins to a few feet within a distance of 20 to 30 miles farther north.

Information concerning the thickness of the Citronelle formation in Louisiana is meager. The formation has been observed through a vertical range of over 150 feet, and may safely

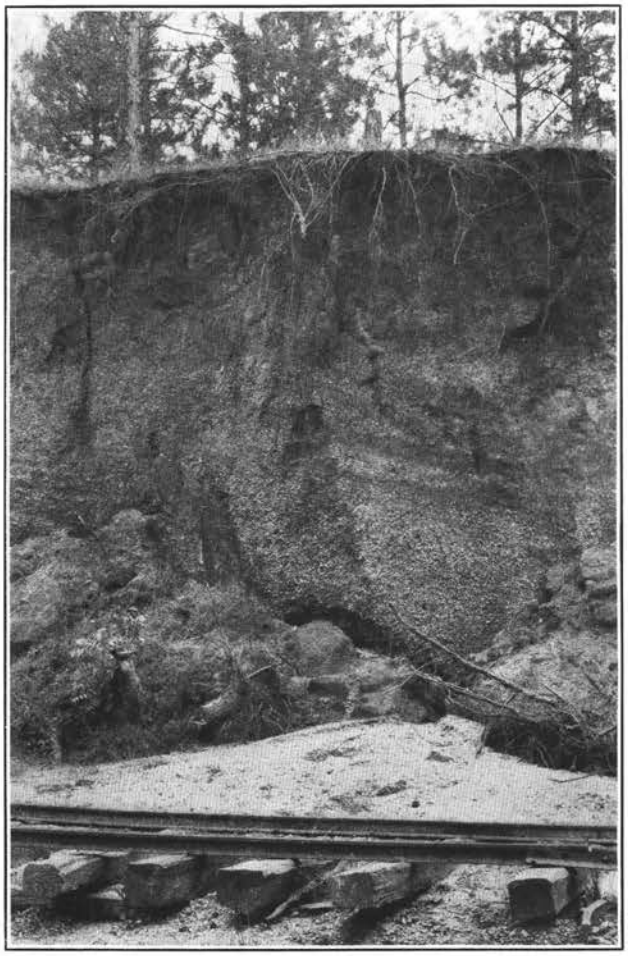
[1] Crider, A. F., and Johnson, L. C., Underground water resources of Mississippi: U. S. Geol. Survey Water-Supply Paper 159, p. 32, 1906.

A.

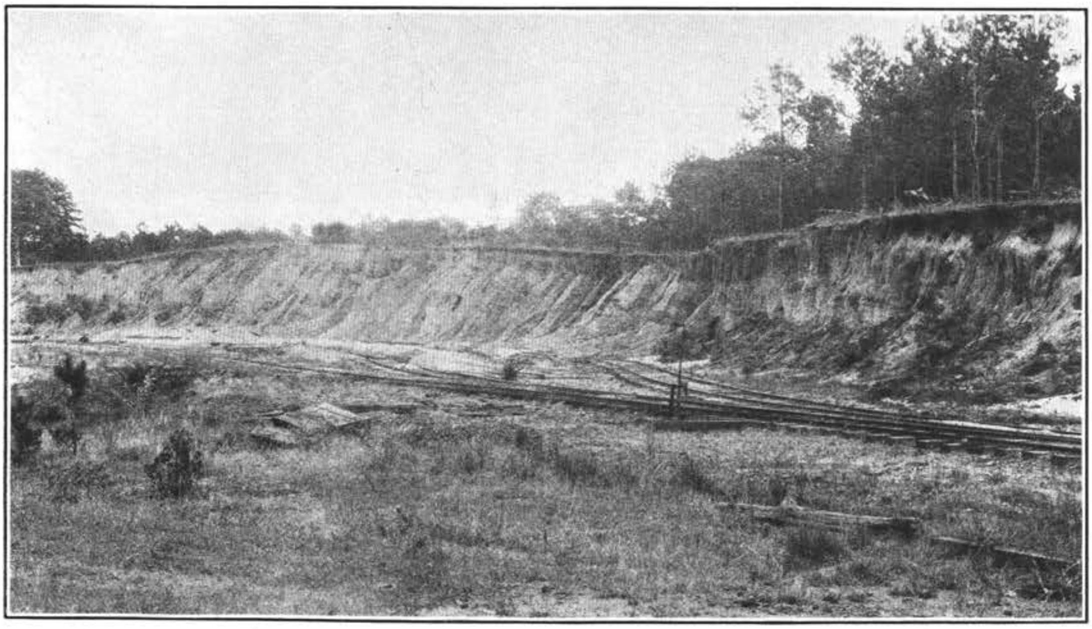


B.

SILT UNDERLAIN BY SAND AND GRAVEL OF THE CITRONELLE FORMATION, ROCKY SPRINGS, MISS.



A.



B.

GRAVEL PIT 1 MILE SOUTH OF WEATHERSBY, MISS.

Photographs by E. W. Shaw.

be credited with a minimum thickness of that amount, and this agrees with the thickness assigned to the formation in the well at Ludington. (See Pl. XLIII, in pocket.) East of Mississippi River the well at Bass penetrated 90 feet of yellow clay and 10 feet of sand, like the materials exposed at Port Hickey. This portion of the section is referred to the Pleistocene. It rests on 220 feet of clay that is regarded as the southward extension of the clays found in the upper part of the Citronelle formation in southern Mississippi, and the cherty sands and chert gravels immediately below this clay may safely be correlated with the sand and gravel that form the basal part of the Citronelle formation. This would give a thickness of 400 feet for the formation at Bass, and if the subjacent clay is included the thickness is still greater. Near the coast the deposits of Pleistocene sand, gravel, and clay can not be separated from the Citronelle formation, and its thickness has not been determined, though it probably thins rapidly in that direction.

TOPOGRAPHY.

GENERAL FEATURES.

The Citronelle formation occupies an area where the characteristic topography of the seaward margin of the Coastal Plain changes to the more diversified topography of the Tertiary beds. The contrast between the varied physiographic expression of this formation and the relatively uneroded terraces of Pleistocene age farther south is striking and would serve as a basis for mapping the seaward margin of the formation except where remnants of the Pliocene plains have been preserved. The landward margin of the formation could not be so readily distinguished by this method, because the topography of the older formations is similar to that of the Citronelle.

The original surface of the formation was a series of plains with gentle slopes toward the Gulf (see Pl. XXXII), but its present topography is the result of dissection so thorough that only a small percentage of the area remains level, the surface being mainly reduced to slopes interrupted by terraces, though near the coast a coating of materials of more recent age obscures the original surface. The general homogeneity of the deposits that constitute the formation permits the drainage channels to form under the influence of the original slope and independent of the stratigraphy. Each of the major streams has numerous tributaries, providing a dendritic drainage that is adequate for nearly all the area covered by the formation. In a few places may be seen remnants of the original surface of the formation, with drainage so deficient that they are partly submerged during periods of prolonged rainfall. On these remnants the variations in level are so slight that they are scarcely noticeable except where there are ponds either in the form of small rounded or elongated depressions overgrown with cypress and other swamp vegetation.

Some of the higher hills, especially those with flat tops, are remnants of the surface of the oldest plain, and by noting their elevations it is in places possible to reconstruct an upland having a maximum elevation of a little more than 500 feet above sea level. However, some of the hills are mere erosion remnants, the original surface having been wholly removed, though the rate of degradation has been sufficiently uniform locally to preserve a certain amount of uniformity in elevation over small areas. This condition is found where a bed of resistant material, such as gravel, is encountered, and a general seaward inclination results because such beds have a slight dip in that direction. The slope of the original surface of the formation remained nearly undisturbed after the time of deposition, because the formation was raised bodily to its present height with only slight change in attitude resulting from a gentle warping of its surface. The presence of remnants of terraces in the valleys that cross the Pliocene upland shows that the Citronelle formation has been terraced since the formation of the highest plain. The lower plains resemble the upper one in topography, but they are much narrower and the continuity of their deposits with those beneath the upper plain suggests that the materials of the lower plains were laid down in the closing stages of the Pliocene.

The range in elevation of the exposures belonging to the Citronelle formation amounts to over 450 feet, because the formation crops out in a few places near the level of the Gulf, and its outliers cap some of the high hills in the areas underlain by Oligocene formations. The average difference is about 250 feet, and if the upper surface of the formation is considered, the range is from about 170 feet on the seaward margin to more than 500 feet on some of the higher outliers farther inland. In general, the increase in altitude is comparatively rapid, the surface rising from about 170 feet to approximately 300 feet within a distance of a few miles, and upon this portion of the formation narrow seaward-facing plains are developed.

PLAINS.

SUBDIVISIONS AND GENERAL CHARACTER.

The surface of the Citronelle formation is divided into four plains, designated, in descending order, the Brookhaven plain, the Sardis plain, the Canton plain, and the Loxley plain. (See Pl. XXXII.) This arrangement is also in the order of age, the Brookhaven plain being the oldest and the others being successively younger. Each plain may be divided into two portions that merge with each other at their points of contact and may be called stream terraces and interstream plains. It has been customary to speak of these features as fluviatile and marine, though the propriety of such a designation may well be questioned, because some portions of the interstream plains are of as distinctly fluviatile origin as any portion of the stream terraces. The exact position of the contact between the deposits of the two types no doubt varied during the progress of deposition, the fluviatile sediments being pushed beyond the limits of the adjacent valley walls where the material was being carried seaward in the form of deltas and retreating into the valleys where estuaries were developed. For these reasons the terms stream and interstream, although arbitrary, are used instead of the more expressive but less accurate terms fluviatile and marine.

BROOKHAVEN PLAIN.

DISTRIBUTION.

The Brookhaven plain, named from Brookhaven, Miss., where it is well known, is the oldest and highest of the Pliocene plains and formerly occupied an area larger than the combined area of all the other Pliocene plains. Its interstream portion forms a belt from 10 to more than 60 miles in width, extending from western Florida across Alabama, Mississippi, and Louisiana into southeastern Texas. The original width of this plain can not now be determined accurately because some portions of the deposit have been removed by erosion, but it must have been more than 30 miles wide north of the Alabama-Florida boundary and 60 miles wide in western Mississippi, from which it narrowed rapidly to somewhat more than 10 miles in southeastern Texas.

The stream terraces of the Brookhaven plain are not well known outside of the Mississippi Valley, where they have been studied by E. W. Shaw.[1]

ALTITUDE.

Because of subsequent erosion and deformation the altitude of the Brookhaven plain as it now appears is variable, being from about 350 to 420 feet above sea level in western Alabama, from 420 to more than 520 feet in western Mississippi, about 320 to 380 feet in southern Louisiana, and about 340 feet in southeastern Texas.

The landward boundary of the plain is not marked by any distinct scarp but by outliers of sand and gravel, locally overlain by sandy clay. These outliers are widely distributed, but their detailed distribution has not been mapped.

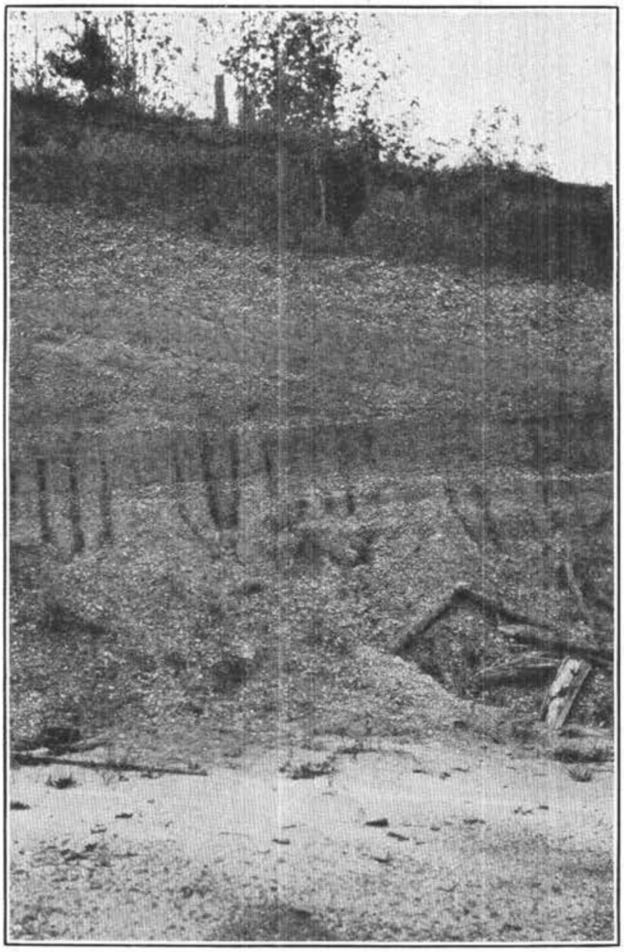
SLOPE.

The interstream portion of the Brookhaven plain slopes seaward at the rate of about 6 inches to the mile, though local variations are to be found in places where the surface has been eroded. From the highest point on this plain in western Mississippi, where its surface is as much as 520 feet above sea level, the plain slopes eastward to about 420 feet above sea level in western Alabama, or at an average of about 6 inches to the mile. The slope from western Mississippi to southeastern Texas is from 520 to 340 feet, or at an average rate of about 5 inches to the mile, in a direction south of west. As the greater portion of this descent appears to be in the eastern portion of Louisiana, the actual rate of slope near Mississippi River may have been nearly a foot to the mile, though the subsequent removal by erosion of this portion of the plain has made exact determinations impossible. The width of this plain in Alabama is variable but is much less than in Mississippi, and the slope toward the south is apparently about 2 feet to the mile.

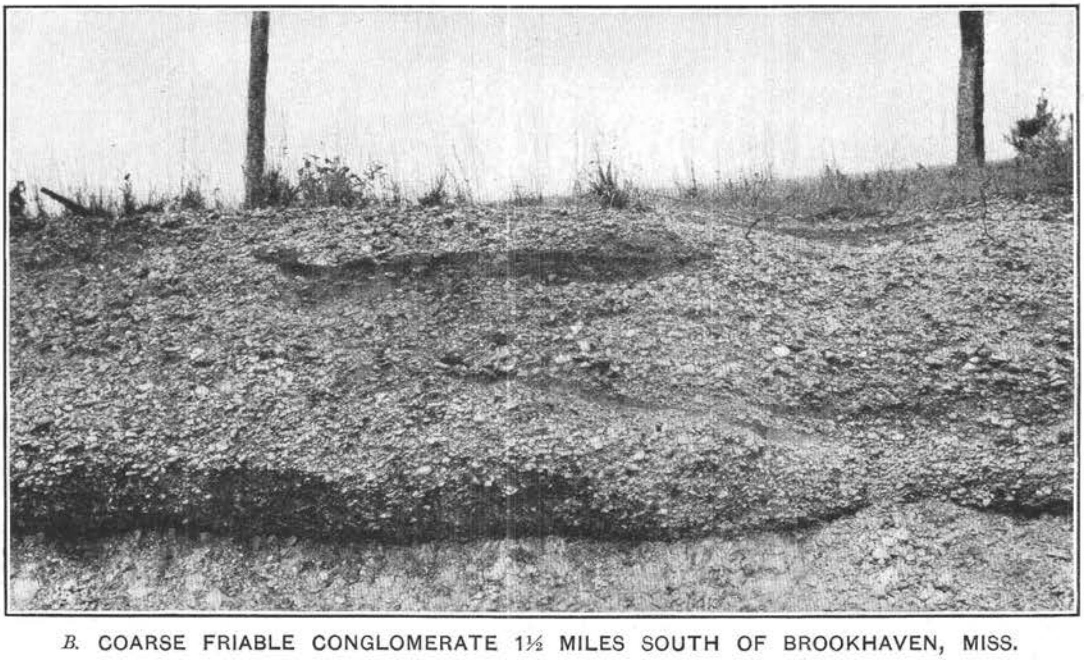
DISSECTION.

The interstream portion of the Brookhaven plain has been deeply dissected by streams, and the original surface is preserved only on the

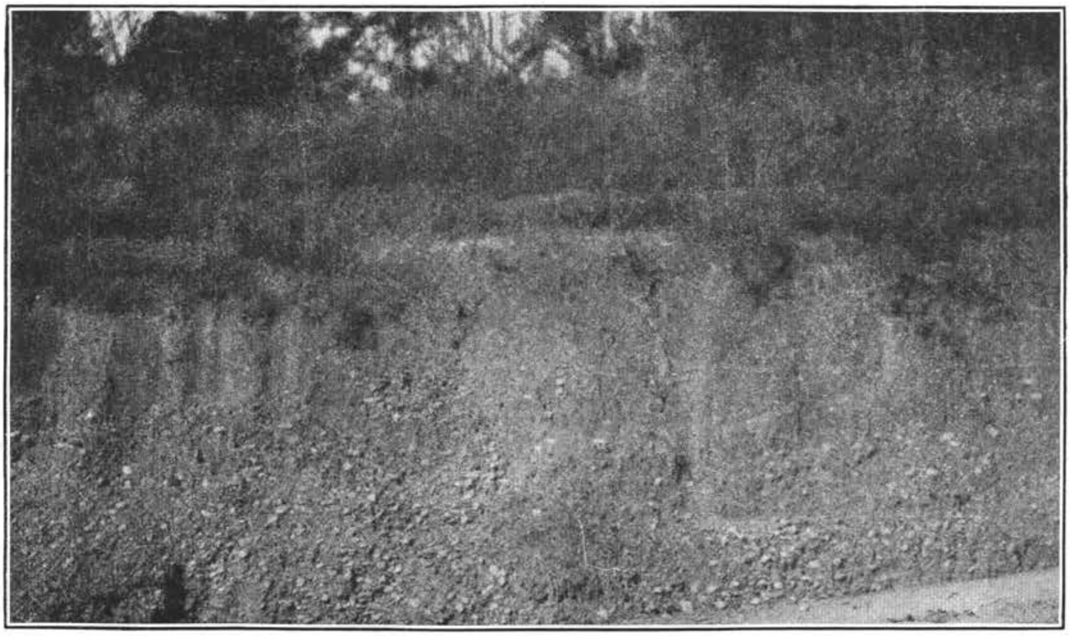
[1] Shaw, E. W., unpublished notes.



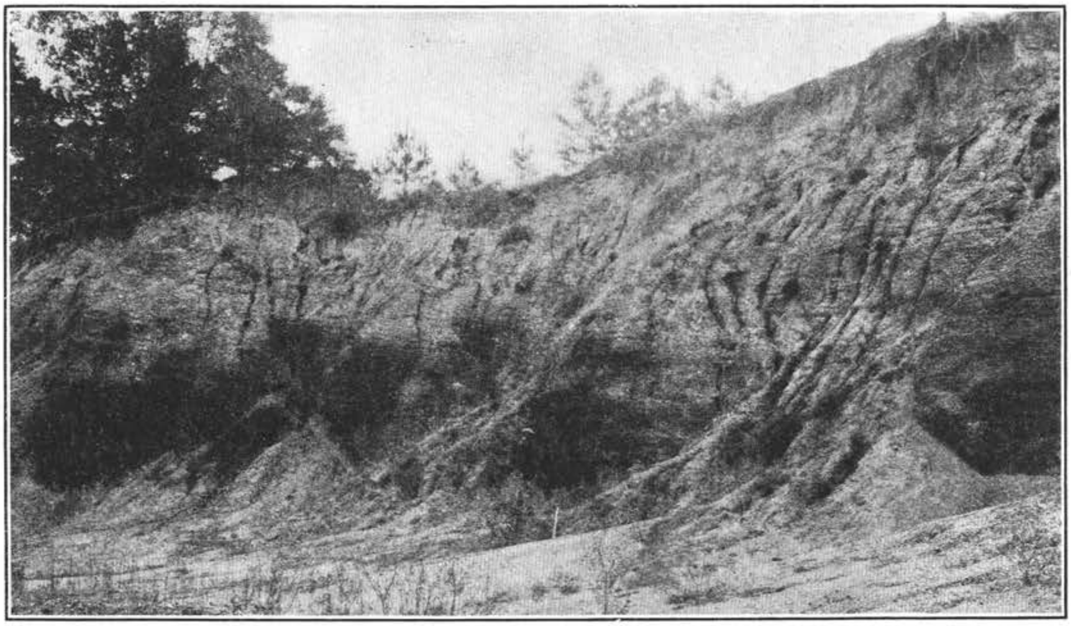
A. IRREGULAR STRATIFICATION OF SAND AND GRAVEL, GRAVEL PIT 2½ MILES SOUTH OF BROOKHAVEN, MISS.



B. COARSE FRIABLE CONGLOMERATE 1½ MILES SOUTH OF BROOKHAVEN, MISS.



A. GRAVEL 2 MILES SOUTH OF ROCKY SPRINGS, MISS.



B. GRAVEL PIT 2½ MILES SOUTH OF BROOKHAVEN, MISS.

divides and in isolated hills. These divides are generally in the form of even-topped ridges or in some localities flat areas several miles in width. A large proportion of this dissection was accomplished during the closing stages of the Pliocene, and the valleys developed at that time have not been broadened except at a few localities. This is shown by the fact that the Pliocene plains younger than the Brookhaven are represented by stream terraces in the valleys that cross the Brookhaven plain.

LITHOLOGY AND SOILS.

The material underlying the Brookhaven plain is in general coarser than that underlying the younger plains. Fine sediments, however, are the rule on the surface of the plain, and the soil derived from them is either loam or sandy loam, with subordinate amounts of clay. Where the plain has been sufficiently eroded to uncover the coarse gravels, as, for example, near Crystal Springs and Hazlehurst, Miss., stony or gravelly loams are common.

STRATIGRAPHIC RELATIONS OF THE DEPOSITS.

The strata forming the interstream areas of the Brookhaven plain rest unconformably on the underlying formations, of upper Tertiary age, and merge with the materials beneath the next younger (Sardis) plain. The history of the formation and dissection of the Brookhaven plain forms a part of the history of the Citronelle formation, as a whole, which is discussed elsewhere.

SARDIS PLAIN.

Below the level of the Brookhaven is another plain that is well developed in the vicinity of Sardis, Miss., and is called the Sardis plain. The stream terrace of this plain in the Mississippi Valley north of the latitude of Vicksburg has been studied by E. W. Shaw.[1]

DISTRIBUTION.

Stream terraces.—A stream terrace of the Sardis plain probably originally occupied an area in the Mississippi Valley extending from eastern Adams County, Miss., nearly to central Louisiana. This is the area where it should have been widest, because here it was formed by the combined action of Mississippi River and its largest tributaries in the region. Subsequent erosion has reduced this terrace to a band less than 15 miles wide bordering the east side of Mississippi River. The width of this terrace on Pearl River, farther east in the same latitude, was from 15 to 20 miles, and the width on both Leaf and Chickasawhay rivers, still farther east, was nearly as great. On Alabama and Tombigbee rivers in Alabama this terrace was apparently twice as wide as on the rivers in eastern Mississippi. In Louisiana the stream terraces belonging to the Sardis plain have been so much dissected by erosion that it is difficult to estimate their width.

Interstream areas.—The interstream portion of the Sardis plain borders the southern margin of the Brookhaven plain and extends from central Alabama westward to southeastern Texas. In western Mississippi it has a breadth of about 30 to 35 miles, and it narrows gradually eastward to the Alabama-Florida boundary, where it is only about 15 miles wide. In western Louisiana and eastern Texas the interstream areas are still narrower, having an average width of about 10 miles.

ALTITUDE.

The altitude of the stream terraces of the Sardis plain is in general greatest near Mississippi River and declines gradually eastward to Florida and westward to Texas. They have a general slope in the direction of stream flow except in western Mississippi, where deformation has altered the original slope. On the east side of Mississippi River the stream terrace of the Sardis plain has an altitude of about 380 feet above sea level east of Vicksburg and near Woodville and Centerville. Near Natchez it is about 75 feet higher. In the Pearl River valley the plain slopes from about 410 feet a few miles north of Jackson to about 400 feet east of Brookhaven and to 360 feet near the Mississippi-Louisiana boundary. On Chickasawhay River and along the streams in Alabama and west of Mississippi River in Louisiana the slope appears to be steeper, though exact determinations of altitude have not been procured.

The altitude of the inner margin of the interstream plain in western Mississippi is about 420 feet, in western Alabama about 350 feet,

[1] Shaw, E. W., unpublished notes.

and in western Louisiana about 320 feet. The outer margin of the plain has an altitude of about 350 feet in southwestern Mississippi, 310 feet in western Alabama, and 270 feet in western Florida. In western Louisiana and eastern Texas the outer margin has an altitude of about 270 feet.

The width of the plain is variable, being from 30 to 35 miles in western Mississippi, 10 to 15 miles near the Alabama-Florida boundary, and 8 to 10 miles in eastern Texas. The narrowing of the plain both to the east and west of its place of maximum width is gradual, though marked local variations are found where the terrace has been partly removed by erosion.

SLOPE.

The slope of the stream terraces of the Sardis plain was probably originally steep, but the exact rate can be determined on very few streams because there are few reliable determinations of altitude. In western Mississippi deformation has given the stream terrace a slope away from the coast from Natchez to Vicksburg at the rate of about 6 inches to the mile. From Natchez southward it slopes seaward at the rate of about 9 inches to the mile. The slope of the interstream plains has been less affected by changes resulting from deformation and, if the steep descent from the Brookhaven plain is omitted, amounts to about 1 foot to the mile in western Mississippi, between 2 and 3 feet to the mile near the Alabama-Florida boundary, and about 3 feet to the mile in western Louisiana and eastern Texas.

DISSECTION.

The Sardis plain has undergone somewhat less erosion than the Brookhaven plain, though locally the stream terraces have been entirely removed. In general the terraces have been reduced in area by the meandering of the major streams and have been separated into small isolated plains by the erosion of tributary streams.

The interstream plains are extensively eroded near the principal streams, but on some of the divides there are still remnants of the original surface from 5 to more than 10 miles wide. Most of these remnants are crossed by shallow channels of wet-weather streams that provide adequate drainage, but in a few places, as, for example, near Atmore and Georgetown, Ala., the surface of the plain is so flat that shallow ponds form during wet weather. Even near the Mississippi Valley at Centerville and Woodville some portions of this plain are well preserved, being trenched by very shallow valleys, but the conditions here are favorable for the preservation of the original surface, because during the development of the drainage of southwestern Mississippi the stream encountered ledges of hard rock similar to that at Fort Adams at depths of 40 to 120 feet below the surface of the Sardis plain, and this hard rock retarded the erosion and resulted in the partial preservation of the original Pliocene surface where it would otherwise have been destroyed.

LITHOLOGY AND SOILS.

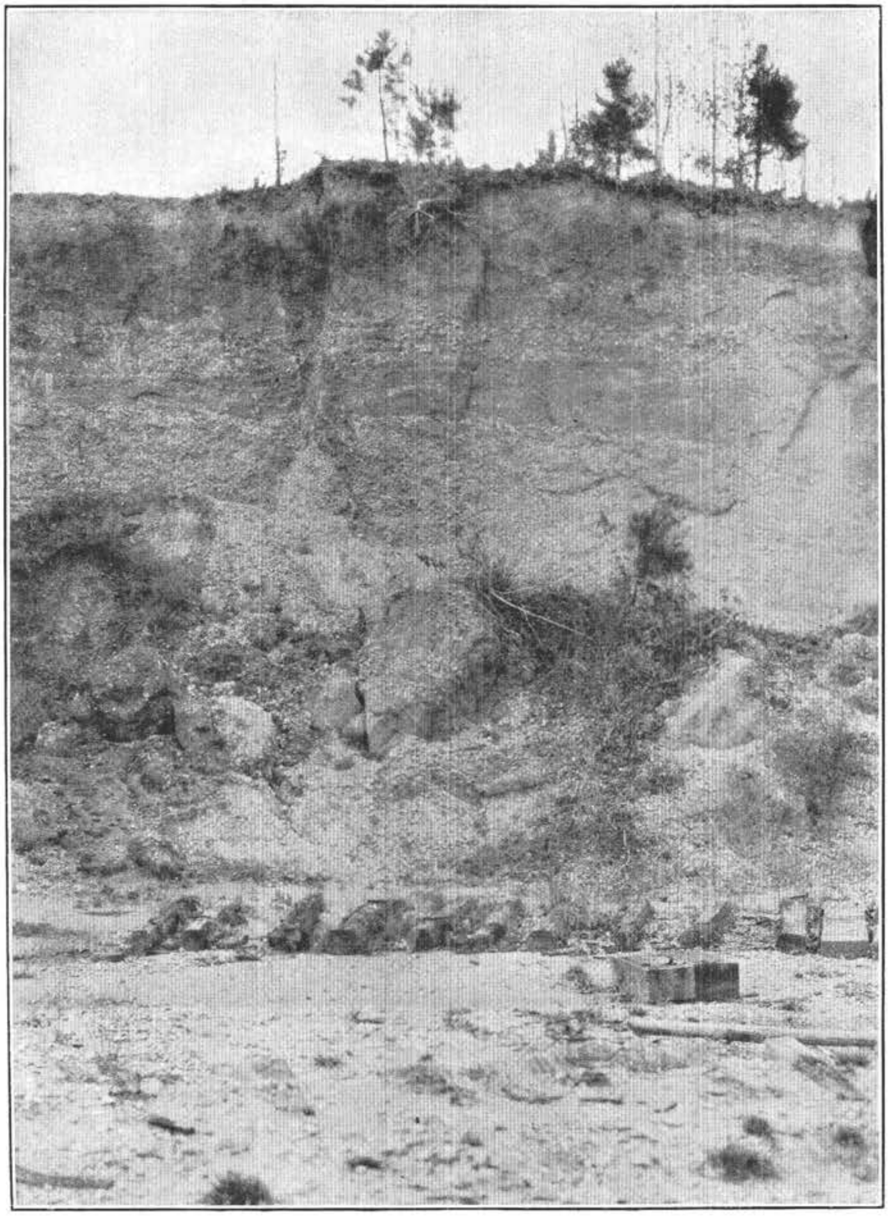
The materials beneath the Sardis plain are essentially the same as those beneath the Brookhaven plain, consisting of coarse cross-bedded sands and gravels near the base of the deposits overlain by finer sands and sandy clays. In general the gravels are finer than in the deposits of the Brookhaven plain, though near Mississippi River coarse gravels are found beneath the landward margin of the Sardis plain. Gravels are not abundant except in the area where sediments were supplied by Mississippi River. The upper member of the plain is a sandy clay of red or yellow color, and where the surface of the underlying Tertiary formations was high, as at Clinton and Woodville, Miss., this material rests directly upon them, the basal sands and gravels being absent.

The soils derived from the weathering of the surface materials of the Sardis plain are either loam or sandy loam, though in a few places where the upper member has been removed by erosion gravelly loam is found.

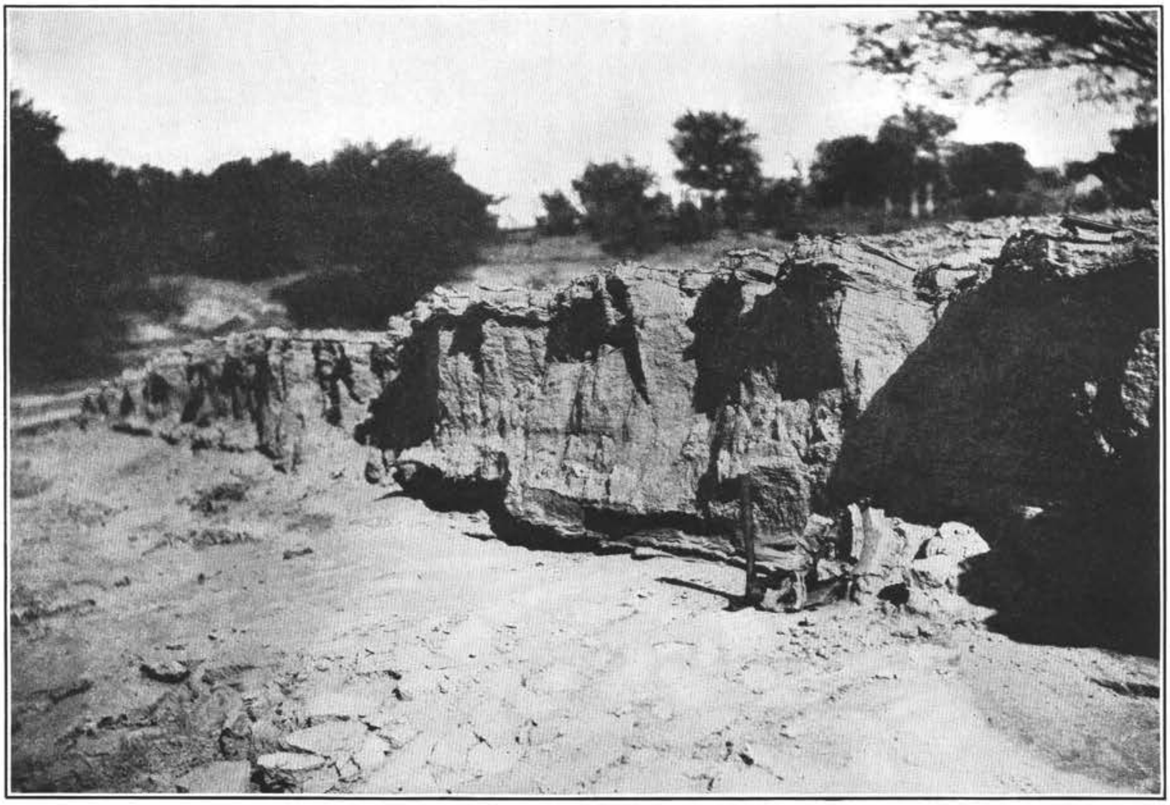
STRATIGRAPHIC RELATIONS OF THE DEPOSITS.

Near the north edge of the Sardis plain the stream-terrace deposits rest unconformably on the deposits of the Brookhaven plain. Farther north remnants of the Brookhaven plain are above the level of the base of the Sardis plain, and the deposits of the latter plain rest unconformably on older Tertiary formations.

The interstream deposits of the Sardis plain are continuous with those of the Brookhaven plain and were deposited when the sedimenta-



A CLOSE VIEW OF GRAVEL AND CONGLOMERATE AT PIT SHOWN IN PLATE XL, *B*.



A. CLAY FRAGMENTS DERIVED FROM UNDERCUTTING BY A SMALL STREAM, SULPHUR CREEK, LIVE OAK COUNTY, TEX.

B. A CLOSE VIEW OF THE FRAGMENTS SHOWN IN PLATE XLII, *A.*

Photographs by T. W. Vaughan.

tion was pushed farther seaward because of a slight general change in the altitude of the land. The change was apparently gradual, and the zone of rapid sedimentation was carried progressively seaward with continuous deposition along the margin of the older plain. This may have resulted in partial unconformity between the deposits of the two plains, though probably the unconformity was not greater than at many other places within the deposits beneath the plains.

ANTON PLAIN.

The Canton plain borders the seaward and streamward margins of the Sardis plain and originally formed a continuous belt at a slightly lower level than the Sardis plain. The name is applied by Shaw [1] to a stream terrace of this plain at Canton, Miss., and is extended to other stream terraces that can be correlated with that one and to the interstream plains that merge with the stream terraces at the seaward ends of the valley.

DISTRIBUTION.

Stream terraces.—Although the stream terraces of the Canton plain are better preserved than those of the older plains, they are represented only by mere fragments of the original deposits. The terrace in the Mississippi Valley doubtless had a width of many miles, but remnants in western Mississippi are 10 to 12 miles from the present position of the river. This terrace has probably been entirely removed by erosion in the area between Mississippi and Ouachita rivers and it has not been recognized between Ouachita and Red rivers.

The stream terraces of the Canton plain have been noted at a number of places in the valley of the rivers of eastern Mississippi and western Alabama, but the observations have not been sufficiently systematic to warrant discussing the distribution of the terraces in detail. In western Louisiana and southeastern Texas still less detailed information has been obtained concerning their distribution, though a poorly preserved terrace at an elevation of 285 feet on the east side of Sabine River between Neame and Evans Ferry is tentatively correlated with the Canton plain.

Interstream areas.—The interstream portions of the Canton plain are well developed in Louisiana east of Mississippi River and extend across southern Mississippi and Alabama into western Florida. In Louisiana the interstream areas of this plain extend westward from a point a few miles west of Woodworth, passing north of De Ridder and across the State line into eastern Texas.

The original width of the interstream areas of the Canton plain in southern Mississippi and the adjacent portions of Louisiana was about 12 to 15 miles, and they narrow eastward to Baldwin County, near the Alabama-Florida boundary line, where the width is approximately 6 to 8 miles. In western Louisiana and eastern Texas the interstream areas are about as wide as those in Alabama.

ALTITUDE.

The stream terraces of the Canton plain are lower than those belonging to the older plains, though considerable local variation is found, the altitude depending on the size of the stream. As a rule, the stream terraces of all the plains naturally rise to higher levels and away from the coast have steeper gradients on the small streams than on the large. An exception is found in the Mississippi Valley, where the terrace in the vicinity of Newmans Grove, east of Vicksburg, rises to only about 300 feet above sea level and the altitude increases slightly toward the coast, being nearly 380 feet east of Natchez. Thence the terrace slopes southward to about 350 feet near the southern boundary of Mississippi. Both inner and outer margins of the stream terraces were originally marked by scarps, but in many places these features have been destroyed by erosion.

The interstream areas in southern Mississippi range in altitude from about 350 feet on the landward margin to about 280 feet on the seaward margin. The altitude decreases gradually from western Mississippi to western Alabama, where the landward margin is about 310 feet above sea level and the seaward margin 250 feet, and there is a still further decrease in western Florida, where the altitude of the landward margin is about 270 feet and that of the seaward margin about 220 feet. A similar but slightly more rapid descent west of Mississippi River brings the surface of the plain to about the same altitude in western Louisiana and eastern Texas that it has near the western boundary of Florida.

[1] Shaw, E. W., unpublished notes.

The margins of the interstream plain are not bounded by distinct scarps but they are marked by an increase in gradient. At many places the margins have been destroyed by erosion, because the changes in gradient have furnished favorable places for the development of lines of drainage.

SLOPE.

The slope of the stream terraces of the Canton plain is in general seaward, though the rate is not easily determinable because of the lack of detailed information. The terrace on the east side of Mississippi River from Newmans Grove to the latitude of Natchez forms an exception because of deformation subsequent to deposition. The slope of this terrace is reversed, being northeastward, and it amounts in the aggregate to 30 feet in 60 miles, or about 6 inches to the mile. From the latitude of Natchez to the northern boundary of Louisiana the slope of this terrace is southward at the rate of about 9 inches to the mile.

The interstream portions of the Canton plain slope more steeply than those of the Sardis and Brookhaven plains, the average slope being from 2 to 3 feet to the mile, if the steepened landward margin is disregarded. Local variations are common, however, and in many places the original slope has been destroyed by erosion.

DISSECTION.

Both stream and interstream portions of the Canton plain have been greatly dissected, and the remnants now appear as isolated areas having nearly level surfaces or as even-topped divides between the major streams. In places these divides are several miles in width, but the undrained areas are smaller than those on the Sardis plain. This is attributed to the fact that the Canton plain was narrow and the original surface had a steeper slope than the Sardis plain.

LITHOLOGY AND SOILS.

The lithology of the Canton plain is, in general, like that of the Citronelle formation as a whole. Gravel is less abundant in the deposits beneath this plain than in those beneath the Sardis and Brookhaven plains, though it is reported in some wells and is exposed in a few deep valleys. The surface of the plain is composed of fine sandy clay and silt similar to the material forming the surface of the older plains and the soils are chiefly loam and sandy loams.

STRATIGRAPHIC RELATIONS OF THE DEPOSITS.

The materials underlying the Canton plain doubtless have the same stratigraphic relations as those beneath the Sardis plain, but the exposures are not deep enough to permit satisfactory observations.

LOXLEY PLAIN.

The lowest of the Pliocene plains that are underlain by deposits of the Citronelle formation is well preserved in the vicinity of Loxley, Baldwin County, Ala., and is therefore named the Loxley plain.

DISTRIBUTION.

Stream terraces.—The Loxley plain has a width of only a few miles where it is represented by remnants of stream terraces. In the Mississippi Valley the original extent of the stream terrace belonging to this plain can not be easily determined, though in the vicinity of Sicily Island, where the terrace is the result of erosion and deposition by Mississippi and Ouachita rivers, it may have been 30 to 40 miles wide. The average width in the Mississippi Valley between Sicily Island and Vicksburg was probably not much greater than 25 miles. The original width was apparently less than 10 miles in the valleys of the rivers in eastern Mississippi and western Alabama and Florida, except in the Alabama and Tombigbee drainage basins, where this terrace is more than 25 miles wide at its southern margin.

Interstream areas.—The interstream areas of the Loxley plain occupy a belt between the Canton plain and the oldest Pleistocene terrace. They vary much less in width than the older terraces of the Citronelle formation, being as wide in western Florida and Alabama as in southern Mississippi and eastern Louisiana. The average width of these areas is about 8 miles and the maximum is about 15 miles. On the eroded outer margin of the plain the underlying deposits have been exposed in places by the removal of the younger beds, and if the maximum width should be extended to include these exposures it would amount to slightly more than 30 miles. However, these more or less isolated exposures represent surfaces eroded during the Pleistocene epoch. The width of the interstream portions of the Loxley plain in southwestern Louisiana and southeastern Texas is about 8 miles. This plain is well developed in an area that extends from Forest Hill to De Ridder, La., and thence westward, passing a few miles south of Newton, Tex.

ALTITUDE.

The stream terraces of the Loxley plain vary in altitude, being higher on the small streams than on the large, and they increase in altitude away from the coast. This generalization, however, does not apply to the terraces of the rivers in western Mississippi, where the altitude has been changed by deformation. East of Vicksburg the terrace in the Mississippi Valley is about 280 feet above sea level, and east of Natchez the altitude is nearly 40 feet higher. From Natchez southward to the Louisiana boundary it declines to about 270 feet above sea level. The terrace on Pearl River has an altitude ranging from about 230 feet northwest of McNeil to about 300 feet near Monticello and 320 feet near Jackson. The altitudes observed on Leaf River range from about 250 feet near Hattiesburg to about 200 feet near Merrill, and those in western Alabama, on the west side of the Tombigbee, from about 250 feet east of Seaboard to about 200 feet northwest of Mobile. On Conecuh River they range from 200 feet near the Alabama-Florida boundary to about 230 feet east of Kirkland. Terraces of this age were recognized as far east as Yellow River, in northern Florida, where the altitudes obtained by barometric readings were somewhat greater than 200 feet, and near Crestview, where the altitude on the interstream plain is about 190 feet.

On the west side of Mississippi River, in Louisiana, the gravel deposits on the top of the Sicily Island hill and on the upland west of Ouachita River are tentatively referred to a stream terrace of the Loxley plain, and other stream terraces at altitudes of 200 to 225 feet were noted farther west, on the west side of Red River near Woodworth and on Sabine River west of Neame.

In Louisiana east of Mississippi River the interstream areas stand at 280 to 220 feet above sea level, and the altitude decreases slightly from the Mississippi Valley eastward, being 250 to 210 feet in southern Mississippi, 250 to 190 feet in western Alabama, 230 to 170 feet near Loxley, in southern Baldwin County, Ala., and 220 to 160 feet near Yellow River, in western Florida. All these figures should be regarded as approximate, because neither landward nor seaward margins of the interstream portions of the Loxley plain are very sharply defined.

West of Mississippi River the decrease in altitude is more rapid than east of it, bringing the inner margin of the plain down to about 220 feet above sea level in central Louisiana. Farther west, near Forest Hill, in central Louisiana, the altitude ranges from 220 to 180 feet. From central Louisiana to southeastern Texas the altitude is nearly uniform and about the same as near Forest Hill. Along the Kansas City Southern Railway, which crosses this plain, the landward margin just north of De Ridder has an altitude of about 220 feet and the seaward margin north of Bon Ami is approximately 40 feet lower. South of Newton this plain is represented by the tops of the hills that rise 180 to 220 feet above sea level.

SLOPE.

The stream terraces of the Loxley plain have a general slope in the direction of stream flow except in a part of the Mississippi Valley, where deformation since the materials were laid down has caused a reversal of the normal direction. Between southern Warren County and southern Jefferson County, Miss., the Loxley stream terrace slopes northeastward at about the same rate as the stream terrace of the Canton plain. Accurate determinations of slope are not possible, because measurements of altitude are difficult to procure on account of the thick mantle of loess that covers the Pliocene plains. From southern Jefferson County, Miss., to northern Louisiana the terrace slopes southward at the rate of 1 to 1½ feet to the mile.

On Pearl River the stream terrace of the Loxley plain has very little slope between Jackson and Monticello, but south of Monticello it slopes toward the coast at the rate of about 1 foot to the mile. The terrace on Leaf River slopes a little more than 1 foot to the mile from Hattiesburg to Merrill, and the terrace on the west side of Tombigbee River slopes about 1 foot to the mile. On Conecuh and Yellow rivers the slopes may be somewhat higher than farther west, amounting to 1½ feet to the mile, though the altitudes used in making this estimate were determined with a barometer and are subject to correction. In western Louisiana and eastern Texas there are few data for estimating the rate of slope of the stream terraces, but such observations as have been made indicate slopes of at least 1 foot to the mile.

The slopes of the interstream areas of the Loxley plain amount to 5 or 6 feet to the mile, but these figures include a comparatively steep descent along the landward margin of the plain from the surface of the Canton plain, and in addition some allowance should be made for the erosion of the seaward margin in post-Pliocene time. Observations on uneroded surfaces indicate a slope of 1 or 2 feet to the mile, the rate of slope being apparently greatest near Mississippi River and decreasing slightly both to the east and to the west.

DISSECTION.

The Loxley plain is much less eroded than the Sardis and Brookhaven plains, but it shows somewhat greater erosion than the next older or Canton plain, because it forms a fringe about this plain and was attacked first by the streams in post-Pliocene time. In addition, the seaward margin of the Loxley plain was eroded at the time of the formation of the oldest Pleistocene terrace. In general, the surface of the Loxley plain has been reduced to slopes except on the divides between the large streams, where there are flat areas several miles wide covered by small undrained depression.

LITHOLOGY AND SOILS.

The lithologic description of the Citronelle formation as a whole will apply in a general way to the materials beneath the Loxley plain, though the exposed materials, except where there has been an unusual amount of erosion, are largely sandy clays or silts. Locally fine or moderately coarse gravel has been exposed by erosion, and well records show that gravel exists at many places where it is not exposed. In general, the percentage of fine material in the deposits beneath the Loxley plain is greater than in those beneath the older plains of the Citronelle formation. The soils are largely loams and sandy loams.

STRATIGRAPHIC RELATIONS OF THE DEPOSITS.

The stratigraphic relations of the materials underlying the Loxley plain are similar to those of the deposits underlying the older plains. There is apparently no marked break between the sediments beneath the Loxley plain and those beneath the Canton plain, except possibly in the upper portion of the deposit, where a slight subsidence during the closing stages of deposition on the Loxley plain may have permitted the transgression of the sediments upon the margin of the Canton plain. The exposures are so poor that opportunities to examine the contacts between the deposits of these plains are rare. In the stream valleys the terrace sediments of the Loxley plain were deposited unconformably on those that were laid down during earlier Pliocene time, and farther up the streams they are conformable on still older formations.

PALEONTOLOGIC CHARACTER.

The scarcity of organic remains in the Citronelle formation has long been a bar to its satisfactory discrimination and correlation. Heretofore no identifiable fossils have been discovered except fragments of silicified wood, which might have been derived from some older formation by erosion. The numerous exposures that were studied during this investigation furnished no remains of either fresh or salt water organisms, though possibly this might be explained in part by the weathered character of the outcrops. It is probable that the processes of weathering would remove traces of shells from sands, but even where unweathered layers of sand or clay have been examined they have, except in two places, been found to be nonfossiliferous. Failure to find remains of marine organisms warrants the assumption that the beds are largely nonmarine, and this view is strengthened by the character and arrangement of the sediments. The absence of fresh-water fossils is probably due to the scarcity of animal remains capable of preservation, together with the unfavorable conditions for preservation resulting from the mode of origin and character of the deposits.

The only identifiable organic remains obtained from the Citronelle formation were fossil plants collected in a cut on the Mobile & Ohio Railroad south of Lamberts and at Red Bluff, on the shore of Perdido Bay, in Alabama. At both places the fossil plants occur in beds of dense clay, stained black by organic matter, and they owe their preservation to the character of the matrix, which excluded the air, thus preventing their destruction by weathering. These fossils are described by Mr. Berry on pages 195–208, and further reference to them is unnecessary. The relation of the leaf-bearing clays to the other beds in the exposures where they were collected is similar to the relations shown by many of the other lenses of clay that occur in the formation.

The leaf-bearing clays are near the top of the formation, and those at Red Bluff are somewhat younger than those at Lamberts. The plants collected at Lamberts were obtained from a bed that is younger than the outliers that cap the high hills to the north, but the upper portion of the formation near the coast is younger still. The fossils at Red Bluff were found in the upper beds near the coast, though no doubt some higher layers have been removed by erosion at this locality. The leaf-bearing clays are younger than most of the coarse gravels that form outliers along the landward margin of the formation, because the gravels pass under the clay beds on the uplands and are found in wells near the coast. Beds deposited contemporaneously with those near the coast extend into the valleys, where they form terraces in the valleys of the principal streams. These terraces contain coarse gravels a short distance away from the coast and present conditions unfavorable for the presence of fossils. The beds penetrated by wells at Fort Morgan and Pensacola are apparently marine, and marine Pliocene fossils may have been found in wells elsewhere along the coast, though samples of drillings are seldom preserved and information concerning such fossils is fragmentary.

ORIGIN.

The Citronelle formation contains practically every variety of clastic sediments, and nearly all of them may be represented in a section only a few feet thick, many small exposures ranging through all the intermediate stages from coarse gravel to fine clay. In mineral composition the deposits are similar to ordinary clastic sediments, being made up largely of quartz or silicates, such as kaolin. The many variations in physical character, together with rapid alternations of materials of different sizes (see Pls. XXXVI–XXXIX), indicate changing conditions of sedimentation such as are characteristic of areas where there are many variations in direction and velocity of the currents transporting the materials. These conditions prevail in the valleys of streams subject to changes in velocity produced by floods and quiet water. Similar conditions are found along shore lines where rivers supply detritus of varying coarseness to be reworked by waves. More detailed observations on sedimentation might reveal characteristic differences between fluviatile deposits and those made along the margin of the sea, with intergradations where deposits of the two kinds merge, but in the absence of such observations it is not always easy to distinguish the deposits of the two classes.

The character and arrangement of the sediments comprising the Citronelle formation suggest that they are in part fluviatile, in part estuarine, and in part shallow-water deposits made at or near the strand line, where there was some wave action. The coarse gravels are much less rounded than similar materials that have been subjected to prolonged subaqueous erosion and are therefore thought to be of fluviatile origin. This belief is supported by the confused character of the stratification, which shows lenticular bedding and an alternation of imperfectly assorted sediments of different grades. It is possible, however, that some of the gravels were deposited along the shore, where they were partly reworked and redeposited by waves.

The absence of remains of marine organisms and the character and arrangement of the Citronelle sediments suggest that they are mainly fluviatile. Attempts to explain the lack of marine fossils by supposing that they have been removed by solution during the processes of weathering are not entirely satisfactory, because comparatively fresh exposures of the formation have been examined at many localities without finding traces of marine organisms.

On pages 194–195 Mr. Berry discusses the ecologic conditions of the plants whose fossil remains have been found. He suggests barrier beaches, possibly with sand dunes, a mile or more wide, crossed by inlets and inclosing shallow lagoons. These lagoons, he thinks, must have been a mile or more in width, and still wider where large rivers formed estuaries. Dunes were probably built along the landward margins of the lagoons. This description agrees with the general features of portions of the Gulf coast to-day and may represent condi-

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tions that existed at the places where the plants grew. It does not, however, seem possible to account in this way for the various kinds of deposits found in the formation throughout a large portion of the area where it is exposed.

The conditions described by Mr. Berry might account for all the sediments except the fluviatile deposits, though it is more probable that at the mouths of some of the large streams like the Mississippi the sediments were built into broad deltas. Under the influence of shore currents some of the materials brought to the shore by the streams were spread across the interstream spaces until they coalesced to form extensive deposits. This condition harmonizes with the theory of the formation of lagoons, beaches, and dunes alongshore. As the sea encroached upon the land the beaches and dunes would be destroyed and the lagoons filled by the action of the waves, and thus distinctive shore features would not be recognizable in the formation. Probably at some stages of deposition rapid subsidence would produce estuaries where at times of relative quiescence deltas had been formed. Sometimes estuaries and deltas might both exist along the same shore, just as the broad Delta of the Mississippi is flanked on one side by the estuaries of southwestern Louisiana and on the other side by the estuaries of southeastern Mississippi and southern Alabama.

Certain features indicate that the conditions were not uniform and that there may have been many changes in the site of most rapid sedimentation. For example, at Brookhaven there is a thick deposit of sand at the base of the formation, overlain by coarse gravel, and this in turn by sands and clays. This alteration would result from a shifting of the direction of the principal currents that transported the sediments, or from reversal of movement along the strand line during the progress of deposition, or from uplift farther inland, causing enough increase in velocity to permit the streams to spread gravel over the basal sands. While material was being laid down upon the upland the site of rapid sedimentation was shifted landward and the beds previously deposited were covered by finer sediments. At the same time the older shore features were destroyed, and in this way fine sediments were deposited some distance landward upon the coarse fluviatile sediments. However, that the fine materials did not extend entirely across the area in which the Citronelle formation is now exposed is indicated by the fact that the erosion of the formation has not been sufficient to remove a great amount of material and the landward edge of the formation is now composed of coarse sands and gravel. If fine sands and clays had been deposited on this portion of the area erosion would probably have been insufficient to remove them entirely.

The emergence of the seaward margin of the formation permitted the duplication of some of the shore phenomena of the earlier depression, including the formation of deltas, bars, and other shore features, but these features have been destroyed by subsequent erosion. Intermittent changes in level during emergence account for the terracing seen at high levels in the present valleys, and it is probable that the fossil plants now found in the upper portion of the formation belong to this period.

The upper sand beds show a renewal of the quiet-water conditions that existed before the deposition of the gravel, and in the closing stages of Citronelle time the deposits were fine sand and silt, such as are laid down by flood waters of a muddy stream at times of overflow. This overflow began when the streams eroded their channels below the general level of the deposits already made and continued as long as the waters spread over the flood plains adjacent to the streams.

Some of the terraces in the stream valleys that trench the older formations represent episodes in the post-Pliocene history of the region, but those that stand at high levels were formed during the closing stages of the deposition of the Citronelle formation. Knowledge of the details of the distribution and relations of these terraces is still incomplete, but enough is known to warrant the conclusion that they merge into the deposits classed with the Citronelle formation.

The interstream portions of the Sardis, Canton, and Loxley plains were each built against the steep front of the next older plain as the result of changes in level that shifted sedimentation seaward. The changes may have been caused by general uplifting of the land, by withdrawal of the sea, or by an upward movement some distance inland that enabled the streams to carry their loads of detritus farther seaward. Of these possible explanations the last seems the least probable, because such a change would have resulted in the deposition of a larger percentage of coarse sediment along the seaward margin of the formation; moreover, the base-level of the streams was lowered, as is shown by the formation of stream terraces that coalesce with the interstream plains. This lowering of the base-level might have been the result either of upward movement of the land or of recession of the water, or of both causes operating simultaneously. The warping of the plains suggests a land movement but it does not prove that such a movement was the sole cause or even the most effective cause of the changes in base-level, though the warping was largely contemporaneous with those changes, as is suggested by the fact that the post-Pliocene terraces are not deformed.

The lowering of the base-level resulted in the removal of a portion of the deposits already formed and their redeposition along the seaward margin of the older beds. The intermittent character of the changes permitted the formation of terraces in the stream valleys, and at the same time the deposits made along the seaward margins of the older beds were built into interstream plains either by the coalescing of deltas or more probably as the combined work of streams and waves.

The closing stage of the formation of each plain seems to have been a partial submergence, which permitted the development of small lagoons and other depressions on the surface, though there is no evidence of marine erosion and deposition in the form of beach ridges such as would have resulted from vigorous wave action. Each successive stage of deposition was closed by a renewed lowering of base-level, and as the change progressed finer sediment was spread over the coarse detritus in the stream valleys. Some of the fine silt that covers the uneroded portions of the interstream plains may have been deposited as the result of a rise in the level of the streams as deltas were built seaward, though these deposits are too widely distributed to be explained as a whole in that way. Moreover, evidence of slight submergence is afforded by partly filled valleys emerging at the levels of the surfaces of some of the younger plains. That this resubmergence came at the end of the period of deposition of the materials forming the plains and not after the shaping of the existing valleys is proved by the absence of deep filling in these valleys.

SURFACE DEPOSITS.

Erosion of the surface of the Citronelle formation began at the end of Pliocene deposition and has continued down to the present time. It was accomplished by the same forces that are now active, including stream corrasion, surface wash, wind action, and the work of organisms; and although the action of these agencies may have varied in intensity at different times, evidence of such variation is not apparent. There was a constant shifting in the sites of most active erosion, and portions of the eroded materials were redeposited many times. Much of this redeposited material may be seen on the slopes, and where it resembles the subjacent deposits of Pliocene age it is not readily recognized, though in many places it may be distinguished because of the concentration of relatively coarse detritus, such as pebbles or fragments of iron-cemented sandstone or limonite, which has resulted from the partial removal of the finer materials. The redeposited materials do not form a continuous mantle but are distributed on all the slopes and are exposed in many shallow gullies, especially along wagon roads. They range in age from the earliest period of erosion of the Pliocene deposits to the present day, but in many places they have been undisturbed for a long time because of protection by vegetation.

Since the beginning of the terracing, in Pleistocene time, erosion and redeposition have been very largely concentrated on the lower slopes and in the bottoms of the valleys, and this has resulted in the formation of deposits of definite types that will be mentioned in discussing the Pleistocene deposits.

PLEISTOCENE TERRACES.

During the Pleistocene epoch extensive terraces bordered by seaward-facing scarps were formed along the seaward front of the Pliocene deposits. These terraces extend into the river valleys, where they merge with terraces of fluviatile origin. In most places the Pleistocene deposits forming these terraces are relatively thin, though near Mississippi River and other large streams thick constructional deposits were made. Names have been applied to the terraces and are used on the accompanying diagrams and in some of the sections (Pl. XXXII, p. 170), as well as in the text.

The Pleistocene age of the oldest terrace, the St. Elmo, is inferred from the fact that it merges, in the Mississippi Valley, into the Natchez formation, which is regarded as sub-Aftonian.[1] The Natchez formation contains crystalline pebbles and underlies a terrace that was doubtless formed during the Pleistocene epoch. The younger terraces, named in the order of the age, are the Port Hickey, the Hammond, and the Pensacola. The name Port Hickey is taken from a locality on Mississippi River where the typical materials of the Port Hudson formation are exposed. The Hammond terrace is named from Hammond, La., and the Pensacola terrace from Pensacola, Fla.

The level, uneroded surfaces of these terraces are in sharp contrast with the erosional features of the Citronelle formation, but they have their counterparts in the uneroded portions of the interstream plains of the Citronelle. Shallow depressions extend from the larger river valleys diagonally toward the coast, and most of them are bordered by low natural levees. These channels resemble those now being formed across the Mississippi Delta, and they show the constructional origin of the subsurface deposits. In some of the areas between the streams, seaward-facing scarps border the inner margins of the Pleistocene plains, and in places there are low ridges and shallow ponds whose long axes lie parallel to the shore line. These features show that wave action has been an influential agent in forming the surface, and it is probable that both wave and stream action prevailed at the same time along different portions of the coast and that their relative efficiency varied with the changing relations of the land and the water.

The exact relations of the different terraces to the glacial deposits is not fully known, though the St. Elmo terrace, which appears to be older than the great deposits of loess that fringe the east side of the Mississippi Valley and to be contemporaneous with the crystalline gravel at Natchez, is regarded as sub-Aftonian. The Port Hickey terrace appears to be younger than the principal deposits of loess. If this loess is considered to be of Iowan age these relations would indicate that the St. Elmo terrace is pre-Iowan and the Port Hickey terrace post-Iowan. The loesslike silt that forms the surface of the Port Hickey terrace may be of Wisconsin age, and if so, this would place the terrace in the interval between the deposition of the Iowan loess and that of the Wisconsin silt. The lower terraces must necessarily be younger than the Wisconsin silt.

In addition to the terraces of Pleistocene age a similar terrace of Recent age now rises a few feet above sea level and extends outward beneath the shallow waters of the Gulf.

WELL LOGS.

The accompanying diagrams of well logs (Pl. XLIII, in pocket) show the characteristics of the Citronelle formation at a number of localities and the relation of this and other formations penetrated in drilling the wells. The correlations with formations exposed at the surface are based on such information as could be obtained concerning the lithologic character of the materials penetrated in the wells, supplemented by the evidence of fossils. In general it may be said that the correlations represent the most probable subdivisions, though the lines between different formations are somewhat indefinite.

Well No. 1, drilled by the Baldwin County Oil Development Co. in southeastern Alabama, shows at the surface a thin deposit of sand and clay that is classed as Pleistocene because it underlies a terrace of that age. Beneath this is a thick bed of sand containing some gravel and thin beds of rock and clay, correlated with the Citronelle formation. The more clayey beds immediately underlying the Citronelle formation are classed with the Pascagoula clay, and the accuracy of this correlation is strengthened by the fact that at depths of 730 feet and more in a well drilled near this locality fossils that were classed as Miocene [1] were obtained. The materials penetrated below 900 feet in well No. 1 have been doubtfully correlated with several formations, but Claiborne fossils were identified from a collection obtained at the well.

The Fort Morgan well (No. 2) was drilled on a narrow sandy island opposite the entrance to Mobile Bay. This well is unique in showing an

[1] Chamberlin, T. C., and Salisbury, R. D., Geology, vol. 3, p. 387, 1906.

[1] Smith, E. A., The underground water resources of Alabama, p. 316, Alabama Geol. Survey, 1907.

unusually large percentage of sand. Fossils were obtained at various depths, and a list is given on page 194. According to Mr. Dall's interpretations, the Quaternary material extends to a depth of about 1,290 feet. The materials below that depth were doubtfully correlated with the Pliocene because they contain fossils that were supposed to be of Pliocene age. They may represent the seaward extension of the Citronelle formation.

Through the courtesy of Mr. A. G. Curtis, manager of the Southwestern Gas Co. at Shreveport, La., a log was obtained of the Jarvis & Meacham well No. 1, on the level upland of Mobile County at Semmes, Ala., about 12 miles west of Mobile. This well (No. 3) shows a thickness of more than 200 feet of sand and clay with a bed of gravel near the base. The gravel consisted very largely of coarse chert pebbles but included some finer pebbles of quartz. Some of the chert pebbles were more than an inch in diameter, and most of them were subangular or only slightly rounded, resembling the pebbles found farther north in Alabama and in south-central Mississippi. Beneath the sand and gravel were layers of pink and white sand and clay extending to a depth of 390 feet. All this material is included in the Citronelle formation in the diagram. From the underlying clays and associated sand beds fossils were obtained at several horizons. They were submitted to C. W. Cooke, who reported that the characteristic fossils of the Pascagoula clay were present. The well penetrated some distance into the Oligocene formations, but no fossils of that age were collected and the descriptions of the material are not sufficiently definite to permit correlations.

In southern Mississippi, especially near the coast, there is a somewhat uniform general sequence of beds, although many minor variations are recorded in the logs of wells, probably because the formations are lenticular.

The well at Bond, Harrison County (No. 4), encountered red sandy clay and white sand having a total thickness of about 190 feet. The upper portion of this material may safely be correlated with the Citronelle formation, and perhaps all of it should be so included. A thick clay bed that begins at 190 feet and the sand below it are classed as the Pascagoula clay which is in turn underlain by a thicker bed of clay, the Hattiesburg clay. At 780 feet some chert gravel was encountered similar to that obtained in the wells at Hattiesburg at the base of the Hattiesburg clay. This gravel, associated with sand and clay, was reported at intervals to a depth of 1,120 feet, and this portion of the well section is correlated with the Catahoula sandstone.

Farther south, at Wortham, the well of the Gulf & Ship Island Railroad (No. 5) shows some 20 feet of yellow clay that is assigned to the Pleistocene. The underlying sandstones, sands, and clays, with a bed of gravel at the base, are placed in the Citronelle formation. Beneath this formation is a bed of massive blue clay, the Pascagoula clay, which is in turn underlain by gray sand of uncertain age.

The De La Morton well at Laine, Miss. (No. 6), encountered sand and clay containing tree trunks to a depth of nearly 160 feet. Beneath this material clay predominated to about 565 feet, where a bed of gravel nearly 40 feet thick was reached. This clay and the underlying gravel are classed with the Citronelle formation. Characteristic fossils of the Pascagoula clay were found at a slightly greater depth and were reported at intervals nearly to the bottom of the well. The first casing was set at a depth of 881 feet, and apparently some of the Pascagoula fossils came from a slightly greater depth and continued to appear in the cuttings long after the drill had penetrated to other formations. Tentative correlations of the deeper formations are presented on the diagram.

At Brookhaven the well belonging to the Southern Gravel & Development Co. (No. 7) encountered gravel and red sands that are classed with the Citronelle formation. The material below these beds is all designated clay, and subdivision into formations is impossible.

At McComb (well No. 8) the Citronelle formation has an apparent thickness of about 220 feet, though some doubt exists as to the correctness of the correlation of the materials designated "hard gumbo and dry gravel." This gravel did not come from the beds encountered near the surface, because a casing had been set in the well at a depth of 117 feet. Beneath the Citronelle formation the Pascagoula clay is recognized, and it is possible that the underlying Hattiesburg clay was reached.

At Osyka (well No. 9) the Citronelle formation is about 150 feet thick and is underlain by blue clay and some sand and gravel that are correlated with the Pascagoula clay. The point of contact between the Pascagoula and Hattiesburg clays is not clearly defined, and it is not possible to separate the Hattiesburg clay from the Catahoula formation.

The well at Woodville (No. 10) shows an unusual condition in southern Mississippi, where, because of the presence of relatively hard sandstone, a hill of hard Miocene sandstone (Pascagoula clay) rose high enough to be above the level of the coarse sediments of the Citronelle formation. As a consequence of this condition the material deposited on the hill represents only a portion of the upper fine-grained sediments of the formation. The diagram of this well with its thin deposits of sand and clay should be contrasted with the diagram of the Bass well, where the Citronelle formation is much thicker. These two diagrams illustrate the marked irregularity of the upper surface and the steep slope of the Miocene surface toward the coast, though it should be noted that the gradient of this surface was probably increased by downward flexing near the Pliocene shore.

At Bass, La., the well belonging to B. A. Bass (No. 11) passed through about 100 feet of Pleistocene clay, with a little sand at the base. Below this is about 360 feet of clay, underlain by sand and containing some chert gravel, all classed with the Citronelle formation. The sands and clays at greater depths are correlated with the Pascagoula clay. These correlations are the result of a study of a set of samples of the materials penetrated.

The correlations of the formations penetrated in the Camp-Hinton Lumber Co.'s well (No. 12) are probably approximately correct, as the materials penetrated are typical of the several formations.

The well at the Natchez ice factory (No. 13) encountered about 50 feet of sand and gravel that have been assigned to the Citronelle formation and probably underlie the gravels of the Natchez formation. The underlying materials are typical of the Hattiesburg clay and Catahoula formation.

Exact correlations of the materials penetrated in the well at Bayou Sara (No. 14) are difficult. The beds in the upper 60 feet apparently belong to the alluvium of the Mississippi Valley, and the underlying sands are thought to belong to the Citronelle formation. Beneath these sands are interbedded clays and sands of the Pascagoula clay, and still lower is a thick mass of clays underlain by interbedded sands and clays, not subdivided into formations.

In western Louisiana, at Ludington, the well of the Ludington & Van Schaik Co. (No. 15) shows 150 feet of sand and gravel that belong to the Citronelle formation. Some of the older formations have been differentiated, but the log of the well below 1,600 feet is difficult to interpret.

At Fullerton the well of the Gulf Land & Lumber Co. (No. 16) encountered about 95 feet of clays containing some interbedded sand and gravel, referred to the Citronelle formation. Beneath this are more massive clay beds and some thick sands that are thought to belong to the Pascagoula clay. The massive clays below 400 feet are with some uncertainty correlated with the Hattiesburg clay.

THE FLORA OF THE CITRONELLE FORMATION.

By EDWARD WILBER BERRY.

INTRODUCTION.

The flora of the Citronelle formation, the character of which is somewhat briefly indicated in this report, is of special interest for several reasons. It is contained in widely distributed deposits that have often been considered as forming a part of the so-called Grand Gulf formation, which recent work has shown to embrace a series of mappable units ranging in age from the lower Oligocene to the Pliocene. It is of a very recent aspect and yet it contains a considerable number of extinct types, some of which represent genera unknown in the Pleistocene or Recent floras of North America and therefore indicate Pliocene age. As practically no Pliocene plants have heretofore been recognized on this continent the present flora has an enhanced importance as a basis for future comparison. It also affords very definite evidence of the physical conditions under which it flourished.

BOTANIC CHARACTER.

Eighteen species are recognized in this preliminary contribution, a number much too small for an extended botanic analysis. The collections contain representatives of perhaps a dozen additional species, the material of which is obscure or too fragmentary for accurate determination without a very extended comparison with Recent forms. The 18 identified forms represent 15 genera, 13 families, and 11 orders. There are two gymnosperms, one monocotyledon, and 15 dicotyledons, all of which are arborescent forms. Three species—the bald cypress, water oak, and water elm—are abundantly represented in both Pleistocene and Recent floras. Fifteen species can not be identified with Recent or Pleistocene forms and are therefore considered extinct. The flora as represented is, with three exceptions, an assemblage closely resembling those to be found at the present time along the south Atlantic and Gulf coast. The three exceptions are not out of place in this assemblage but simply represent types no longer found in this immediate area. They include a species of water chestnut (Trapa) that was abundant in the American Tertiary but is now found only in Europe and Asia; a Cæsalpinia that is now represented in the Bahamas; and a Bumelia that is now confined to the West Indies and peninsular Florida, though Bumelia is still represented by other species in southeastern North America. The remains of the bald cypress, water chestnut, and live oak are by far the most abundant in the collections, but the other oaks, the gum, and the hickory are not uncommon. The rarest remains are those of Yucca, Prunus, and Vitis. Yucca is almost never fossilized, and Vitis is usually represented by small seeds that might easily escape detection. The most closely related living species, with their ranges, are indicated in the subjoined table, and the number of species regarded as extinct that are named by prefixing *pre* to the name of the corresponding existing species shows not only the ancestral character of this Pliocene flora, but the close affiliation between it and the Pleistocene and Recent floras of the same latitude.

Fossil plants from Citronelle formation and corresponding existing species.

Pliocene forms.	Most closely related existing species.		
	Name.	Northern limit.	Southern limit.
Taxodium distichum	(a)	Delaware	Cape Romano and Mosquito Inlet, Fla.
Pinus sp	Pinus clausa Sargent	Southern Alabama	Peace Creek and Halifax River, Fla.
Yucca sp	Yucca aloifolia Linné	North Carolina	Louisiana.
Hicoria pretexana	Hicoria texana Le Conte	Eastern Texas	Eastern Texas.
Betula prenigra	Betula nigra Linné	Massachusetts	Florida and Texas.
Fagus lambertensis	Fagus americana Sweet	Ontario	Trinity River, Tex.
Quercus nigra	(a)	Southern Delaware	Cape Malabar, Fla.
Quercus catesbæifolia	Quercus catesbæi Michaux	North Carolina	Louisiana.
Quercus lambertensis	Quercus heterophylla Michaux	New Jersey	Texas.
Quercus previrginiana	Quercus virginiana Miller	Virginia	Mexico.
Planera aquatica	(a)	North Carolina	Trinity River, Tex.
Cæsalpinia citronellensis	Cæsalpinia bahamensis Lamarck.	Bahamas	West Indies.
Prunus sp	(?)		
Vitis sp	(?)		
Trapa alabamensis	Trapa natans Linné	Central Europe	Southern Europe.
Nyssa aquaticaformis	Nyssa aquatica Linné	Southern Illinois	Nueces River, Tex.
Bumelia preangustifolia	Bumelia angustifolia Nuttall	Indian River, Fla	Bahamas.
Fraxinus sp	Fraxinus floridana Sargent	Southern Georgia	Lower Apalachicola River, Fla.

[a] Still existing.

PHYSICAL CONDITIONS INDICATED BY THE FLORA.

That this flora is comparable in a broad way to the existing flora of the same region has just been pointed out. Although one of the modern representatives (*Fagus americana*) reaches northward to Ontario, it is not identical with the fossil form and, moreover, finds its optimum conditions much farther south. One other, also a form not identical with its fossil representative, reaches southern New England, but the others that range northward are forms of the southern flora, like the yucca, live oak, turkey oak, and water elm, that reach their northern limit in the Atlantic Coastal Plain, between southern Delaware and North Carolina. The species are, without exception, coastal forms, and the modern representatives of several (Hicoria, Cæsalpinia, Bumelia, and Fraxinus) do not range more than 150 miles inland from the Gulf coast. Without further elaboration, I think it will be conceded that the climatic conditions of this epoch in the Pliocene could not have been appreciably different from those of the present time in southern Alabama.

The physiography during late Pliocene time and, to a certain extent, the vegetation also, may be compared with those of Recent time along the east coast of the Florida Peninsula north of latitude 28°, or along the Gulf coast from the mouth of Ocklockonee River westward to Mobile Bay. We may picture a more or less straight series of barrier beaches, probably with active sand dunes, a mile or more in width, and broken in places by inlets. Back of these beaches there were wide lagoons, of variable width, perhaps not less than a mile and certainly reaching a much greater width where some river expanded into a broad estuary, with its shallow and muddy bayous. The water in the lagoons varied from fresh to salt according to the presence or absence of inlets and the position of the rivers. As is so common at the present time, the inner margins of the lagoons were bordered in places by lines of old, probably quiescent, vegetation-covered dunes, approximately parallel with the seaward zone of dunes. These rested on the seaward margin of the mainland or were separated from it by a narrow lagoon of fresh water or by fresh marshes or swamps. The mainland was low, flat, and alternately muddy and sandy, and had a very gentle gradient. The shallow depressions of its surface afforded a congenial environment for the development of cypress ponds or mixed tupelo gum swamps, with the associated water elm, Hicoria, and

Fraxinus, suggesting Recent conditions as exemplified by the flatwoods of eastern Florida.

Certain mesophytic genera inhabiting river banks and bottoms, such as Taxodium, Nyssa, Hicoria, Betula, Fagus, Vitis, and Planera, are preserved as fossils, while the abundantly preserved nuts of Trapa indicate that it was common in the sluggish river waters. The rivers were unquestionably sluggish and meandering. They expanded in their lower courses into estuaries or broad bayous, bordered by swamps in which grew a great abundance of Taxodium, replaced here and there by Nyssa, with perhaps a sprinkling of other mesophytic genera such as Hicoria, water oak, and Planera. The old dunes as well as parts of the barrier beaches (islands or peninsulas) supported a thick scrub of various species of live oaks and black oaks, with some pines. The single specimen of a yucca indicates the probable abundance of this xerophytic genus on the beaches and dunes, its habitat and persistent leaves fully accounting for its rarity in the fossiliferous clays. The species of Prunus, Cæsalpinia, and Bumelia probably grew in somewhat similar habitats. (See Pl. XLIV.)

The physical conditions that I have pictured are based on the two localities that have furnished fossil plants, and the preceding statement was written in the spring of 1911.[1] It is therefore of interest to confirm the essential correctness of these conclusions by quoting from Dall's report [2] on certain Pliocene invertebrates from wells in southern Georgia and Louisiana and from exposures near Burkeville, Tex. He writes:

> The interest of this fauna lies not only in its being strictly brackish water and containing a large number of hitherto unknown species, but in its wide distribution along the edge of the Pliocene Coastal Plain, forming a faunal horizon hitherto unrecognized.
>
> The conditions appear to have been not unlike those which obtain at certain portions of the Gulf coast to-day; probably lagoons into which the streams poured fresh water carrying with it small fresh-water gastropods and occasionally valves of Unionidæ. On the other hand, the sea had access to the lagoons, keeping the salinity of the water such that oysters and anomias could flourish with other smaller mollusks which frequent oyster beds, while occasionally purely salt-water shells might be ejected by wandering fishes or carried by violent storms.

[1] Berry, E. W., A study of the Tertiary floras of the Atlantic and Gulf Coastal Plain: Am. Philos. Soc. Proc., vol. 50, pp. 314-415, 1911.

[2] Dall, W. H., On a brackish-water Pliocene fauna of the southern Coastal Plain: U. S. Nat. Mus. Proc., vol. 46, p. 22, 1913.

AGE INDICATED BY THE FLORA.

The three still existing species and the similarity of the extinct forms to those of the Pleistocene and Recent would seem to indicate a relatively late time in the Pliocene. The facies as a whole is modern rather than Miocene. On the other hand, there are no known American Miocene floras nearer to this region than Virginia, and the large proportion of extinct types, much greater than in any of our extensive Pleistocene floras, would argue for a Pliocene age. This is also indicated by the abundance of Trapa, no longer native in the Western Hemisphere. The argument is further strengthened by the presence of coniferous remains, not described in this report because of their uncertain character but believed to represent the genus Glyptostrobus, which is now oriental but was common in America during the Tertiary. It is corroborated by the faunal studies of Dall previously mentioned and by the areal stratigraphic studies of Matson outlined on pages 172–173. Moreover, the flora is definitely older than that from the Mississippi River bluffs in western Kentucky,[1] which I have regarded as Pleistocene, though the beds in which it occurs are overlain by heavy gravels altogether lacking glacial materials and for that reason some students are inclined to consider them as late Pliocene rather than early Pleistocene.

My conclusion is, then, that the flora found in the Citronelle formation belongs in the later half of the Pliocene epoch and is directly ancestral to the Pleistocene and Recent floras of the same region.

THE FLORA.

Order CONIFERALES.

Family PINACEÆ.

Subfamily TAXODIINÆ.

Genus TAXODIUM L. C. Richard.

Taxodium distichum (Linné) L. C. Richard.

Plate XLV, figures 1–6.

Taxodium distichum. Holmes, Elisha Mitchell Sci. Soc. Jour., p. 92, 1885.

Taxodium distichum. Hollick, Maryland Geol. Survey, Pleistocene, pp. 218, 237, pl. 68, 1906.

[1] Berry, E. W., The Mississippi River bluffs at Columbus and Hickman, Ky., and their fossil flora: U. S. Nat. Mus. Proc., vol. 48, pp. 293-303, pl. 12-13, 1915.

Taxodium distichum. Berry, Torreya, vol. 6, p. 89, 1906; Jour. Geology, vol. 15, p. 339, 1907; Am. Naturalist, vol. 43, pp. 432–434, figs. 1, 2, 1909; Am. Jour. Sci., 4th ser., vol. 29, p. 391, 1910; Torreya, vol. 10, p. 263, 1910; Plant World, vol. 16, pp. 39–45, figs. 1, 2, 1911; Am. Jour. Sci., 4th ser., vol. 34, p. 219, figs. 1, 2, 1912; Torreya, vol. 14, pp. 160, 162, 1914; U. S. Nat. Mus. Proc., vol. 48, p. 296, 1915.

Twigs, seeds, cone scales, and cones occur at both of the known plant beds in the Citronelle formation, and one of the localities (Lambert) has yielded remains of the staminate catkins. All these parts are well shown in the accompanying figures. None of these remains can be distinguished from those of the existing species. If they represent that species they constitute the oldest known authentic remains of it, for it has not heretofore been found in deposits older than Pleistocene. This statement is seen to lack significance, however, when it is recalled that it would be a difficult task to formulate good differential characters for the very common and widespread Tertiary species *Taxodium dubium* of Sternberg; in fact, most writers refer to it as *Taxodium distichum miocenum.* Moreover, indubitable remains of the bald cypress have been recorded from the late Pliocene of Germany by Geyler, Kinkelin, and Engelhardt under the name *Taxodium distichum pliocænicum.* A subconscious desire to substantiate the Pliocene age of the Citronelle formation might dictate the reference of the Citronelle bald cypress to this supposed variety from the European Pliocene. The probabilities are, however, entirely favorable to the supposition that the forms on the two sides of the Atlantic were distinguished by features that have not been preserved, though both may have been geographic varieties of *Taxodium dubium.* It must be admitted that although possibly distinct the Citronelle form can not be differentiated from the existing species, and in any case it unquestionably represents the immediate ancestor of that species.

Turning to the geologic record we find that no fossil species of cypress have been recorded with certainty from strata as old as the Cretaceous, although it is quite possible that some of the twigs of conifers that are usually referred to Sequoia may really be those of the cypress, and the fact that some of them were deciduous might also suggest this possibility. In the earliest Eocene, however, in the days when the primitive mammalian fauna was replacing the last of the dinosaurs, the ancestors of the cypress had an almost cosmopolitan range. The records are very numerous and are based on the remains of leafy twigs, which seem to have thus early acquired the deciduous character for which their modern descendant is remarkable. Cone scales have also been found, and in some localities—for example, in Alberta, in the basal Eocene—the wood, showing the characteristic anatomical features of the genus, is preserved. For high latitudes there are Eocene records from Siberia, Manchuria, Alaska, Grinnell Land, Greenland, and Spitzbergen. From this northern area the cypress seems to have spread southward over the western provinces of Canada at least as far as Montana, Wyoming, and Nevada. For the next succeeding geologic epoch, the Oligocene, the records are rather meager if we assume that all the Arctic Tertiary occurrences are Eocene and not in part Oligocene. There are, however, a number of European records of Oligocene occurrences, including southern France and the Baltic provinces of the German Empire, from which the cypress extended eastward into Asiatic Russia. In the succeeding Miocene epoch the cypress extended from Japan on the east to Austria, Switzerland, and Italy on the west. In North America at this time the cypress was present in Virginia, on the east coast, and in Oregon, on the west coast.

For the last epoch of the Tertiary, the Pliocene, American records are lacking aside from those of the Citronelle formation, but a cypress scarcely if at all distinguishable from the still existing species was perhaps the most common denizen of the shores of the greatly extended Pliocene (Plaisancian) sea that spread over southern Europe and eastward into Asia.

The Tertiary period was followed by the climatic changes that ushered in the glacial or Pleistocene epoch. Records of Pleistocene migration are scanty, but we know that the cypress became extinct in Eurasia and that it retreated toward the Gulf region in America, perhaps oscillating southward and again northward with the advance and retreat of the ice front. The still existing form in Mexico may be a relic of such a southward migration. There are a large number of records of American Pleistocene cypress swamps based on the preserved trunks and typical knees. The peat of many of these swamps is packed with the cones and seeds, or a lens of clay may have preserved the deciduous twigs. I have collected unmistakable staminate aments from the Pleistocene clays at one place in North Carolina. On the final recession of the last ice sheet the climate became somewhat warmer than that of to-day, as is shown by certain subfossil animals and plants collected at several points from Maryland to Massachusetts, as well as by the isolated occurrence of members of the existing flora many miles to the north of their normal range. An example of this sort has been recently recorded by Sears [1] for Essex County, Mass. My own records of Pleistocene cypress include seven localities north of the present range of the species, one in New Jersey, nearly 150 miles north of the present northern limit, and one at Buena Vista, Va., west of the Blue Ridge, which forms its present northwestern limit. That these facts have more than a local significance is shown by the admirable and exhaustive studies of Scandinavian students who have conclusively demonstrated a considerable northward postglacial extension and a subsequent retreat of the existing flora. In regard to the cypress this last statement is confirmed by the subfossil occurrences which show that its range is steadily contracting.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.; Red Bluff, Perdido Bay, Baldwin County, Ala.

Collections: United States National Museum.

Subfamily ABIETINEÆ.

Genus PINUS Linné.

Pinus sp.

Plate XLV, figures 8, 9.

Large and well-defined seeds of a species of pine occur in the collections from Lambert. The wings are not preserved, but many seeds of existing species preserved in Pleistocene and subfossil deposits also lack the wings. The seeds found at Lambert are more like those of *Pinus tæda* Linné than those of any other existing species with which they have been compared, but whether they represent an existing or extinct species has not been determined.

Associated with the seeds are fragmentary but perfectly recognizable leaves of Pinus. These too have not been specifically determined. A number of the existing pines are coastal species, the loblolly (*Pinus tæda*) is of common occurrence along shores, and *Pinus serotina* Michaux is distinctly a coastal-swamp form. *Pinus clausa* Sargent, of Florida and southern Alabama, frequents beach ridges and dunes and is found on the Santa Rosa Peninsula in association with the live oak so abundantly represented in the Citronelle formation.

It has not been possible to determine whether the fossil leaves and fruit represent a species of the beach ridges or of the low coast of the mainland.

Occurrence: Citronelle formation, near Lambert, Mobile County, Ala.

Collection: United States National Museum.

Class ANGIOSPERMÆ.

Subclass MONOCOTYLEDONÆ.

Order LILIALES.

Family DRACÆNACEÆ.

Genus YUCCA Linné.

Yucca sp.

Plate XLV, figure 7.

A narrowly linear-lanceolate and acuminate distal fragment of a very rigid coriaceous entire margined monocotyledonous leaf, which constitutes the scanty remains of this form, is insufficient for a specific description, and if it occurred in beds belonging to a more remote geologic period or in a region and latitude where the possibilities of the flora were unknown no positive generic determination could be made. In the light of these contributory facts, however, it is certain that this fragment represents some species of Yucca, whether a still existing or an extinct species it is impossible to determine.

The genus Yucca contains a score or more of existing species confined to the more arid parts of the central and southern United States and Central America. They have been extensively studied in recent years by William Trelease, to whose writings the reader is referred for a discussion of the very interesting facts of their geographic distribution. The present fossil fragment agrees exactly with the leaves of *Yucca aloifolia* Linné, a form ranging on coastal sands from North Carolina to Florida

[1] Sears, J. H., A southern flora and fauna of post-Pleistocene age in Essex County, Mass.: Rhodora, vol. 10, pp. 42-46, 1908.

and westward along the eastern Gulf coast. Prof. Trelease writes in a personal letter:

> *Yucca aloifolia* is probably of a different early stock from the other existing species, which have either capsular fruit or a dry core to the fruit when this becomes fleshy, *aloifolia* lacking such a core.

So far as I know, no indubitable fossil remains of Yucca have heretofore been discovered, so that the importance of the present occurrence, despite the meagerness of the remains, merits its discussion. The existing southeastern species are distinctly forms of sandy coastal regions, and the sands and dunes along the coast during the time of the deposition of the Citronelle formation may be appropriately pictured as supporting an *aloifolia*-like form. That its remains have not been more abundantly encountered in the deposits of this age is obvious from the foliage habit in this genus, as the leaves are persistent until they become practically desiccated, so that it would require a cyclonic disturbance or a rapid transgression of fine sediments to place them within reach of successful fossilization. That the type and only specimen is a distal part of a leaf sharply broken across merely emphasizes the preceding statement.

Occurrence: Citronelle formation, near Lambert, Mobile County, Ala.

Collection: United States National Museum.

Subclass DICOTYLEDONÆ.

Order JUGLANDALES.

Family JUGLANDACEÆ.

Genus HICORIA Rafinesque.

Hicoria pretexana Berry, n. sp.

Plate XLV, figures 10–13.

The genus Hicoria is represented by both leaflets and nuts that may indicate more than one species, although I have ventured to unite them as representing the nuts and the lateral and terminal leaflets of a single form. It may be described as follows: Leaves odd pinnate; number of leaflets not determinable. Terminal leaflet oblong-acuminate with cuneate base, nearly equilateral. Midrib stout. Secondaries numerous, subopposite to alternate, diverging from the midrib at wide angles, nearly straight in their courses, camptodrome in the marginal region, sending small tertiary branches to marginal teeth. Margins entire at base, above with small crenate teeth. Length about 10 centimeters; maximum width about 4 centimeters. Lateral leaflets narrower and more inequilateral, otherwise like the terminal; petiolules wanting. Nuts oblong-ovate in profile, bluntly pointed at both ends, slightly compressed, about 2.5 centimeters long and 1.25 centimeters in diameter, obscurely four-angled.

This species greatly resembles the existing *Hicoria texana* Le Conte, a large tree confined to the river bottoms and low wet woods of eastern Texas.

The fossil form was evidently not uncommon, as the leaflets and the nuts were found at both the fossiliferous localities.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.; Red Bluff, Perdido Bay, Baldwin County, Ala.

Collections: United States National Museum.

Order FAGALES.

Family BETULACEÆ.

Genus BETULA Linné.

Betula prenigra Berry, n. sp.

Plate XLV, figures 14, 15.

Leaves of medium or small size, broadly ovate in general outline. Apex cuneately pointed, base broadly rounded; margin somewhat irregularly crenate. Length 3.5 to 4 centimeters; maximum width 2 to 2.5 centimeters. Petiole stout, about 7.5 millimeters in length. Midrib stout, prominent on the lower surface proximad, becoming thin distad. Secondaries thin, diverging from the midrib at angles of about 45°, craspedodrome, six or seven pairs.

The present species suggests the leaves of the Pleistocene and Recent *Betula nigra* Linné, which inhabits deep, rich, often wet soils of banks, bottoms, and swamps from Massachusetts to Florida and Texas near the coast and up the Mississippi and Missouri valleys to eastern Nebraska and Minnesota. The existing birches are prevailingly north-temperate forms, *nigra* being the only species found in the warm climate of Florida, Louisiana, and Texas. It is also the only wet-ground species, as well as the only species ripening its seeds in the spring or early in summer. This character points to its derivation from a species of warm climates, such as the present fossil form. *Betula nigra* may be distinguished from *Betula prenigra* by the cuneate base of its leaf, which has a subrhombic form, and by the commonly sublobate and doubly serrate margins.

The genus Betula is widely distributed in existing floras of the North Temperate Zone from the Arctic Circle to Texas in North America and to southern Europe, the Himalayas, China, and Japan in the Old World. About 30 species are recognized, of which about half are American. Numerous fossil species have been described, the earliest of which occurs in great abundance in the basal Upper Cretaceous (Dakota) of North America.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Family FAGACEÆ.

Genus FAGUS Linné.

Fagus lambertensis Berry, n. sp.

Plate XLVII, figure 5.

Leaves of relatively small size compared with those of the existing species, broadest midway between the apex and the base, full and rounded laterally, narrowing to the bluntly pointed tip and the similarly broadly cuneate base. Margins entire below, remotely toothed along the middle, the obscurely serrate teeth becoming more crowded distad. Length about 4.5 centimeters; maximum width about 3 centimeters. Texture subcoriaceous. Petiole short and stout. Midrib medium stout, thin on the upper surface and prominent on the lower surface of the leaves. Secondaries numerous, subparallel, craspedodrome, thin but well marked; they diverge from the midrib at angles of about 45° at regular intervals, becoming more crowded in the tip and pursuing straight ascending courses. Tertiaries not made out.

The present species is clearly distinct from the existing species. The leaves of our common American Pleistocene and Recent form, *Fagus americana* Sweet, are larger and more oblong and have acuminate tips and somewhat distant or even remote, abruptly serrate teeth. It ranges from Canada to western Florida and Texas and in the Southern States is confined to river bottoms and swamp margins. Its leaves during the Pleistocene epoch, even in the far South, were smaller than those of the Recent trees and may indicate an approach to the present fossil species.

The genus includes four living species of the North Temperate Zone—one in southeastern North America, one in Europe, and two in eastern Asia. A great many fossil species of Fagus have been described, and the oldest known was found in the Upper Cretaceous of both Europe and America. The genus had a much wider distribution during the Tertiary than at present and was practically cosmopolitan, being found in association with the related genus Nothofagus of the Southern Hemisphere in Australia, South America, and Graham Land. *Fagus lambertensis* is the first Pliocene beech to be recorded from North America, but several Pliocene forms are abundant throughout central and southern Europe, and the genus has also been found in beds of this age in Japan.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Genus QUERCUS Linné.

Quercus previrginiana Berry, n. sp.

Plate XLVI, figures 1–8.

Leaves of variable size; elliptical, oblong elliptical, or obovate, ranging from long and narrow to short and broad. Apex evenly rounded, narrowly pointed, emarginate or retuse. Base rounded to narrowly cuneate. Margins entire, commonly revolute, evenly rounded, or in part irregularly rounded or incipiently sinuate. Length from 2.5 to 7 centimeters; maximum width, at or above the middle, from 1 centimeter to 2.5 millimeters. Texture very coriaceous. Petiole relatively long and very stout, ranging in length from 3 millimeters in very small leaves to 1 centimeter in larger leaves. Midrib stout, sometimes flexuous, prominent on the lower surface of the leaf. Secondaries numerous, stout, prominent on the lower surface, diverging from the midrib at various angles, usually wide, from 45° to 75°; they range from opposite to alternate, but are prevailingly opposite or subopposite; they diverge at irregular intervals and are predominantly straight in their courses but become camptodrome in the marginal region. The tertiaries are well defined, particularly on the lower surface of the leaf, where they form a minute isodiametric areolation, well shown in figures 5 and 7. On the upper surface their degree of representation gives a more open and strikingly different appearance, as may be seen in the upper surfaces shown in figures 1, 3, and 4.

This species is unquestionably close to and prenuncial of the Pleistocene and existing species *Quercus virginiana* Miller—in fact, leaves of the latter may be found which almost exactly match all the variations shown in the live-oak leaves found in the Citronelle formation. The variations in the leaves of *Quercus previrginiana* are regarded as an indication of their synthetic character; the similar variations in the leaves of *Quercus virginiana* are regarded as atavistic characters.

In the existing flora *Quercus virginiana* is a relatively short, massive, spreading tree ranging from Virginia to northeastern Mexico. It is confined to the Coastal Plain and never grows naturally far from the coast except in Texas, where it extends up the Rio Grande to the New Mexico border. It reaches its maximum development along the southern Atlantic and eastern Gulf coasts in rich hammocks but is equally at home on low sandy ridges and on old dunes. It has been recorded from Pleistocene deposits near Columbus, Ky.,[1] near Monroeville, Ala.,[2] and at Abercrombie Landing, Ala.,[3] and appears to have frequented an environment exactly comparable with its present habitat.

Associated with *Quercus virginiana* in the existing flora are a number of species or varieties that have had a common origin. Among these are the dwarf varieties *minima* and *maritima* and the recently differentiated *Quercus geminata*. Somewhat more removed are *Quercus laurifolia*, *Q. chapmani*, *Q. myrtifolia*, *Q. brevifolia*, and *Q. oblongifolia*. Some of these may be regarded as specialized for particular habitats and perhaps derived from *Quercus previrginiana;* for example, *Quercus oblongifolia*, a denizen of arid foothills and mesas in western Texas, northern Mexico, and southern Arizona and New Mexico; *Quercus breviloba*, of inland limestone prairies from central Alabama to Texas; *Quercus chapmani*, of coastal pine barrens from South Carolina to Florida; and *Quercus myrtifolia*, of seashores and dunes from South Carolina to Florida. The willow oaks *Quercus phellos*, *Q. brevifolia*, and *Q. imbricaria*, if they have diverged from a common stock with *Quercus previrginiana*, did so at a far more remote period. The correlative range of some of these forms and their restricted habitats within the general range lend weight to the hypothesis that some of them at least had a common and not remote ancestor, and it is partly a consideration of these probable facts together with minor differences that has led me to differentiate the Citronelle live oak from the existing *Quercus virginiana*, for even if it does not represent the original stock from which *Q. virginiana*, *Q. geminata*, *Q. breviloba*, *Q. chapmani*, and *Q. myrtifolia* have been evolved it certainly is ancestral to the first two and it is not far removed from the ancestor of the last three.

Quercus previrginiana is exceedingly abundant at the Lambert locality and less common at Red Bluff, where, however, all forms of its leaves are represented, so that there is nothing to indicate that it was not equally abundant at both localities in late Pliocene time.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.; Red Bluff, Perdido Bay, Baldwin County, Ala.

Collections: United States National Museum.

Quercus catesbæifolia Berry, n. sp.

Plate XLVI, figures 12, 13.

Leaves large, deeply divided by rounded open sinuses into five oblong lobes with straight sides, acutely pointed and with a subordinate acute tooth on either side toward their tips, especially in the terminal lobe. Base entire, broadly cuneate, inequilateral. Petiole short and stout. Midrib stout, prominent, and curved. Secondaries stout, diverging at various angles, those forming the median vein of lateral lobes or running to marginal teeth stouter than their fellows and craspedodrome, the rest of the secondaries camptodrome. Tertiaries largely percurrent. Texture coriaceous.

The present species is very close to the existing *Quercus catesbæi* Michaux, which ranges from North Carolina along the coast to eastern Louisiana on dry, barren sandy ridges and reaches its largest size in tidewater South

[1] Lesquereux, Leo, On some fossil plants of recent formations: Am. Jour. Sci., 2d ser., vol. 27, p. 364, 1859.

[2] Berry, E. W., Additions to the Pleistocene flora of the Southern States: Torreya, vol. 14, p. 161, 1914.

[3] Berry, E. W., Pleistocene plants from Alabama: Am. Naturalist, vol. 41, p. 693, pl. 1, fig. 2, 1907.

Carolina and Georgia. The existing species is common on the barren hills of Maubila Ridge, which forms the divide between Mobile and Escatawpa rivers and is made up of sediments of the Citronelle formation.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Quercus lambertensis Berry, n. sp.

Plate XLVI, figures 9, 10.

Leaves of various sizes, equally pointed at the apex and base, consisting primarily of a large triangular cuneate terminal lobe, a corresponding cuneate base and one or two slightly developed median lateral lobes on each side. Lobes all acute but not produced. Intervening sinuses open and rounded. Petiole short and stout. Midrib stout, usually curved. Secondaries numerous, stout, diverging at wide angles, all camptodrome except one or two median pairs, which are more prominent and run to the tips of the lateral lobes (craspedodrome). Texture coriaceous.

The smaller leaf figured well illustrates the characteristic form of this species. Although its small size and undeveloped lateral lobes suggest the juvenile leaves of several existing species of Quercus, the large and unquestionably mature leaves are represented by numerous imperfect specimens which show that these juvenile characters persisted throughout life. I have seen small leaves of the turkey oak (*Quercus catesbæi* Michaux) that resembled the fossil, and the leaves of the little-known species *Quercus heterophylla* Michaux, which by some botanists is considered a hybrid between *Q. phellos* and *Q. velutina*, are somewhat closer to the fossil than any other existing form. *Quercus lambertensis* is less common than the associated *Quercus catesbæifolia* but, like that species, is believed to have been an inhabitant of the dry sandy ridges near the coast.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Quercus nigra Linné.

Plate XLVI, figure 11.

Quercus nigra Linné. Berry, Jour. Geology, vol. 15, p. 342, 1907; Am. Naturalist, vol. 41, p. 693, pl. 1, figs. 3, 4, 1907; Am. Jour. Sci., 4th ser., vol. 29, p. 394, 1910.

Leaves of this species, of normal size and characteristic obovate form, have been found in the beds of the Citronelle formation, and are of exceptional interest as an indication of the antiquity of this handsome oak. The modern tree is an inhabitant of low rich woods and bottom lands. Its range is nearly coincident with the Coastal Plain from southern Delaware to eastern Texas, and it also extends up the Mississippi Valley to southeastern Missouri and western Kentucky. The species is common in the Pleistocene deposits of North Carolina and Alabama, where it is represented by both leaves and acorns. The leaves of the existing tree are remarkable for their diversity and the development of acutely lobed forms with broad bases. It is significant that the leaves from the Citronelle formation, as well as the numerous leaves from the Pleistocene, are without exception those with the obovate or slightly and roundly three-lobed broad tip and narrowly pointed base, which must therefore be regarded as the ancestral type for the species.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Order URTICALES.

Family ULMACEÆ.

Genus PLANERA Gmelin.

Planera aquatica (Walter) Gmelin.

Plate XLVII, figures 1–4.

Planera aquatica. Hollick, Torrey Bot. Club Bull., vol. 19, p. 332, 1892.

Planera aquatica. Berry, Jour. Geology, vol. 15, p. 343, 1907; U. S. Nat. Mus. Proc., vol. 48, p. 300, 1915.

Planera gmelini Michaux. Lesquereux, Am. Jour. Sci., 2d ser., vol. 27, p. 365, 1859.

The present species is very abundant in the clays of the Citronelle formation south of Lambert. All sizes of leaves are represented, and there is a close identity in the variations of size, form, and margin between these fossil leaves and those of the existing species. They range from small lanceolate and nearly equilateral leaves with finely serrate margins, 12 millimeters in length and 5 millimeters in maximum width, through various sizes to larger ovate leaves having markedly inequilateral bases and coarse crenate teeth, 4.5 centimeters in length and 2 centimeters in maximum width. Several of these varieties have been figured, and there can be no question that they are identical with the living species. The venation also is identical with that shown in the corresponding leaves of existing trees of this species.

The genus Planera is monotypic in the existing flora. Its single species, the water elm, is a small tree of swampy habitats, ranging from the valley of Cape Fear River in North Carolina along the coast to the valley of Trinity River in Texas and up the Mississippi Valley to lower Wabash River in Illinois and southwestern Indiana. It reaches its maximum development in southern Arkansas and western Louisiana.

Planera aquatica has been recorded by Hollick from the late Miocene or Pliocene sandstone at Bridgeton, N. J.; by Lesquereux from the Pleistocene of Columbus, Ky.; and by Berry from the Pleistocene of Hickman, Ky., and Neuse River in North Carolina. It evidently had a more extensive range in the late Tertiary than at the present time.

The genus appears in beds of early Upper Cretaceous age, where it is represented by four recorded species in Greenland, Marthas Vineyard, New Jersey, and North Carolina, which would seem to indicate an occidental origin. In confirmation of this supposition, the five known Eocene species are also confined to North America, the records including Alaska, Greenland, and the Fort Union and Green River formations of the Rocky Mountain province. The single known Oligocene species is European. There are two or three Miocene species, the records including Colorado, New Jersey, Virginia, Iceland, Sakhalin, Japan, and most European countries. The widespread Miocene species *Planera ungeri* Ettingshausen lingered throughout southern Europe during the Pliocene.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Order ROSALES.

Family CÆSALPINIACEÆ.

Genus CÆSALPINIA Linné.

Cæsalpinia citronellensis Berry, n. sp.

Plate XLVII, figure 6.

Leaflets of small size, elliptical to oval in general outline, with a broad, abruptly pointed inequilateral apex and a similar base. Margins entire. Texture subcoriaceous. Petiolule short or wanting. Length about 7 or 8 millimeters; maximum width, about midway between the apex and the base, about 4 millimeters. Midrib thin. Secondaries thin, three or four pairs, diverging from midrib at a wide angle and camptodrome. Tertiaries not visible.

The genus to which this species belongs contains about 40 existing species of the Tropics and subtropics of both hemispheres. It is no longer represented in the United States, although fossil forms are present in this area in Upper Cretaceous and younger beds. The genus is still prominent in tropical America, and the fossil species here described is very similar to the existing *Cæsalpinia bahamensis* Lamarck, of the West Indies.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Family AMYGDALACEÆ.

Genus PRUNUS Linné.

Prunus sp.

Plate XLVII, figure 7.

This genus is represented by a characteristic large stone, which is ovate, compressed, and apiculate, about 2 centimeters in length and 8 millimeters in maximum width, and rather larger than stones of our native southern species. Apparently it represents an extinct form of large-fruited beach plum.

The genus has many fossil and over a hundred existing species, which are cosmopolitan throughout the North Temperate Zone and extend to low latitudes in North America and Asia.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Order RHAMNALES.

Family VITACEÆ.

Genus VITIS Linné.

Vitis sp.

A single well-defined small seed of Vitis, not specifically determinable, is contained in the collections from Red Bluff, Perdido Bay, Ala.

Order MYRTALES.

Family HYDROCARYACEÆ.

Genus TRAPA Linné.

Trapa alabamensis Berry.

Plate XLVII, figures 9, 10.

Trapa alabamensis. Berry, Torreya, vol. 14, p. 107, figs. 4, 5, 1914.

Coriaceous nuts, rhomboidal and roughly bilateral in outline, much swollen and tuberculated medianly, with normally two short, conical, acuminate, slightly recurved horns. The base is rounded and shows a conspicuous scar. The sides are somewhat unsymmetrical and faintly and irregularly ribbed and usually show three large tubercles on each face above the middle. The base is large and full. The apex is but slightly produced or truncated. Length from tip to tip of the horns about 4 centimeters; height about 2 centimeters.

Trapa alabamensis Berry is very close to the existing *Trapa natans* Linné, especially to the two-horned variants (the species is normally four-horned). *Trapa natans* is larger and more symmetrical and has stouter, more recurved horns, a more extended apex, and a stouter and more symmetrical body. The present species is common in the late Pliocene clays of southern Alabama and was evidently very common in the slow-flowing streams and bayous that emptied into the lagoons along the low Pliocene coast.

The genus Trapa, formerly included in the family Onograceæ, is now made the type and only genus of the Hydrocaryaceæ (Trapaceæ Dumort, 1827). There are three existing species, all aquatics and all confined to the Old World except for the naturalization of *Trapa natans* Linné in New England and New York. *Trapa natans* is irregularly scattered throughout central and southern Europe, and that its area of distribution is contracting is shown by its occurrence in postglacial deposits at very many localities beyond its present range in Russia, Finland, Sweden, and Denmark. The two other existing species are *Trapa bicornis* Linné and *Trapa bispinosa* Roxbury, of southeastern and southern Asia.

The genus has an extended geologic history. Rosettes supposed to represent the floating leaves (*Trapa? microphylla* Lesquereux and *Trapa? cuneata* Knowlton) are widespread in the Rocky Mountain province in beds of late Cretaceous and early Tertiary age. The oldest recognizable fruits are a large bicornute form from the Eocene of Canada and Alaska and *Trapa wilcoxensis* Berry, from the lower Eocene (Lagrange formation) of Tennessee. An Oligocene species (*Trapa credneri* Schenk) has been recorded from Saxony, and no less than five Miocene species have been described—one in Japan and the rest in Europe, where two species continue into the Pliocene. The existing *Trapa natans* has been found in the preglacial beds of England and Saxony and in many interglacial and postglacial deposits in Portugal, Italy, Netherlands, Germany, Sweden, Russia, and Denmark, Gunnar Andersson in a recent paper (1910) mentioning 18 localities in West Prussia, 6 in Denmark, 17 in Sweden, and 29 in Finland. Trapa evidently became extinct in the Western Hemisphere soon after the close of the Pliocene epoch, for it is not a native in the existing flora (it is naturalized in New England and New York), nor has it been recorded from the Pleistocene.

Occurrence: Citronelle formation, Red Bluff, Perdido Bay, Baldwin County, Ala; Lambert, Mobile County, Ala.

Collections: United States National Museum.

Order UMBELLALES.

Family CORNACEÆ.

Genus NYSSA Linné.

Nyssa aquaticaformis Berry, n. sp.

Plate XLVII, figure 8.

Large stones, ovate-lanceolate in profile, nearly circular in cross section, rounded proximad and somewhat gradually narrowed and sharply pointed distad, 2.75 to 3 centimeters in length and slightly over 1 centimeter in maximum diameter below the middle, ornamented with about 12 thin longitudinal, sharply keeled ridges 1 to 2 millimeters in height.

This very characteristic Nyssa stone is common in the Citronelle formation. Among recent forms it is similar to the stones of the common cotton or tupelo gum, a denizen of swamps and bayous near the coast from the Dismal Swamp in Virginia through the Gulf States to Nueces River in Texas and northward up the Mississippi to the lower part of the Ohio River valley. The genus comprises five existing species in southeastern North America and one in southeastern Asia. Although some of the American species extend northward to New York and southern New England, their center of distribution is in the Georgia region. The genus is known from the Upper Cretaceous onward and was evidently cosmopolitan in the Northern Hemisphere during the Tertiary period.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.; Red Bluff, Perdido Bay, Baldwin County, Ala.

Collections: United States National Museum.

Order EBENALES.

Genus BUMELIA Swartz.

Bumelia preangustifolia Berry, n. sp.

Plate XLVII, figure 11.

Leaves obovate-spatulate in outline, with a broadly rounded tip, narrowing rapidly below the middle to a narrow, considerably decurrent base. Margins entire. Texture coriaceous glabrous. Length about 4 centimeters; maximum width above the middle about 2.5 centimeters. Petiole short and stout. Midrib very stout and prominent. Secondaries numerous, thin, subparallel, diverging from the midrib at wide angles, rather straight in their courses and camptodrome in the marginal region. Tertiaries thin, close-set, percurrent at nearly right angles to the midrib.

The present form, which is not abundant in the collections, resembles the leaves of the existing *Bumelia angustifolia* Nuttall in a great many particulars. The latter is a small evergreen shrubby or arborescent form occurring along the coast of the lower half of peninsular Florida and on the keys and the Bahama Islands. It is also said to occur in the lower part of the Rio Grande valley, so that the present late Pliocene form, which was found in an intermediate situation, may indicate that a closely allied ancestral form was common along the Gulf coast in pre-Pleistocene time. The fossil, which is described as a new species, is very close to the existing species, differing merely in its more decurrent base and more prominent venation. Some of the leaves of the modern species almost exactly match the fossil, but many of them are much narrower and relatively more elongated. They may be regarded as variants from the type prevailing during Pliocene time. It would do very little violence to the facts to consider the Citronelle form identical with the existing species, but in view of the foregoing considerations it is believed to be wiser to regard it as prenuncial.

The genus Bumelia includes about a score of existing species that are confined to America, ranging from the southern United States through the West Indies and Central America to Brazil. It includes also numerous fossil species of which the oldest comes from the Upper Cretaceous (Dakota sandstones) of the western interior. In addition to the six American lower Eocene species, which are the prototypes of still existing forms, these are two Eocene (Ypresian) species in southern England. There are about a dozen Oligocene species, ten of which are widespread in Europe, one is found in the Apalachicola group of western Florida, and two, represented by both leaves and fruit, are found in the Vicksburg limestone of Louisiana and Texas. Seven or eight Miocene species are widely distributed in Europe and one is recorded from the late Miocene of Colorado (Florissant lake beds).

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

Order GENTIANALES.

Family OLEACEÆ.

Genus FRAXINUS Linné.

Fraxinus sp.

Plate XLVII, figure 12.

Small and poorly preserved leaflets of Fraxinus are contained in the collections from Lambert. The material is not extensive enough for specific determination, but its resemblance to the leaves of the water ash of Georgia and Florida (*Fraxinus floridana* Sargent) suggests comparisons with that species, to which the fossil species is clearly related. The leaflets are oblong-acuminate in outline, being widest near the middle and tapering almost uniformly both proximad and distad. Margins entire below, serrate above.

Occurrence: Citronelle formation, Lambert, Mobile County, Ala.

Collection: United States National Museum.

PLATES XLV-XLVII.

PLATE XLV.

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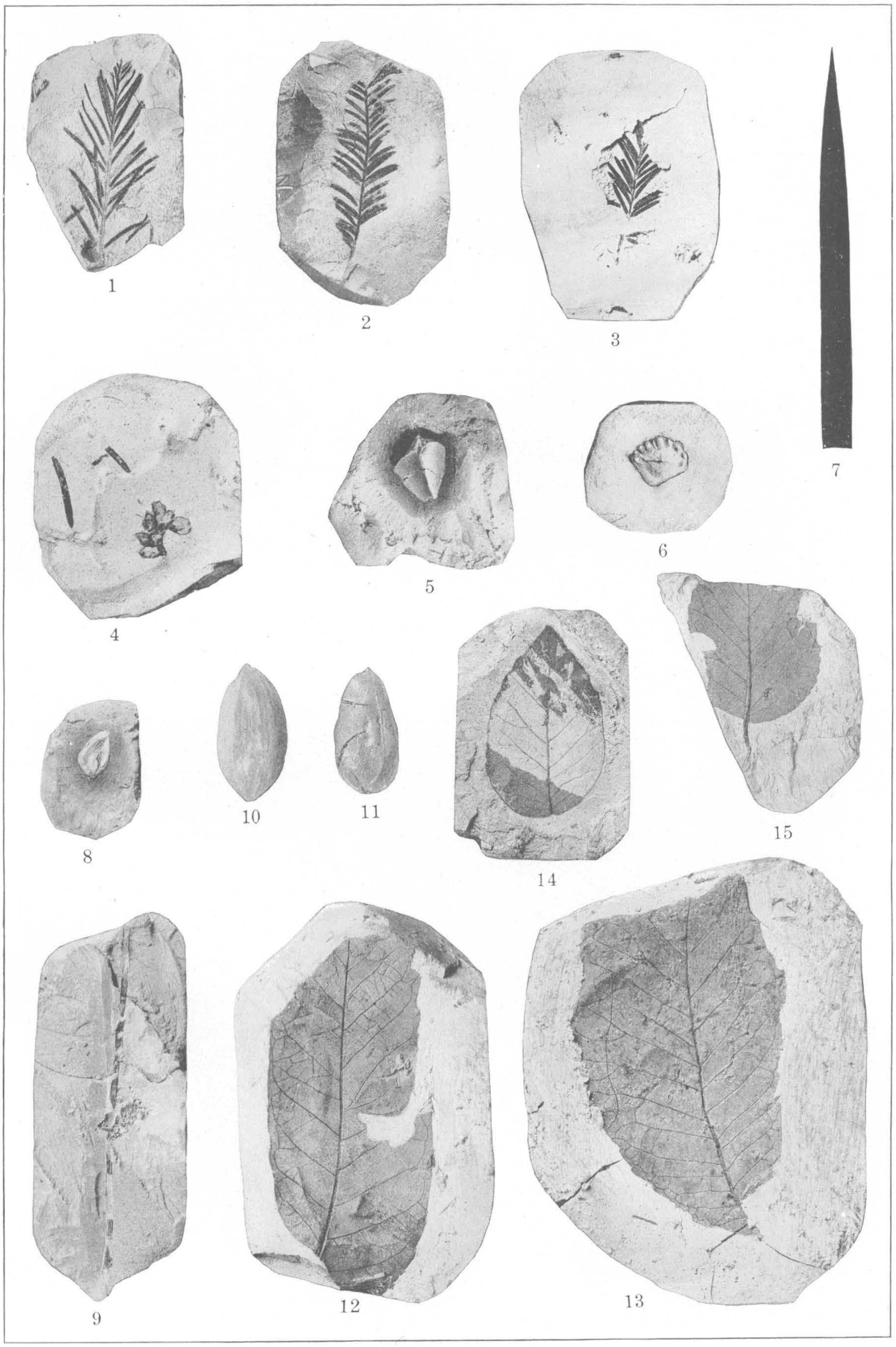
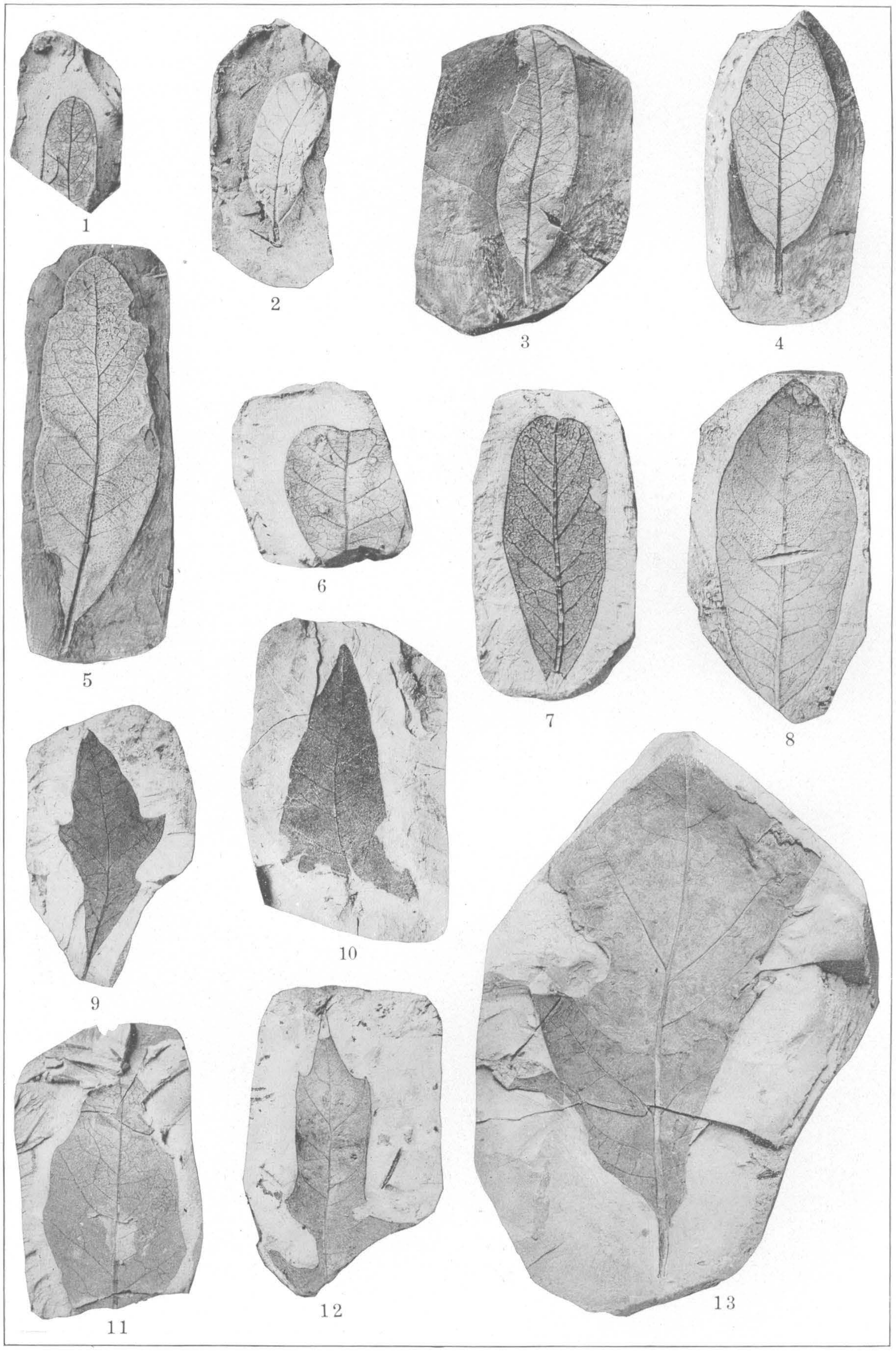
FIGURES 1–6. *Taxodium distichum* (Linné) L. C. Richard 195
1–3. Deciduous twigs.
4. Detached leaves and part of a catkin, enlarged.
5. Seed.
6. Cone scale.
7. Yucca sp. Fragment of terminal part of leaf 197
8, 9. Pinus sp 197
8. Seed.
9. Leaf.
10–13. *Hicoria pretexana* Berry 198
10, 11. Nuts.
12. A lateral leaflet.
13. A terminal leaflet.
14, 15. *Betula prenigra* Berry 198

All collected at Lambert, Ala.



FLORA OF THE CITRONELLE FORMATION.



FLORA OF THE CITRONELLE FORMATION.

PLATE XLVI.

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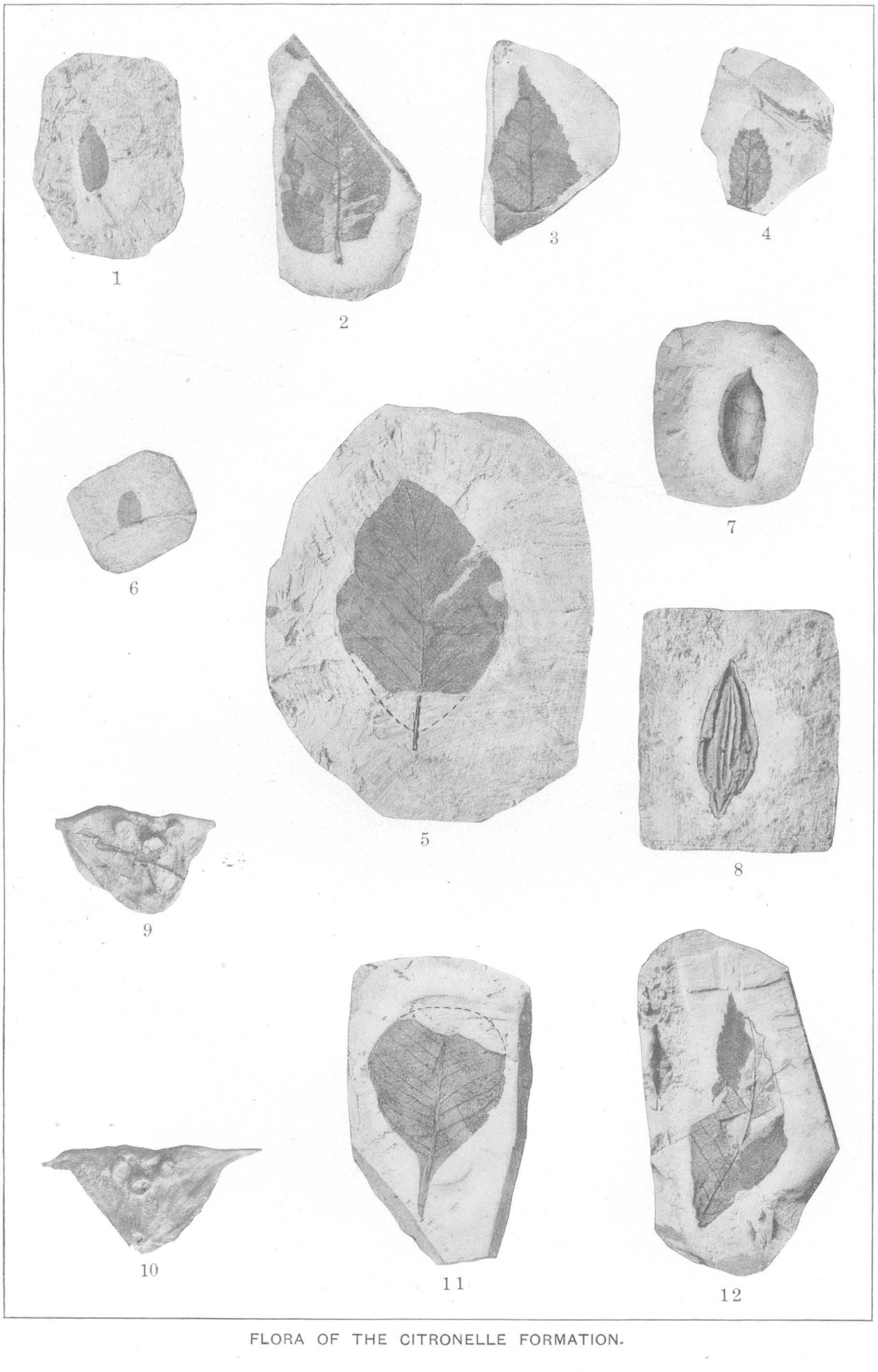
FIGURES 1–8.	*Quercus previrginiana* Berry	199
9, 10.	*Quercus lambertensis* Berry	201
11.	*Quercus nigra* Linné	201
12, 13.	*Quercus catesbæifolia* Berry	200
	All collected at Lambert, Ala.	

PLATE XLVII.



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