THE CATAHOULA SANDSTONE.

By George Charlton Matson.

DEFINITION OF THE FORMATION.

The name Catahoula was first used in 1905 by Veatch [1] as a synonym for "typical Grand Gulf," but the description of the formation, which is here quoted, was not published until the following year.[2]

> Overlying the fossiliferous Vicksburg clays and limestones is a series of sandstones and greenish clays which are generally quite different, lithologically, from any of the older beds of the Tertiary series in Louisiana and Arkansas. The sandstones which are the characteristic feature of this formation range in thickness from a few inches to 50 or 60 feet, and thicknesses of as much as 140 feet have been reported.[3] These sand beds are often cemented by silica into very hard quartzites, but such occurrences are essentially local, and the quartzitic beds pass laterally in very short distances into soft sandstones or even unconsolidated sands. These sandstones and quartzitic layers have resisted erosion more than the underlying clays and unconsolidated sands of the Eocene and so have formed a line of rocky hills, the Kisatchie Wold, extending across Louisiana, into Texas on the one hand and into Mississippi on the other.
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> These beds contain no indication of marine life, but land plants are abundant and fresh-water shells have been found in several places. The change from the conditions existing in the Vicksburg is very marked and indicates an elevation during which the region where the oceanic conditions were favorable for the growth of marine life was considerably south of the present outcrop of the formation.
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> These beds were observed at Grand Gulf, on Mississippi River, in Claiborne County, Miss., by Wailes, the first State geologist of Mississippi, who referred to them as the "Grand Gulf sandstones." [4] Later Hilgard [5] used the name "Grand Gulf group" to include the beds exposed in southern Mississippi between the Vicksburg and the relatively recent coastal clays (Port Hudson) and the name has been used with varying shades of meaning by different authors since that time.[6]
>
> In view of this confusion and in order to furnish a name not likely to be misunderstood, the name Catahoula formation is used in this paper as a synonym for the "typical Grand Gulf" or the "Grand Gulf proper." This new name is from Catahoula Parish, La.,[7] which is directly across the Mississippi Valley from Grand Gulf and where there are many outcrops which are lithologically and stratigraphically counterparts of the beds of the old type locality.

Investigations made by the author in 1911 showed that the beds at the Catahoula type locality are in part the equivalent of the Chattahoochee formation and in part the equivalent of the Vicksburg limestone, and that although Veatch defined the Catahoula as of Oligocene age, he included in his maps and descriptions of the formation sandstone and quartzite of marine origin that are now known to belong to the Fayette sandstone, of Eocene age. It is proposed to restrict the name Catahoula to the nonmarine deposits (of Oligocene age) found at the type locality and to eliminate the marine Eocene sandstones and quartzitic beds with associated clays of the Kisatchie Wold, included by Veatch in his description and mapping of the formation. These sandstones and quartzites contain imprints of marine fossils, and some of the associated clays are darker and more calcareous than those of the typical Catahoula. From their relations to the typical Jackson deposits these beds are known to be of Jackson age, and they are also known to repre-

[1] Veatch, A. C., Report on the underground waters of northern Louisiana and southern Arkansas: Louisiana Geol. Survey Bull. 1, pt. 2, pp. 84, 85, 90, 1905.

[2] Veatch, A. C., Underground water resources of northern Louisiana: Louisiana Geol. Survey Bull. 4, pp. 38–40, 1906; Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 42–43, 1906.

[3] Kennedy, William, Texas Geol. Survey Third Ann. Rept., p. 63, 1892.

[4] Wailes, B. C. L., Agriculture and geology of Mississippi, pp. 216-219, 1857.

[5] Hilgard, E. W., Report on agriculture and geology of Mississippi, pp. 147–154, 1860.

[6] In this connection see the following: Smith, E. A., and Aldrich, T. H., Science, new ser., vol. 16, 1902, pp. 835–837; Idem, vol. 18, 1903, pp. 20–26; Dall, W. H., Science, new ser., vol. 16, 1902, pp. 946–947; Idem, vol. 18, 1903, pp. 83–85; Hilgard, E. W., Science, new ser., vol. 18, 1903, pp. 180–182.

[7] It may be of historic interest to note that one of the first references to the outcrops of this formation is to the exposures at Catahoula Shoals in Catahoula Parish, which were even at that early day correctly correlated with the exposures east of the Mississippi. (See Darby, William, A geological description of the State of Louisiana, pp. 45–46, Philadelphia, 1816.)

sent the eastward extension of the Fayette sandstone.

The name Catahoula formation as originally used by Veatch was intended as a synonym for "typical Grand Gulf" or the "Grand Gulf proper." The present usage makes it include that portion of the "Grand Gulf" which is equivalent to the Chattahoochee formation and the Vicksburg limestone in the western part of the Gulf embayment. It is believed that subsequent study may permit the separation of the formation into two parts, one equivalent to the Chattahoochee formation and the other equivalent to the Vicksburg limestone.

The validity of Veatch's objection to the old name "Grand Gulf" is strengthened by the recognition of beds of Vicksburg age at the type locality of the Catahoula sandstone—Catahoula Parish, La. An additional reason for abandoning the name "Grand Gulf" is that it originally included nearly all the Tertiary deposits younger than the Vicksburg limestone.

ORIGIN OF THIS INVESTIGATION.

During the spring of 1910 the writer, working under the direction of T. Wayland Vaughan, began a study of the younger Tertiary beds of the Gulf Coastal Plain. This investigation was intended to cover the Tertiary formations younger than the Vicksburg limestone, and, as originally planned, the field studies were to begin in western Florida and were to be extended as rapidly as practicable across Alabama and Mississippi, with a hasty reconnaissance on the west side of Mississippi River for the purpose of correlating the formations east of the river with the formations recognized by Veatch[1] in Louisiana.

As the work progressed it became apparent that the investigations serving as a basis for the conclusions reached by Veatch were not sufficiently thorough to permit satisfactory correlation, and the plans were enlarged to include a portion of the State of Louisiana. The field investigations were interrupted by many demands for work in other areas and were not completed until May, 1913. The preparation of the reports was still further delayed by the demands for investigations in other portions of Louisiana and Texas, so that office work was not completed until the summer of 1914.

PREVIOUS INVESTIGATIONS.

The first report mentioning the "Grand Gulf sandstone" is that by Wailes, of the Mississippi State Geological Survey.[2] This author described the typical materials found at Grand Gulf, on Mississippi River, and correlated them with what he called the Davion rock, at the place now known as Fort Adams, farther down the river. He succeeded in tracing sandstone eastward from Grand Gulf throughout the area between the Bayou Pierre and Big Black River, and eastward to the vicinity of Raymond and Mississippi Springs, though he noted the fact that the rock changes in character, becoming more uniform in texture and softer east of Grand Gulf. His description of the equivalent of the "Grand Gulf sandstone" in the vicinity of Bayou Pierre and Mississippi Springs was apparently the result of field observations, and he drew a correct conclusion concerning the continuation of this formation eastward beyond Pearl River.

The next extensive report dealing with the "Grand Gulf" was published in 1860 by Hilgard,[3] then State geologist of Mississippi. This publication gave a more comprehensive description of the "Grand Gulf sandstone," which, as in Wailes's report, was made to include the rock as far south as Fort Adams. Several excellent sections were described in detail, and the information about specific localities was unusually full. The report was evidently the result of extensive field investigations covering the entire area from Mississippi River to the eastern boundary of the State. Hilgard wished to determine the economic value of this as well as other geologic formations, and he therefore gave a large amount of time to the study of the lithology and chemical composition of the rocks included in the "Grand Gulf." He mentioned the absence of marine fossils in this formation, the general lack of calcareous materials, the wide distribution of gypsum and salt, and the presence at certain

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 42 et seq., 1906.

[2] Wailes, B. L. C., Report on the agriculture and geology of Mississippi, pp. 216–219, 1854.

[3] Hilgard, E. W., Report on the geology and agriculture of Mississippi: pp. 147–154, 1860.

localities of fossil wood and leaves. His conclusions concerning the nonmarine character of the formation appear to be in the main correct, as is also the table showing the "Grand Gulf formation," as he mapped and described it, containing representatives of geologic formations ranging in age from the top of the Oligocene Vicksburg limestone to the Pliocene. In the description of different localities Hilgard's report is an exceptionally valuable source of information to those who wish to examine the different types of sediments included by him in the formation.

After the appearance of Hilgard's report many years elapsed before field investigations were again undertaken in the areas where the "Grand Gulf formation" is exposed. In 1893 Johnson [1] described the extension of the "Grand Gulf" into Alabama and divided it into four phases, which, arranged in order from the oldest to the youngest, are (1) the Bayou Pierre phase, in which the rock is highly siliceous and in places quartzitic; (2) the Fort Adams or Ellisville phase, including the softer sandstones and dense clay; (3) the Hattiesburg phase, which is less siliceous than the two preceding and in places lignitic; (4) the Pascagoula phase, which consists of tenacious clays containing calcareous nodules and locally abounding in shells of mollusks. Unfortunately, some of the lines separating the different phases are apparently drawn diagonally across the strike and they do not separate distinct lithologic or time units. The first two phases of the "Grand Gulf," as discussed by Johnson, appear to include the Catahoula sandstone and in some places younger beds.

A report by E. A. Smith,[2] published in 1894, was confined largely to a discussion of the "Grand Gulf" and other formations in the State of Alabama, but reference was made to the classic localities of Hilgard and Wailes in Mississippi. Most of the beds in Alabama that Smith classed as "Grand Gulf" are now correlated with the formations belonging to the Apalachicola group as developed in eastern Alabama and western Florida.

A subsequent paper by Smith and Aldrich [3] described the "Grand Gulf" of southern Alabama and assigned to it a position in the geologic column above the Pascagoula phase of Johnson. In this discussion the "Grand Gulf" was made to include the mottled clays, sands, and sandstones resting upon the Vicksburg limestone and other clays and sands of similar appearance lying stratigraphically above some of the younger Tertiary formations. The "Grand Gulf," according to these authors, would therefore be a blanket formation of relatively recent geologic age, or, as the authors describe it:

> Our recent observations, however, of the unconformity existing between the Grand Gulf and the fossiliferous Tertiary beds in these localities, and of the occurrence of the former as surface beds southward to the very shores of the Gulf, compel us to change our views and to assign to the Grand Gulf a place in the stratigraphic column not only far above the Tertiaries exposed on the Chattahoochee and Escambia rivers, but also above any unquestioned Tertiary existing in Alabama.
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> The evidence of the comparatively recent age of the Grand Gulf formation thus furnished by its surface distribution is confirmed and extended by the materials brought up from three deep wells bored in Mobile County, viz, one at the brewery in the city, one about 3 miles southwest of the city (the Bascom well), and one at Alabama Port on Mon Louis Island, near the southeastern end of the county.

From the foregoing quotation and the list of fossils given by these authors it is clear that they regarded the "Grand Gulf" as younger than the Pascagoula.

In discussing the paper by Smith and Aldrich, Dall [4] expressed the opinion that the beds they described comprised only the upper portion of what Hilgard called "Grand Gulf." In the same paper Dall restated his views concerning the tentative use of the term "Grand Gulf," as follows:

> In 1898 [5] I was obliged to decide on some portion of the original Grand Gulf which should continue to bear the name, after deduction of beds of which the age had been determined, and fixed upon the Oligocene clays containing lignite and fossil palm leaves, the only fossils cited by Hilgard in his original description, and in my table of Tertiary horizons referred to them as "typical Grand Gulf." The beds which Messrs. Smith and Aldrich call

[1] Johnson, L. C., The Miocene group of Alabama: Science, vol. 21, pp. 90–91, 1893.

[2] Smith, E. A., Johnson, L. C., and Langdon, D. W., Report on the geology of the Coastal Plain of Alabama, pp. 97–107, Alabama Geol. Survey, 1894.

[3] Smith, E. A., and Aldrich, T. H., The Grand Gulf formation: Science, new ser., vol. 16, pp. 835–837, 1902.

[4] Dall, W. H., The Grand Gulf formation: Science, new ser., vol. 16, pp. 946–947, 1902.

[5] U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, p. 340 and table.

"Grand Gulf" in their communication to Science are not the same but are the nonfossiliferous upper portion at the other end of Hilgard's Grand Gulf section. I have little doubt that their assumption as to the late, possibly Pliocene age of these beds is correct, though it can only be proved by further and paleontological evidence, but this decision is merely an equivalent of the ideas above cited from Hilgard and therefore not new.

The views held by Smith and Aldrich were elaborated in a later paper [1] which sums up their conclusions:

1. The Grand Gulf of "Messrs. Smith and Aldrich" is the same fossiliferous formation which Hilgard has described by that name, and not merely "the upper nonfossiliferous portion at the other end of Hilgard's section." It is the same formation which Professor Dall calls the "typical Grand Gulf" in his recent communication and which he considers Oligocene, and a remnant of the heterogeneous Grand Gulf of Hilgard. We are compelled by the facts to believe that this typical Grand Gulf is not Oligocene at all, but that it belongs about a quarter of a mile vertically above the place in the geological scale to which it is assigned by Professor Dall.

2. There is also no Miocene Grand Gulf, as Langdon's discovery has proved and as has been confirmed by other geologists who have studied the Chattahoochee-Apalachicola section. We might perhaps more correctly say there is no Miocene Grand Gulf below the horizon of the Pascagoula, if that be certainly proved to be Miocene.

3. We think our facts prove that the Grand Gulf, all and singular, occupies a place in the geological column below the Lafayette and above the Pascagoula (which is the uppermost of the Tertiary formations as yet determined along the Gulf coast). This is all we have endeavored to show, and it was the raison d'être of our first note. We do not see wherein what we have there said in any way confirms Professor Dall's "earlier determinations" and, furthermore, we think that our view of the age of the Grand Gulf is new, and not a mere equivalent of the views of any other geologist.

In a paper by Dall [2] published subsequently he restated his opinion that the "Grand Gulf" as a whole does not lie stratigraphically above the Pascagoula clay. After disclaiming knowledge based on personal observation, he cited, in support of his position, the statements of Wailes, Hilgard, Smith, Harris, and Miss Maury. The statement by Miss Maury [3] is given below.

The Grand Gulf sandstones reach their eastern limit in south-central Alabama. Near Oak Grove the typical sandstone beds pass beneath the Oak Grove sand, indicating that the sandstone is approximately of the same age as the Chattahoochee.

Dall [4] divided the "Grand Gulf" into "typical Grand Gulf," the equivalent of the lower part of the Chattahoochee; Ellisville phase, Grand Gulf (?), represented in the upper part of the Chattahoochee; beds in Alabama and Georgia corresponding to the Chipola marl of the Apalachicola section; and the Hattiesburg phase and Oak Grove sand, equivalent to the Alum Bluff. He separated the Pascagoula from the "Grand Gulf," and his subdivisions were the same as those made by Johnson.[5]

In 1896 Vaughan [6] discussed the "Grand Gulf group" in Louisiana, and, following the classification adopted by Dall, assigned it to the upper Oligocene:

The upper Oligocene of Louisiana is represented by the Grand Gulf group of Hilgard. These rocks have been described by Hilgard, Hopkins, Johnson, and Lerch. They are composed of clays, sands, claystones, sandstones, and quartzites. So far no fossils, except a few plants,[7] have been collected and determined from them, but they are referred to the Upper Oligocene because they are without doubt the same as the Grand Gulf of Mississippi, the age of which has been fixed.[8]

The literature contains many other references to this formation, but inasmuch as the classifications adopted agree with one or another of those already mentioned, it does not appear necessary to cite all these references.

The first definition of the Catahoula is found in two reports by Veatch,[9] who described the materials occurring west of Mississippi River, correlated them with the typical "Grand Gulf sandstone" at Grand Gulf, Miss., and introduced the new name because of the confusion concerning the use of the name "Grand Gulf" by some of the earlier investigators.

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[1] Smith, E. A., and Aldrich, T. H., The Grand Gulf formation: Science, new ser., vol. 18, pp. 20–26, 1903.

[2] Dall, W. H., The Grand Gulf formation: Science, new ser., vol. 18, pp. 83–85, 1903.

[3] Maury, C. J., Comparison of the Oligocene of western Europe and the southern United States: Bull. Am. Paleontology, vol. 3, No. 15, p. 70, 1902.

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

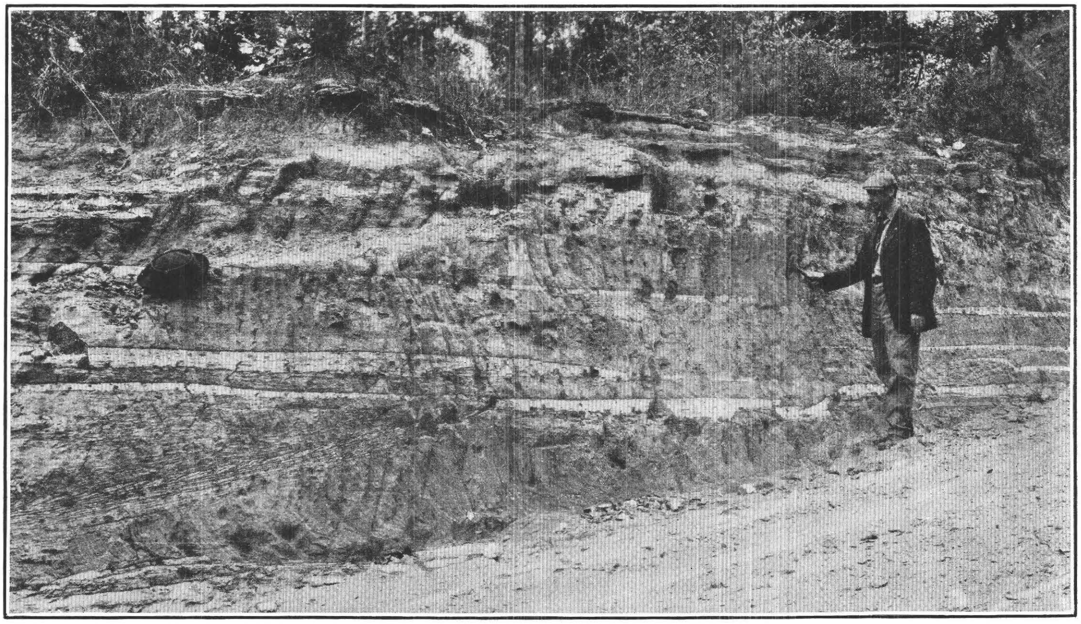
[5] Johnson, L. C., The Miocene group of Alabama: Science, vol. 21, pp. 90–91, 1893.

[6] Vaughan, T. W., A brief contribution to the geology and paleontology of northwestern Louisiana: U. S. Geol. Survey Bull. 142, p. 24, 1896.

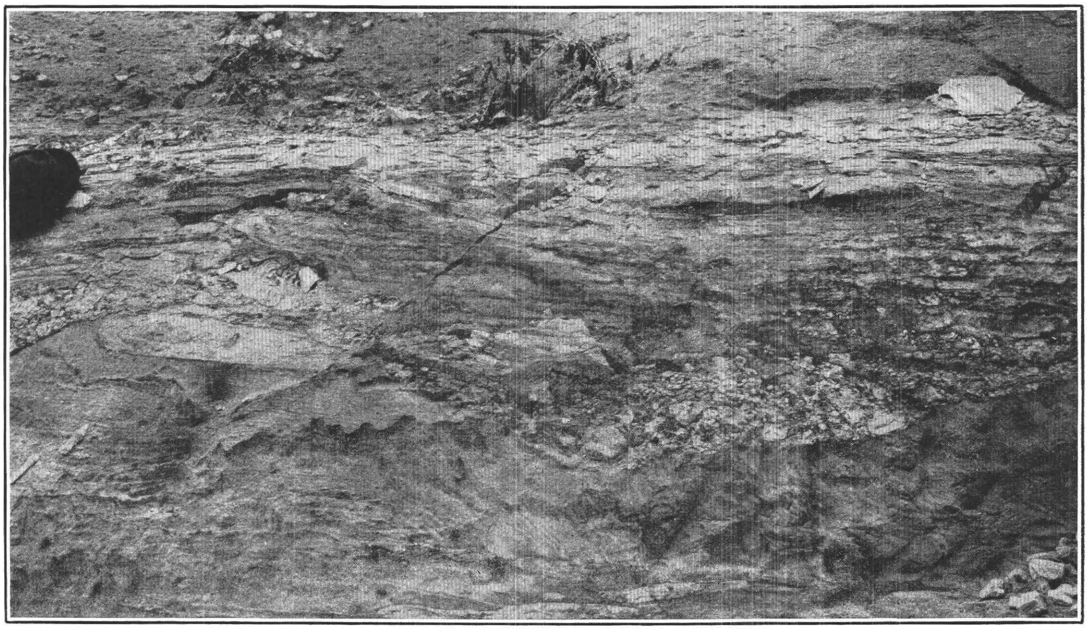
[7] Knowlton, F. H., U. S. Nat. Mus. Proc., vol. 11, pp. 89–91, 1888.

[8] Dall, W. H., and Stanley-Brown, Joseph, Geol. Soc. America Bull., vol. 5, pp. 164, 167, 1894. Smith, E. A., Am. Jour. Sci., 3d ser., vol. 47, p. 296, April, 1894; Chart to geological map of Alabama, 1894. Dall, W. H., U. S. Geol. Survey Eighteenth Ann. Rept., pt. 2, 1898.

[9] Veatch, A. C., Underground waters of northern Louisiana and southern Arkansas: Louisiana Geol. Survey Bull. 1, pp. 84, 85, 90, 1905; Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 42–43, 1906.



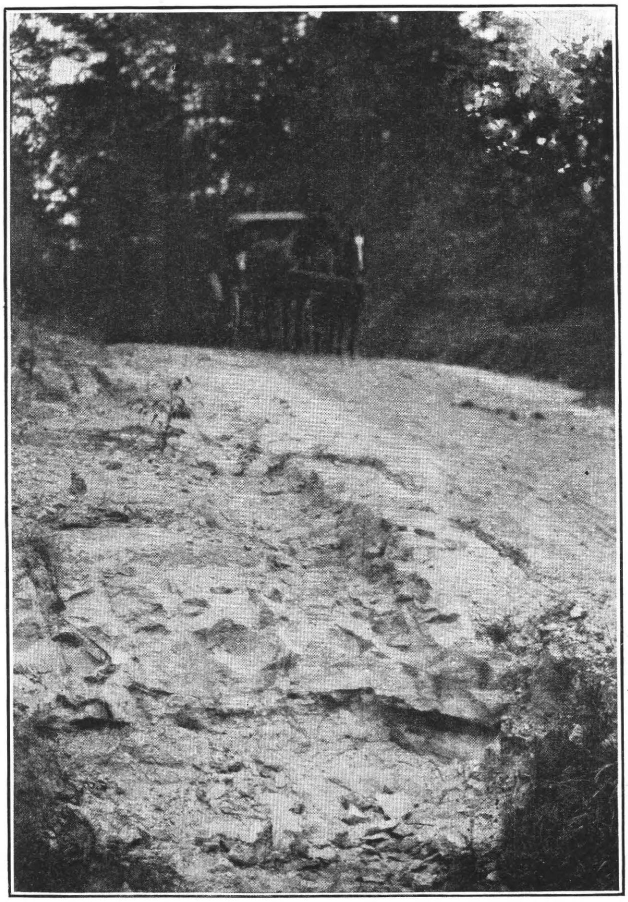
A. INTERLAMINATED AND INTERBEDDED SANDSTONES AND CLAYS.



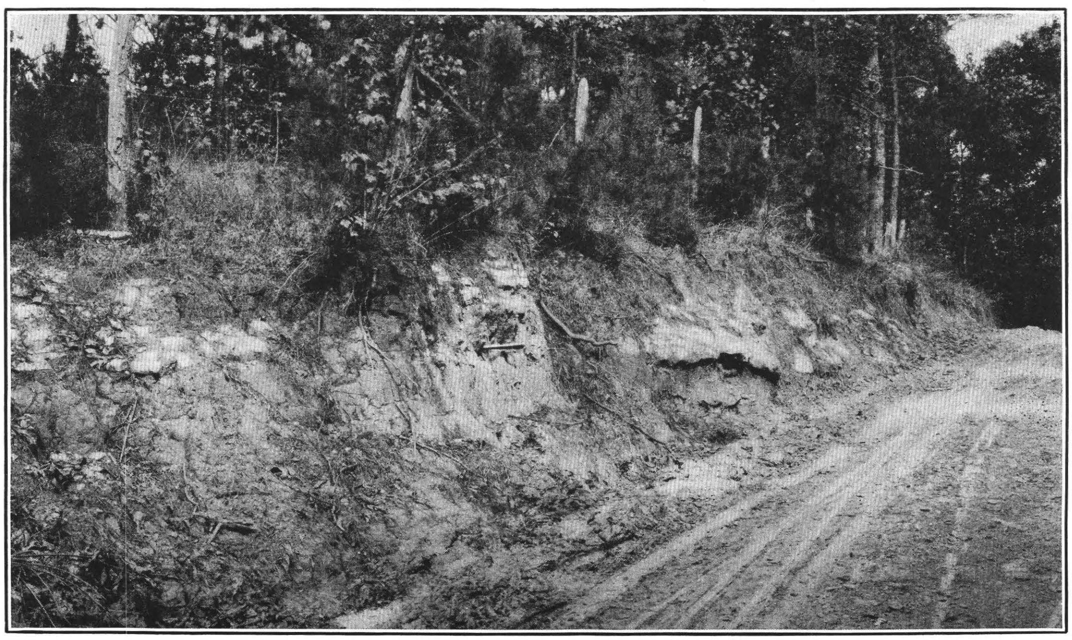
B. SANDSTONE CONTAINING IRREGULAR MASSES OF CLAY.

LITHOLOGIC CHARACTER OF THE CATAHOULA SANDSTONE.

Photographs by E. W. Shaw.



A. FINE-GRAINED SANDSTONE 3 MILES NORTHEAST OF FLORENCE, MISS.



B. WEATHERED SANDSTONE GRADING TO RED SAND, NORTHEAST OF FLORENCE, MISS.

LITHOLOGIC CHARACTER OF THE CATAHOULA SANDSTONE.

Photographs by E. W. Shaw.

Vaughan[1] presented in a recent correlation paper the following quotation from a manuscript by Alexander Deussen:

As here interpreted, the Catahoula sandstone is a lithologic and stratigraphic unit which transgresses several biologic zones. Stated differently, it is conceived to be of different ages and to have been laid down at different periods in the different regions of its occurrence. In southwest Texas it is of Claiborne age, and this kind of deposition seems to have begun in this area as early as Claiborne time. In central Texas, in the region of the Brazos, it is largely of Jackson age. In eastern Texas it is largely of Vicksburg age. According to Matson, the vertical transgression continues across Louisiana into Mississippi, where the formation is of post-Vicksburg age. This kind of deposition began in southwest Texas in Claiborne time, gradually shifted eastward, and prevailed in Mississippi as late as middle Oligocene time. If this interpretation is correct it precludes the possibility of an unconformity between deposits of Eocene and Oligocene ages in the Coastal Plain; no evidence of such unconformity has been found.

LITHOLOGY.

UNWEATHERED MATERIALS.

The Catahoula sandstone is composed of many alternations of sandstones, sands, and clays, the arenaceous sediments predominating and the argillaceous materials being distributed in more or less extensive beds of lenticular shape. (See Pls. XLVIII and XLIX, *A*.) Loose sands are comparatively rare, and interlamination of sands and clays is not conspicuous. The sandstones are commonly fine grained, and many of them contain more or less clay. Locally coarse-grained sandstones or fine-grained conglomerates are found, and the material is largely quartz, either in the form of pebbles or sand. In some of the sand the particles are so minute that the rock resembles clay. An exception to the general character of the conglomerate is found in layers of clay pebbles that have been noted in the sandstones and in the sands resulting from weathering. These clay pebbles and those formed from quartz are commonly distributed in lines parallel to the stratification of the rock, though they are in few places so numerous as to make a definite stratum themselves. In some places masses of clay a few inches in diameter occur in association with pebbles. The occurrence of clay conglomerates is not restricted to any portion of the formation, but the pebbles are scattered from top to bottom and appear to be the result of local conditions of sedimentation rather than to indicate any widespread unconformity.

Cross-bedding is general throughout the formation (see fig. 21 and Pl. LIII, *A*, p. 220), and in some places short lenses of sandstone show concentric banding. The beds are as a rule only slightly indurated (see Pl. LIII, *B*), though in a few places in western Mississippi the rock is sufficiently well cemented to be used for building stone. At Grand Gulf, Miss., near Pollock, La., and at some other localities thin layers are firmly cemented into a very dense quartzite, but rock of this type is apparently of only local occurrence. A change from slightly consolidated sands to quartzite in this formation would scarcely be expected, but it has occurred in some places where the type and quantity of mineral matter in solution in the waters furnished favorable conditions for the deposition of silica in the sands.

The sandstones and sands vary in color from gray to white, with locally a light-greenish tinge. The clays are commonly massive, more rarely interlaminated with sand, and show a tendency toward cuboidal fracture. Many of the clay beds are shown by an ordinary hand lens to contain a very large percentage of fine sand, and in some places this material is noticeable without a lens. In general the clays are somewhat sandy, though some thin beds are notably free from silica. Selenite and probably some of the amorphous forms of gypsum are in places abundant in the clays and occur in a few localities in the sandstones. Here and there rosettes of calcium carbonate occur on the surfaces of the clay layers and in the crevices where the clays are slightly broken or jointed. These rosettes have usually been regarded as accumulations of gypsum, but many of them dissolve with vigorous effervescence when placed in dilute hydrochloric acid, revealing the presence of the carbonate.

The clays of the Catahoula sandstone have a wide range in color, from light gray or white to brown or black. The dark colors are due to the presence of organic matter, either in thin laminæ or distributed in the form of particles of lignitized wood. The purer clays are pale

[1] Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, p. 790, 1912.

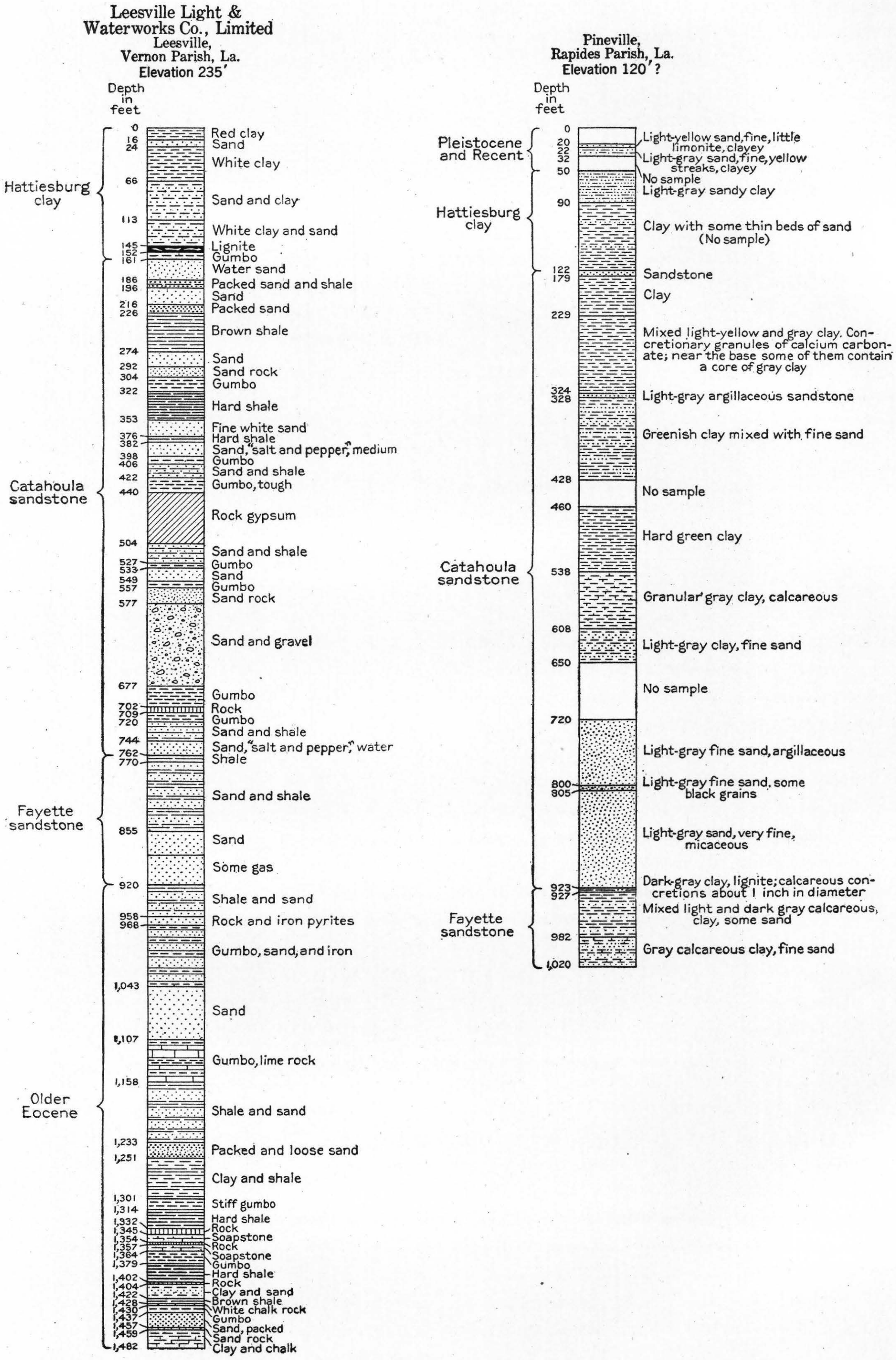
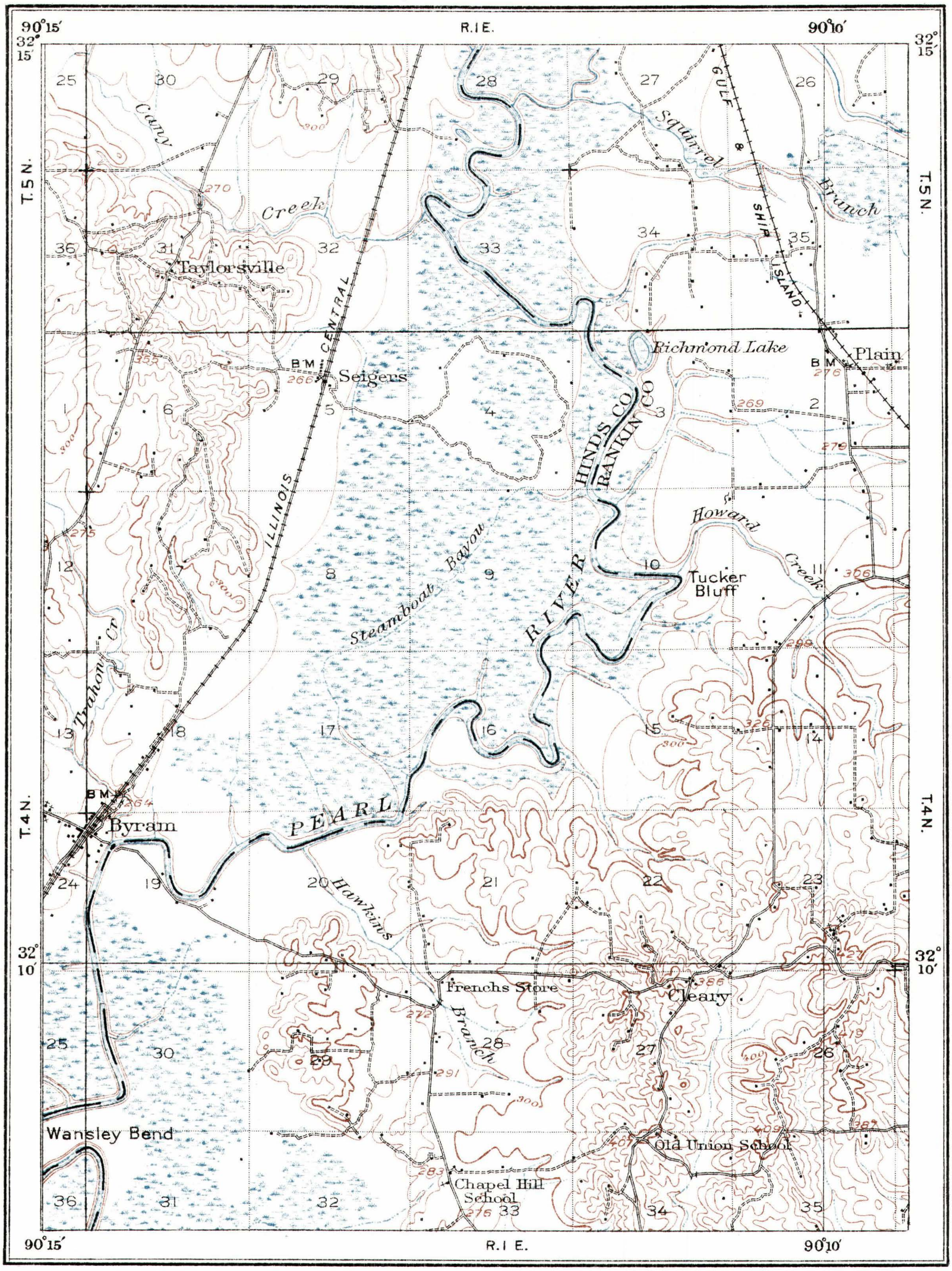


FIGURE 18.—Diagrammatic sections of the Catahoula sandstone, from logs and samples of cuttings of wells at Pineville and Leesville, La.



TOPOGRAPHIC MAP OF A PORTION OF THE FLORENCE QUADRANGLE, MISSISSIPPI

Showing the characteristic rugged topography of the Catahoula sandstone areas, the level plain developed on the underlying Vicksburg limestone, and the broad valley of Pearl River

Scale $\frac{1}{62,500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 20 feet.

Datum is mean sea level.

blue or green when first exposed to the atmosphere, but on weathering the color changes to gray or white.

The thicknesses of the different beds in the formation are indicated in a general way by the sections in figure 18.

WEATHERED MATERIALS.

When exposed to the weather the sandstones of the Catahoula change from light gray or white to deep red or yellow, the transition commonly being effected through various stages of mottling. The change in color is in places due to the presence of grains or small nodules of iron sulphide in the form of pyrite, or marcasite, which on exposure to the moisture and oxygen of the air changes to the hydrous oxide of iron. In this process the chemical compounds which are produced exercise a disintegrating effect upon the sandstone, tending to break it down into more or less incoherent sand. During the first stages the sandstones exhibit a spotted and blotched appearance at points where the iron compounds were originally most abundant, and as the weathering progresses the color becomes a more nearly uniform red and thereafter changes gradually to orange or pale yellow. (See Pl. XLIX, *B*.) In examining beds of this sandstone it is in places possible to trace every gradation from the original light-colored rock to the final product of mature weathering, orange-colored and yellow sand. Certain peculiarities of the texture of the rock are not affected by weathering; for example, where there were layers of pebbles in the original sandstone the pebbles are arranged in a similar way in the weathered sand.

The weathering of the clays produces a more or less sandy, plastic mass of orange or yellow color, but they pass through the same stages of mottling and blotching as the sandstones. During the early stages of the process a peculiar purplish-red color is produced, though this color is not characteristic of this particular terrane but is found also in other formations, both older and younger.

PALEONTOLOGY.

Fossils are rare in the Catahoula sandstone, no remains of marine invertebrates having yet been specifically identified and only a few localities showing any trace of organic life other than lignitized wood. Fossil shells of the genus Unio have been noted in a few places, among them being areas of sandstone in the chalk hills in Louisiana, and imprints of oyster shells were found in a lens of limestone a mile east of Lena, La. At a few places imprints of leaves sufficiently well preserved to be identified have been collected, and these are described on pages 227–243 by E. W. Berry. Silicified wood is widely distributed throughout the formation, and the most common fragments are those of palm trees.

TOPOGRAPHY.

The area in which the Catahoula sandstone is exposed has been extensively eroded, the surface being reduced to slopes. The major streams have cut broad, steep-sided valleys across this formation, and their tributaries have extended their ramifications so as to drain the entire area. The principal rivers crossing the formation are Sabine River, on the western boundary of Louisiana, and the Mississippi and its tributaries, including Red River in Louisiana and Big Black, Pearl, and Chickasawhay rivers in Mississippi. In the region covered by the Catahoula sandstone there is a difference in elevation of 100 to nearly 300 feet between the levels of the streams and the heights of the neighboring portions of the upland. The accompanying topographic map of a portion of the Florence quadrangle, Miss. (Pl. L), shows the characteristic hilly topography of the Catahoula sandstone, the comparatively level plain developed on the Vicksburg limestone, and the broad valley of Pearl River, one of the principal streams in Mississippi.

The major streams have meandered enough to develop broad, steep-sided valleys across the Catahoula sandstone, and most of the valleys have been excavated below their present levels and then partly refilled with alluvium. The amount of this filling is in most places great enough to conceal the underlying Catahoula except on the convex curves of some of the meanders. Pearl River presents unusual conditions because it is partly obstructed at several places by hard layers of sandstone or clay that produce stretches of quiet water interspersed with rapids. Similar conditions are found on Red River near Alexandria, though the conditions there are explained by the fact that the river has been deflected from its old channel in recent geologic time, and a new channel has been formed across spurs of the Catahoula sandstone that project from the adjacent hills.

The northern margin of the formation is characterized by hills rising more or less abruptly above the older geologic formations. (See fig. 19.) The name Kisatchie Wold was used by Veatch [1] to designate the line of high hills in Louisiana south of the contact between the Catahoula formation, as he used the name, and the Jackson formation. Although this portion of the Catahoula of Veatch is now correlated with the Eocene Fayette sandstone, the wold is sufficiently typical of scarps produced under similar conditions to warrant description. (See Pl. LI, *A*.) This topographic feature owes its existence to the fact that the sands and sandstones of the Fayette are more resistant than the clays and marls of the Jackson formation, to the north, and consequently the softer beds have been reduced to lower levels, while the sands and sandstones remain as ridges and hills, with steep slopes to the north and gentle dip slopes to the south. The greater resistance of the Fayette sandstone is not altogether due to the fact that its beds are hard, because, even though they contain many hard layers, the sands and sandstones as a whole are friable except where they have been either case-hardened by the deposition of cementing material on the surface or cemented into irregular ledges of quartzite. Sands are usually more resistant than clays because they are less easily attacked by rain water and sheet erosion and are less readily affected by small streams such as those which do the major part of the erosive work over the large areas underlain by the formation. The sand beds therefore cap hills where they overlie formations that consist of clays and marls.

One of the principal reasons for the greater resisting power of porous materials, such as sand, is that water sinks readily into the pores between the grains and the amount of surface wash is thereby greatly lessened. Water enters marls and clays with much greater difficulty, but after having gained access to the upper layers it imprisons the air contained in the pores below it and, by exerting pressure upon this confined air, causes the separation of the particles and facilitates their removal by erosion. It is therefore apparent that even where a formation is composed of incoherent sand it may be expected to resist erosion more than clays or marls.

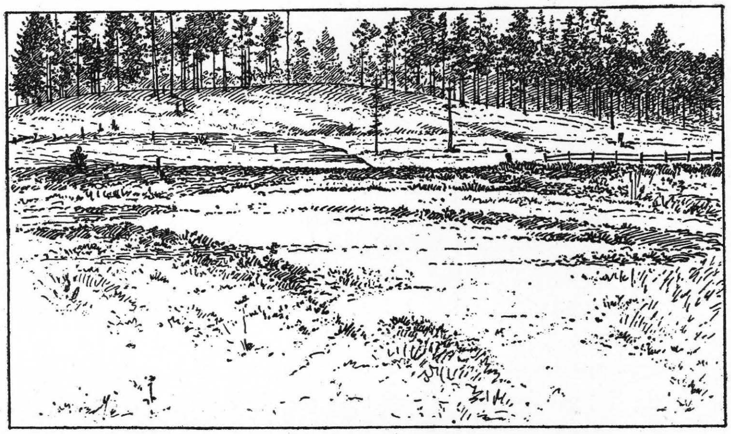
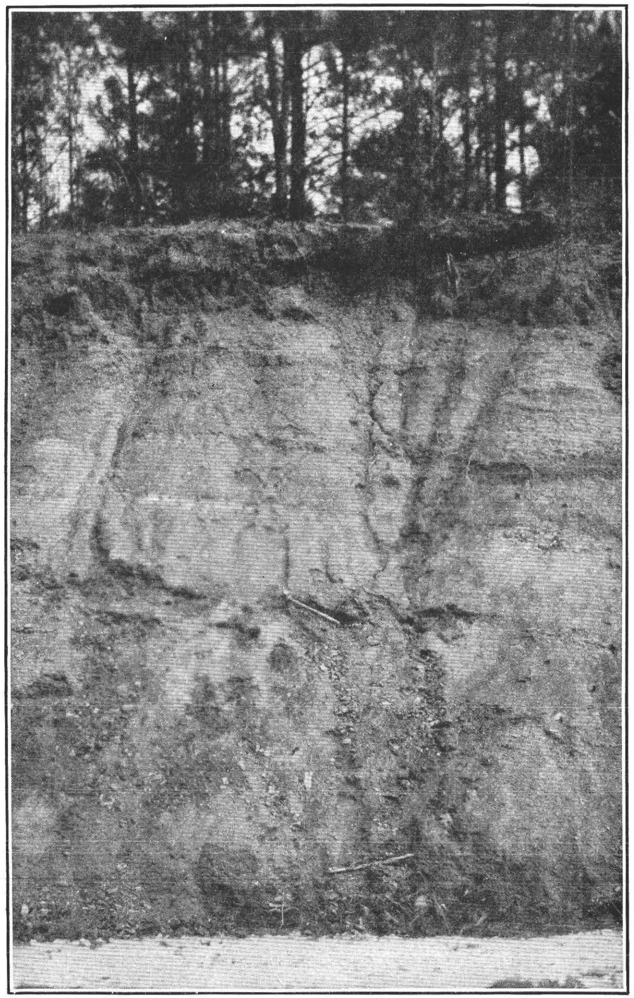


FIGURE 19.—Fayette sandstone forming northward-facing scarp of the Kisatchie Wold north of Hornbeck, La.

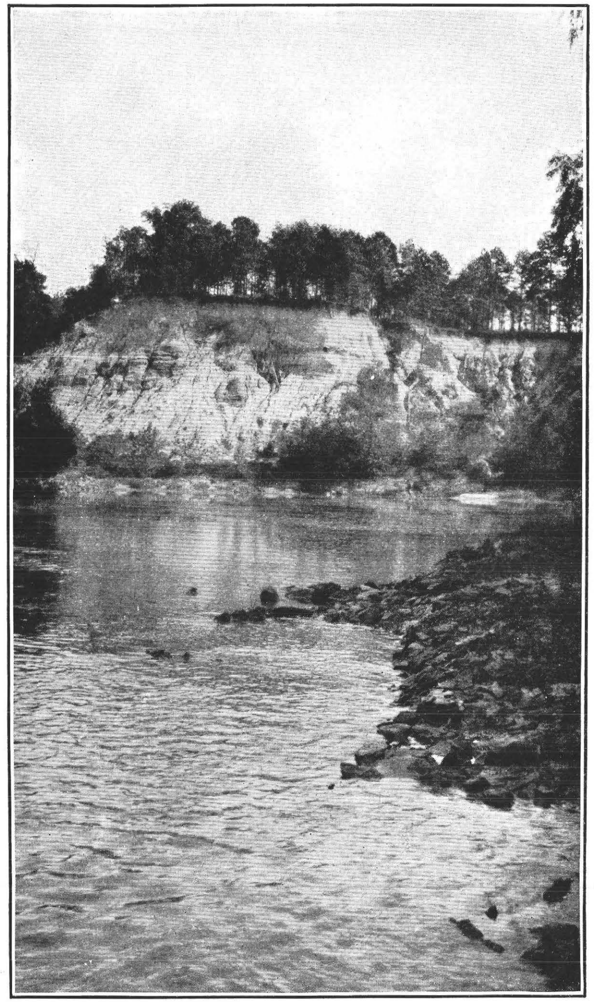
The Kisatchie Wold is less prominent east of the Kisatchie Hills in western Louisiana, but in eastern Louisiana the northern margin of the Catahoula sandstone forms a high ridge above the area to the north. The superior resistance of the sand beds causes more or less marked constrictions in the valleys where the rivers cross the formation. This is especially noticeable in the valley of Mississippi River, but the effect is accentuated because the Mississippi Valley just above the outcrop of the Catahoula sandstone is a composite of the valleys of the main stream and some large

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, p. 15, 1906.



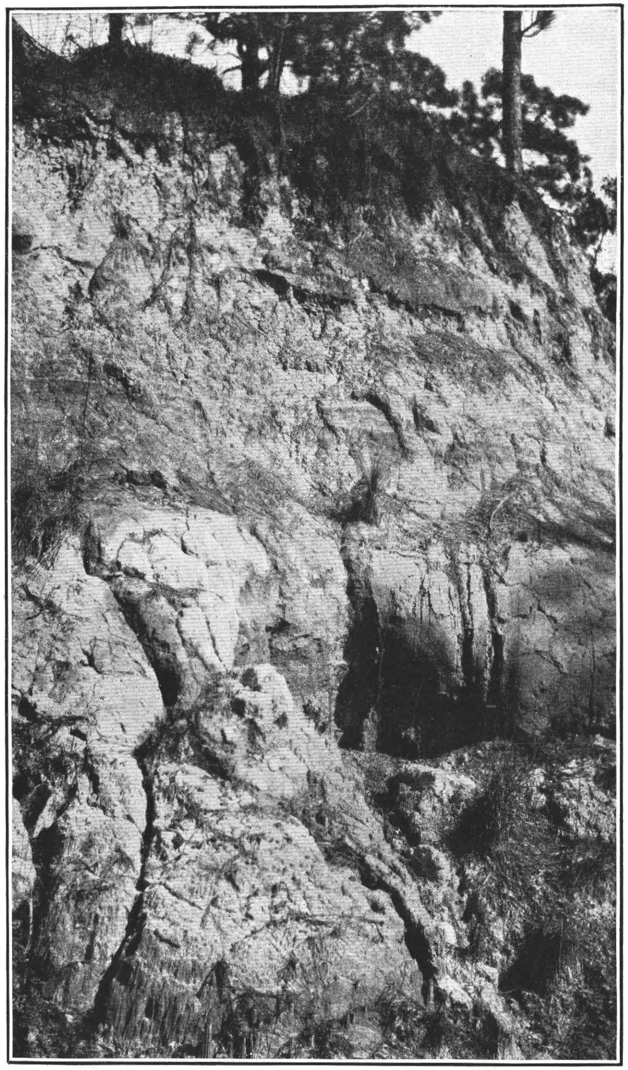
A. LITHOLOGIC CHARACTER OF THE JACKSON FORMATION.

Showing the interbedded dark clay and lenticular layers of the Fayette sandstone which form the gentle slope in the foreground of figure 19.

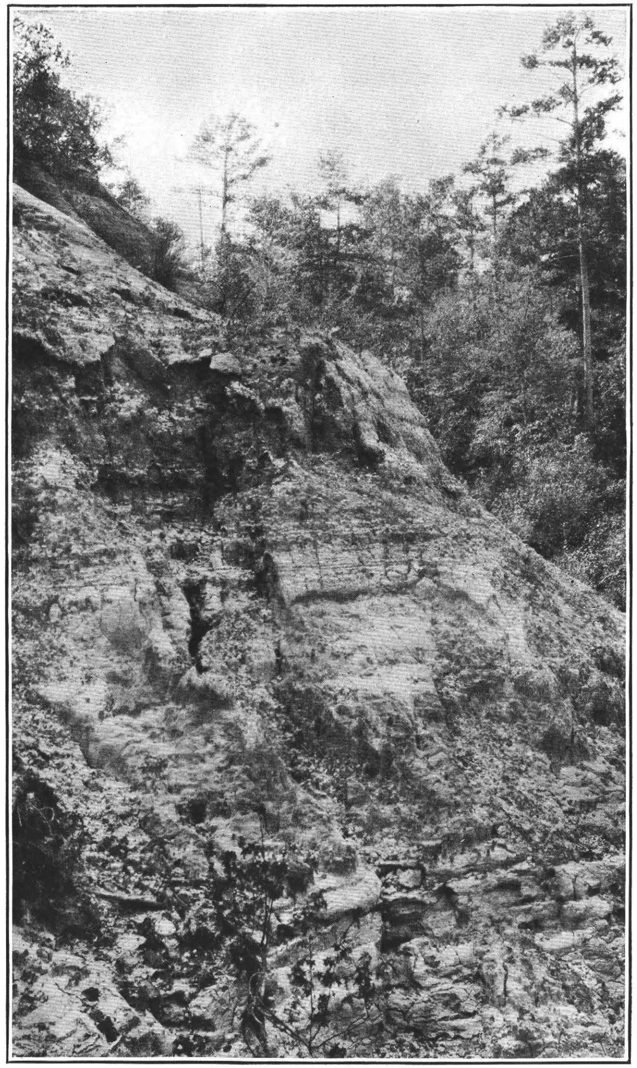


B. TOPOGRAPHIC ASPECT OF THE CATAHOULA SANDSTONE.

Showing sands and clays 3 miles southwest of Waynesboro, Miss.



A.



B.

LITHOLOGIC CHARACTER OF THE CATAHOULA SANDSTONE EXPOSED IN THE BLUFF SHOWN IN PLATE LI, *B.*

tributaries. However, the presence of the resistant sands and sandstones of this formation no doubt helped to control the points of junction of the main stream and tributaries by deflecting the tributaries. East of the Mississippi the Catahoula sandstone is less prominent topographically than in Louisiana, though it continues to form a noticeable scarp facing toward the north.

Rugged topography is found wherever the sands and sandstones of the Catahoula formation are deeply eroded, and steep slopes are produced by layers of indurated sandstones that cap hills. In many places the surface has been almost entirely reduced to slopes and the divides form long, winding ridges, but steep bluffs may be found on some of the major streams. (See Pl. LI, *B*.) The valleys of the small streams are distinctly V-shaped and the drainage has a dendritic form.

Along the northern margin of the Catahoula sandstone the streams show a tendency to follow the outcrop of the softer formations that underlie the Catahoula, but few well-defined examples of consequent drainage were noted, other than some of the small streams. One of the best examples of consequent drainage along the northward-facing scarp is Bayou Toro, a tributary of Sabine River in western Louisiana. Bayou Toro follows the north edge of the Kisatchie Wold for several miles and receives a number of tributaries from the scarp. These tributaries belong to the class known as obsequent streams and are similar to those that have developed along the landward margin of the Catahoula sandstone at many other places.

STRUCTURE.

ABSENCE OF DEFORMATION AND SALINE DOMES.

The Catahoula sandstone has undergone little deformation and presents no marked structural features. From the attitude of the sandstones gentle folds of small extent may be inferred at many places, but it is not everywhere easy to distinguish between cross-bedding on an extensive scale and inclination of beds. Because of the absence of extensive exposures, the confusion occasioned by the lenticular character of the layers, and the extent of cross-bedding, it will require a greater length of time to decipher the structure than could be devoted to this problem during the writer's general reconnaissance.

The absence of saline domes on the outcrop of the Catahoula is noteworthy when it is considered that such structures occur in Louisiana in the area north of the Catahoula sandstone, where Eocene beds are exposed, and also in the area to the south, where the Pleistocene and younger Tertiary formations overlie the Catahoula. Where the Catahoula is at the surface the absence of domes is explained by the porous and resistant character of the beds. It may be argued that the lithologic character of the formation does not furnish a satisfactory explanation of their absence, because the domes near the coast pass through the sandstones, but this argument is believed to be invalid. The formation was laid down near the strand line and it becomes much thinner and more argillaceous toward the Gulf; consequently it is represented in the belt of coastal domes by a thin deposit that should be less resistant to doming than the sandstones at the outcrop.

DIP OF THE CATAHOULA SANDSTONE.

GENERAL DIRECTION.

Local observations on the dip of the Catahoula sandstone show that there is in many places an inclination in a general southerly direction. The prevalence of these local dips indicates that the formation is not horizontal, as has been stated by Hilgard.[1]

> At their lines of contact the Vicksburg and Grand Gulf rocks consist almost throughout of lignite-gypseous laminated clays, passing upward into more sandy materials. They are not sensibly unconformable in place; but while the Vicksburg rocks show at all long exposures a distinct southward dip of some 3° to 5°, the positions of the Grand Gulf strata can rarely be shown to be otherwise than nearly or quite horizontal on the average; although in many cases faults or subsidence have caused them to dip, sometimes quite steeply, in almost any direction.

It is true that in places the sandstone dips in other directions, but the preponderance of southerly dips is noticeable in any long series of exposures like that on Pearl River.

Smith and Aldrich[2] considered the Catahoula to be a blanket formation of comparatively

[1] Hilgard, E. W., The later Tertiary of the Gulf of Mexico: Am. Jour. Sci., 3d ser., vol. 22, p. 58, 1881.

[2] Smith, E. A., and Aldrich, T. H., The Grand Gulf formation: Science, new ser., vol. 16, No. 142, pp. 835–837, 1902.

recent geologic age. This assumption necessitates dips of scarcely more than 200 feet in the distance between the outcrops of the formation and the inner margin of the Pleistocene formations of the Gulf coast. This distance is so great that the dip of the formation would be negligible, and the hypothesis of recent geologic age is not tenable if there is a well-defined dip toward the coast.

It is evident from the following detailed statements that the formation as a whole does not dip in a single direction. The prevalent direction of dip is southeast in central Louisiana and west of south in east-central Mississippi, the change of direction occurring near Mississippi River, where there was evidently an embayment that received the Catahoula sediments.

EASTERN LOUISIANA.

In discussing the stratigraphy along the Ouachita Harris[1] gives the dip of the Catahoula sandstone in eastern Louisiana:

> Three miles south of Danville, at Rock Hill, as has already been stated, the base of the Grand Gulf sandstone layers is 203 feet above tide. The fossiliferous Vicksburg beds in little ravines close by are from 60 to 70 feet below the sandstone layers; the intervening space is covered. Yet in the Harrisburg road perhaps 2 miles farther south thick sand beds were observed beneath the indurated ledges. These we would naturally place in the Grand Gulf stage. Ten miles southeast of Rock Hill, at Catahoula Shoals, borings made by the United States Engineers indicate the presence of hard Grand Gulf layers to a depth of 128 feet above tide. In this direction, therefore, nearly due southeast, the dip is about 31 feet per mile. If, however, we take the approximate elevation of the lower beds of the Grand Gulf just across the river from Colfax as 110 feet and note the distances and directions from each of these points and solve graphically for direction and amount of dip, we find the true dip to be S. 26° E. at the rate of 34 feet per mile.

The dip toward the southeast from Rock Hill to Catahoula Shoals as determined by Harris should have been a close approximation, but the elevation of the "hard Grand Gulf layers" at Catahoula Shoals as given by this author ("128 feet above tide") is a mistake. The boring at Catahoula Shoals did not reach the base of the formation, though it was probably not far above the base, and the bottom of this boring is reported by the Army Engineers[2] to be 186.45 feet below sea level. If the elevation of the base of the formation at Rock Hill is 60 feet less than 203 feet, as may perhaps be inferred from Harris's statement, the dip amounts to 329.45 feet in 10 miles, the distance given by Harris, or about 33 feet to the mile. The true dip may be somewhat greater or smaller, the amount of error depending on the distance between the bottom of the boring at Catahoula Shoals and the base of the formation and also on the distance between the assumed base of the formation at Rock Hill and the true base.

The base of the Catahoula sandstone on the Louisiana & Arkansas Railway 27 miles west of north from Pineville is 190 feet above sea level. A well drilled at Pineville, where the surface is 120 feet above sea level, reached the base of the Catahoula at a depth of 927 feet. The dip of the formation between these two places is therefore about 37 feet to the mile in a direction slightly east of south.

By joining the point where the base of the formation is exposed on the Louisiana & Arkansas Railway with Pineville and Catahoula Shoals the maximum dip for eastern Louisiana is found to be about 38 feet to the mile and the direction S. 24° E.

WESTERN LOUISIANA.

In western Louisiana the Catahoula sandstone has a steeper dip, but the determination is less accurate than in eastern Louisiana. The approximate position of the base of the formation at Leesville, as determined from an incomplete set of samples from a well, is 524 feet below sea level, and the base of the formation near Hornbeck is 320 feet above sea level. The distance between these places is about 16 miles, and the average dip is therefore about 53 feet to the mile in a direction east of south.

SOUTHERN MISSISSIPPI.

The base of the formation on Pearl River, in southern Mississippi, is approximately 220 feet above sea level, and in a well at Monticello it was reached at a depth of slightly less than 800 feet, or about 590 feet below sea level. The distance from the outcrop of the basal beds on Pearl River to Monticello is about 40 miles and the difference in elevation of the

[1] Harris, G. D., Tertiary geology of the Mississippi embayment: Geology of Louisiana, pt. 6, p. 29, 1902.

[2] Chief of Engineers, U. S. Army, Rept. for 1902, pt. 2, p. 1560.

base of the formation is 810 feet. The dip between these two places is therefore about 20 feet to the mile in a direction slightly east of south. Another computation based on the elevation of the base of the formation on the New Orleans Great Northern Railroad near Byram gave a result differing more than 1 foot to the mile. South of Byram the sandstone beds that occur near the base of the formation on this railroad have an elevation of 265 feet above sea level. The base at Monticello being 590 feet below sea level, the descent between the two places amounts to 855 feet. The distance between the two points is 40 miles, and this gives an average dip of $21\frac{3}{8}$ feet to the mile, in substantially the same direction as between Pearl River and Monticello.

At Sanford the top of the Vicksburg was encountered in a well at a depth of 591 feet, or 375 feet below sea level. By joining Sanford with Monticello and with the point where the base of the formation is exposed on Pearl River, the general dip in south-central Mississippi was computed at 23 feet to the mile in a direction about 18° west of south. These figures are believed to be substantially correct, though a small amount of error in this and similar computations is to be expected because of errors in locating the exact points where the base of the formation has been observed and also because the maps used in making measurements for the computations were on a small scale and more or less inaccurate.

THICKNESS.

The Catahoula sandstone is comparatively thin in a large portion of the area where it is exposed, but in central Louisiana it may reach a maximum thickness of 800 feet. The best data for determining the thickness of the formation are afforded by samples of drillings obtained from wells. Of somewhat less value are records of materials penetrated in well

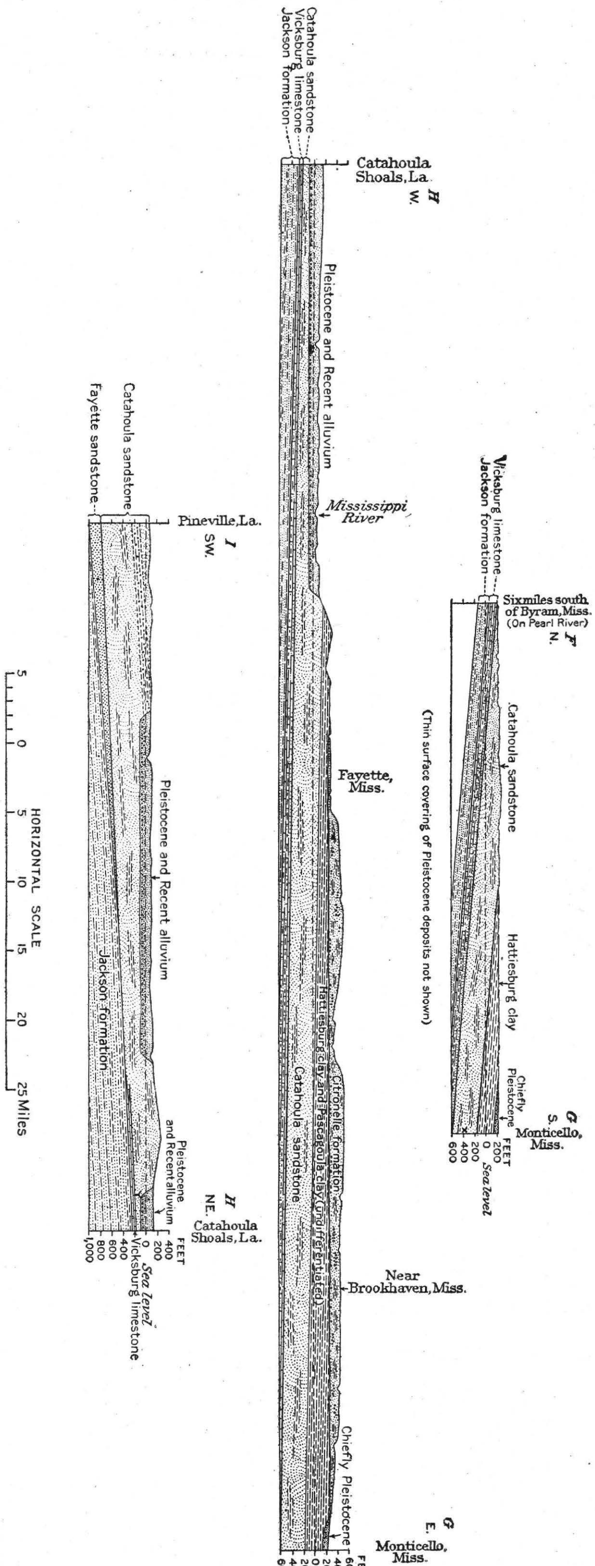


FIGURE 20.—Sections of the Catahoula sandstone. For lines of sections see figure 15 (p. II).

borings, though where such records are carefully kept, with full descriptions of strata, the approximate limits of the formation can be recognized because it is more sandy than either the underlying or overlying beds.

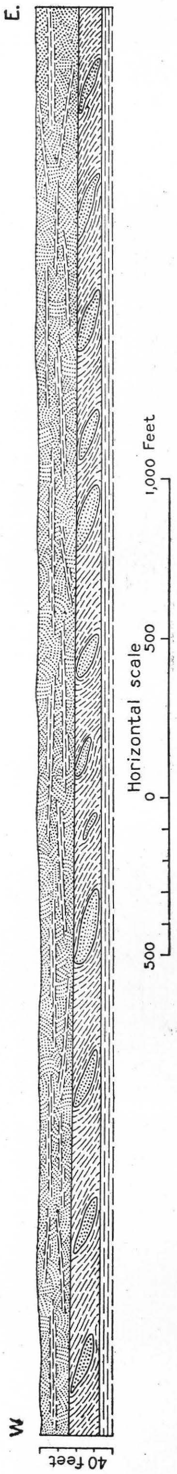


FIGURE 21.—Diagram of an exposure of the Catahoula sandstone between Chopin and Galbraith, La.

In a well at Monticello, Miss., a clay bed 300 feet in thickness overlies the Catahoula sandstone. The base of this clay lies at a depth of 380 feet, and marine shells, from their description undoubtedly Vicksburg, were encountered at about 800 feet. This gives a thickness of 420 feet. Another way of determining the thickness in this portion of Mississippi is by multiplying the rate of dip to the mile (20 feet) by the width of the outcrop in miles. This computation gives a thickness of nearly 400 feet for the formation. Farther west, near Natchez, a well penetrated 550 feet of sands, sandstones, and clays belonging to this formation.

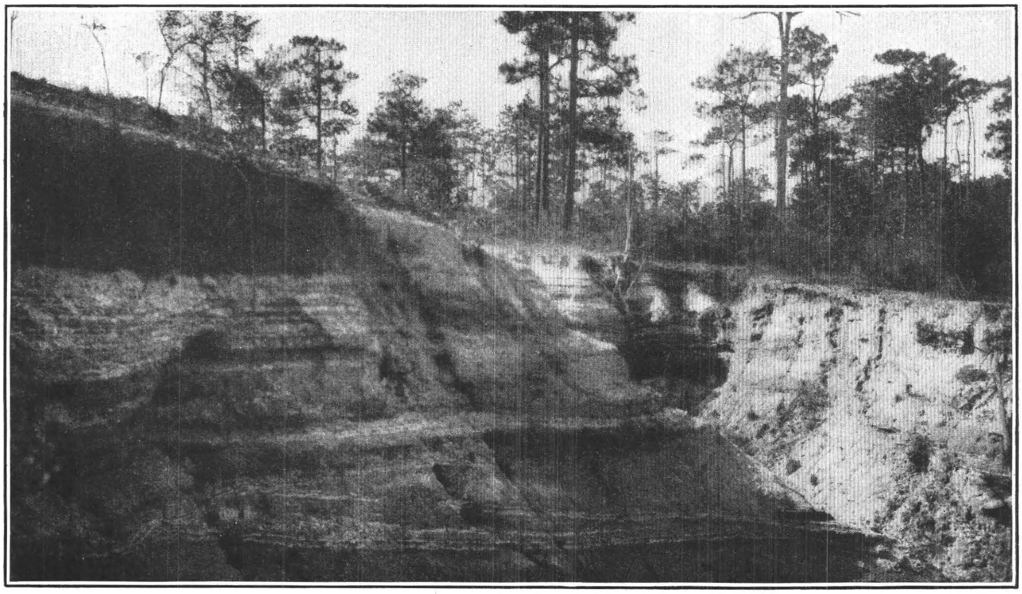
From Pearl River eastward the Catahoula sandstone thins gradually, and near Healing Springs, Ala., it is probably less than 200 feet thick, though not enough information is available to determine the full thickness in eastern Mississippi and western Alabama. West of Pearl River the Catahoula sandstone thickens, but it is not known whether the increase is at a uniform rate. In eastern Louisiana no satisfactory section giving the entire thickness of the formation could be obtained. On the assumption that the dip is uniform in this area the thickness may be computed approximately by multiplying the width of outcrop in Catahoula Parish, which is 16 miles, by the average dip, 33 feet to the mile. This gives a thickness of 528 feet, which is slightly less than the maximum thickness shown by some wells in the central part of the State.

The samples from the Pineville well, in central Louisiana, show a thickness of 800 feet of the Catahoula sandstone, though this may include a portion of the overlying Hattiesburg clay. The character of the samples indicates that the Jackson formation occupies at least 100 feet of this well section. The Catahoula is nearly twice as thick at this locality as at Monticello. The increase toward the west is due to the fact that in that area the Catahoula represents the time interval of the Vicksburg limestone. In other words, while the limestones and marls composing the Vicksburg were being formed in eastern Louisiana and east of Mississippi River, a great thickness of sandy detritus was being deposited in central Louisiana.

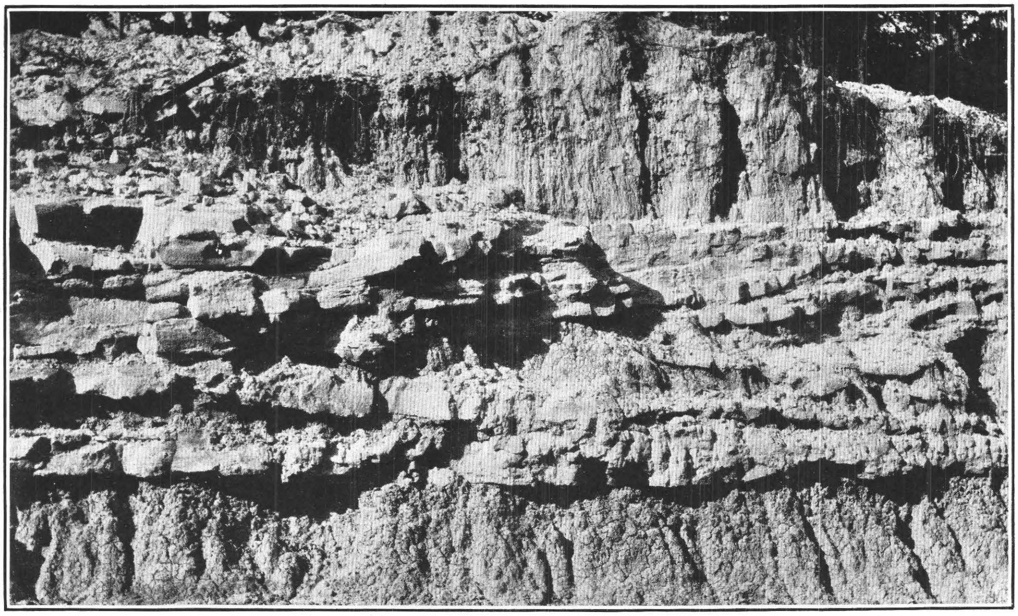
In western Louisiana and eastern Texas there is little direct information as to the thickness of the Catahoula sandstone, but it is inferred that the formation thins in that direction because the samples examined from the well at Leesville, together with the log of the well, showed a thickness of only about 600 feet of the sandstone.

ORIGIN.

All geologists who have studied the Catahoula sandstone have agreed that it is nonmarine, their conclusions being based largely on the absence of remains of marine organisms and the presence of fossils of nonmarine origin, such as leaves and a few scattered fresh-water shells of unios and anodonts, together with the character of the materials constituting the formation. The presence of a large amount of lignitized wood and numerous thin layers of lignite gives evidence of deposition in swamps, and the character of the materials themselves indicates deposition near the strand line, where there are many variations in the kinds and arrangement of sediment. (See Pl. LIII.) The formation is on the whole sandy because of the influx of swift currents bearing coarse detritus, though the presence of layers and lenses of more or less sandy clay shows that the currents were at times gentle, and, on the other hand, the occurrence of pebbles of mod-

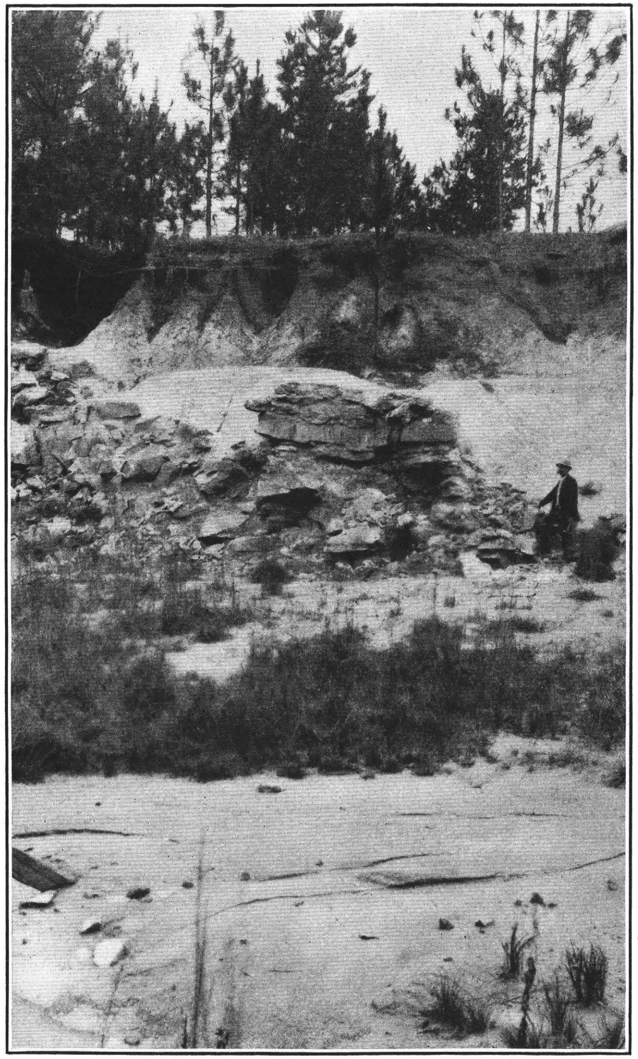


A. CROSS-BEDDED SANDS AND CLAYS, 3 MILES SOUTHWEST OF WAYNESBORO, MISS.

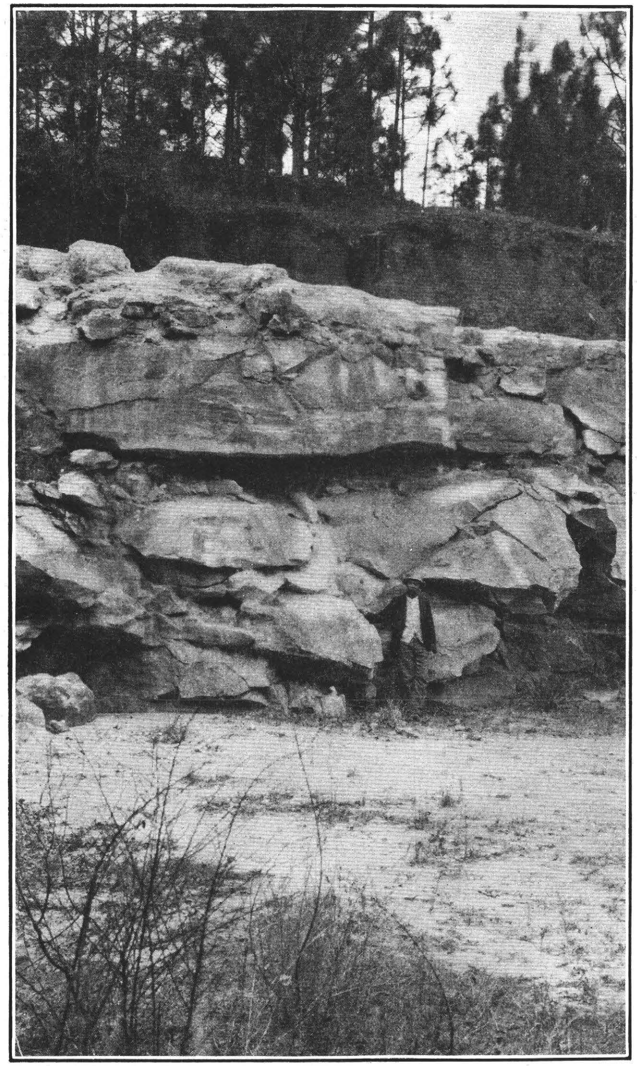


B. SANDSTONES AND CLAYS, MISSISSIPPI SPRINGS, EAST OF RAYMOND, MISS.
Photograph by O. B. Hopkins.

LITHOLOGIC CHARACTER OF THE CATAHOULA SANDSTONE.



A. LIGHT-COLORED SANDSTONE AND DARK-COLORED QUARTZITE.



B. MASSIVE BEDS OF QUARTZITE.

LITHOLOGIC CHARACTER OF THE FAYETTE SANDSTONE.

erate size in the sands indicates that at times the streams had a high velocity.

A peculiar type of bedding may be seen in one of the exposures in central Louisiana, between Chopin and Galbraith. (See fig. 21.) The upper bed consists of typical Catahoula sandstone with thin lenses of clay; the lower bed is of clay, and between these beds is a third, consisting of lenses of sand inclined steeply and separated by clay. The structure here resembles that of a delta, with the beds relatively thin and the sand lenses inclined toward the southeast away from the old shore line.

It has generally been assumed that the conditions of Catahoula time were estuarine and that the currents of water were sluggish. The theory of estuarine origin for a portion of the formation is apparently confirmed by the character of the deposits and by the fact that they contain more or less gypsum, which was doubtless deposited by evaporating saline waters. The hypothesis sometimes advanced that the currents of water entering the estuary were sluggish does not appear tenable, for the formation is made up largely of coarse sediments, though marked fluctuations are indicated by the numerous alternations of clays, sands, and fine conglomerates.

Goldman [1] has presented petrographic evidence that the Catahoula sandstone of Texas contains a large percentage of well-rounded wind-blown sand. This may be a confirmation of the view that the deposits were laid down near the strand line, where they were moved about by the waves and in many places blown about on sand plains or perhaps in a few places built into dunes and ridges. The presence of leaves and fragments of wood of species such as grow in moist tropical climates, however, indicates that there was an abundance of moisture near the coast and probably a luxuriant tropical vegetation. Such conditions do not harmonize with the assumption of extensive wind erosion along the strand line, and it is therefore reasonable to suppose that the rounding of the sand grains was mostly accomplished before the sands were brought to their present position, though a small amount of wear may have resulted from wind erosion along the coast.

[1] Goldman, M. I., Petrographic evidence on the origin of the Catahoula sandstone of Texas: Am. Jour. Sci., 4th ser., vol. 39, pp. 261-287, March, 1915.

The presence of a large amount of unweathered feldspar suggests that the sands had not been subjected to long-continued weathering in a moist climate.

The great thickness of the sandstones in the territory adjacent to Red River indicates changes toward the headwaters of that stream, probably affecting all the streams in the region of the Great Plains. The most probable explanation is that the streams flowing across the Great Plains were rejuvenated by a regional uplift. This would account for the great influx of sand into the Tertiary sea, and it might be accompanied by an arid climate for some distance east of the Continental Divide, provided the uplift raised the mountains high enough to cut off a portion of the moisture. This would furnish favorable conditions for wind action and for the accumulation of the unweathered feldspar which is so abundant in the sand. Conclusions of this character must for the present be regarded as tentative, because the petrographic studies have been confined to samples of sandstone from Texas, and these have not been compared with samples from other localities. The conditions of deposition may have been somewhat different farther east, where the sediments were derived either wholly or in part from more humid regions, and the conditions may have changed while the sands were being laid down.

STRATIGRAPHY.

DIFFICULTIES OF STRATIGRAPHIC WORK.

Most of the exposures of the Catahoula sandstone are of slight value for stratigraphic study because they have been reduced by the processes of weathering to yellow or orange-colored sands and clays that resemble those found nearly everywhere on the Coastal Plain. This similarity in lithologic character is explained by the fact that the materials in most of the formations were derived from the same sources and on weathering assume the same general appearance. Many of the formations showing this characteristic were deposited under conditions sufficiently diverse to make them distinct in lithologic appearance, so that they can be differentiated where they are unaltered.

Stratigraphic work is further confused by the relations of the different beds resulting from the conditions of sedimentation. Thus the contact between the sands and the clays is nearly everywhere irregular, giving the appearance of unconformity, but the irregularities are due chiefly to the fact that the materials were deposited by shifting currents of varying velocity. During periods of uninterrupted deposition by slow currents the sediments were mostly clay mixed with more or less organic matter derived in part from floating vegetation and in part from plants that grew in swamps and marshes. In some places chemical deposits were made in lagoons, but the major part of the material is detrital. With the incursion of flood waters conditions were altered, and the relatively even surface of the clays laid down by the quiet waters was eroded. The stronger currents left deposits of coarser material, such as sand and more rarely pebbles, and these coarse sediments were subsequently, when the floods subsided, buried beneath clay. Frequent changes in the conditions of deposition produced many alterations in the character of the sediments, with irregular lines of contact and marked discordance of stratification between the deposits of different kinds. In many places fragments of clay loosened from earlier deposits were more or less rounded and then incorporated with coarser materials, forming clay conglomerates or breccias. The final result of the varying conditions of sedimentation was a formation containing innumerable instances of lack of conformability between successive beds. The evidences of unconformity may be seen in many sections and at almost any stratigraphic horizon from the top to the bottom of the formation, being distributed throughout the area of outcrop. As the formation is known from well records and samples of material obtained in drilling to be several hundred feet thick, it is clear that the unconformities are of local character and have no broad stratigraphic significance. Failure to understand the meaning of the irregular contacts of materials in the Catahoula formation, together with an attempt to correlate outcrops solely on the basis of general lithologic character, has led to the inclusion of weathered portions of the Catahoula in what has been called the Lafayette formation. It should not be inferred, however, that the so-called Lafayette formation does not contain other beds besides those mentioned.

STRATIGRAPHIC RELATIONS.

UNDERLYING FORMATIONS.

VICKSBURG LIMESTONE.

Hilgard,[1] who was the first geologist to map the extensive "Grand Gulf" deposits, considered the beds to be essentially horizontal, though he reported high local dips in different directions. From the supposed discordance in dip between the Vicksburg limestone and the "Grand Gulf" sandstone he concluded that the two formations are not conformable.

The dip of the Catahoula sandstone is discussed in detail on pages 217–219, where it is shown that in addition to a general seaward slope the formation has well-defined southerly dips converging toward Mississippi River, thus showing an inclination toward the center of the Mississippi embayment, which must have been at that time the site of rapid sedimentation.

The views of Smith and Aldrich [2] have been fully set forth in outlining their controversy with Dall. The differences between these authors are due to dissimilar methods of work. In correlating exposures Smith and Aldrich relied largely on lithologic characteristics, and the similarity of materials led them to believe that a single formation extended across the edges of formations ranging in age from Eocene to Miocene or Pliocene. Dall, relying on the field observations of Johnson and others, together with the knowledge obtained from a study of the faunas of the Gulf Coastal Plain, reached conclusions similar to those held by Johnson, who, as early as 1893, had succeeded in differentiating four "phases" in what had formerly been called "Grand Gulf."

In southern Mississippi the Catahoula sandstone rests conformably on the Vicksburg limestone; in Alabama it rests conformably on the St. Stephens limestone, the upper part of which is of Vicksburg age. Sections that show a constant relation between the Vicksburg and the Catahoula sandstone have been noted at many places. A typical example is furnished by the

[1] Hilgard, E. W., The later Tertiary of the Gulf of Mexico: Am. Jour. Sci., 3d ser., vol. 22, p. 58, 1881.

[2] Smith, E. A., and Aldrich, T. H., The Grand Gulf formation: Science, new ser., vol. 16, pp. 835–837, Nov. 21, 1902.

exposures at Vicksburg, Miss., where the following section was measured:

Section at Vicksburg, Miss.

	Feet.
Catahoula sandstone (nonmarine):	
Coarse friable gray sandstone with local lenses of quartzite and some interbedded gray clay.	20
Blue clay, weathering drab, interbedded and interlaminated with gray sand and friable sandstone (exposed at intervals)	35
Vicksburg limestone (marine):	
Chocolate-colored calcareous clay	18
Fine gray to drab sand	6
Fine sandy marl, very fossiliferous	40

East of Vicksburg many generalized sections were obtained, but details are not available at many places because of poor exposures. The marl bed that forms the basal member of the foregoing section is exposed on Pearl River south of Byram, where it is overlain by dark-colored calcareous clays and these in turn are overlain by interbedded clays and sandstones of the Catahoula formation. Similar conditions were observed on Leaf River near Blakney, Miss., where the same marl bed is overlain by about 40 feet of clay, massive and calcareous near the base and interbedded with gray sandstones in the upper portion of the exposures. On Chickasawhay River near the wagon bridge, 3 miles southwest of Waynesboro, the marl bed is overlain by calcareous clays and marls, with a bed of oyster shells. The contact is not well shown, but small exposures near Triggs Ferry, about 1½ miles west of Waynesboro, show that the drab clays and sands of the Catahoula sandstone rest on an even surface of the clays of the Vicksburg limestone. Farther east, in Alabama, the relation of the Catahoula sandstone to the Vicksburg deposits is the same as in Mississippi, a bed of calcareous clays lying between the upper fossiliferous beds of the Vicksburg and the interbedded sands and clays of the Catahoula. These relations are exhibited south of Manistee, near Manistee Junction, and at several other places.

West of Mississippi River, in Louisiana, the Catahoula sandstone rests unconformably on the Vicksburg limestone, according to Harris and Veatch,[1] who cite Hilgard as authority for the statement. In a subsequent report[2] Harris gives in more detail his views as to the relations of the Catahoula to subjacent formations and makes a definite statement of the direction and the amount of dip. It is clear that he does not agree with Hilgard's statement that the formation is essentially horizontal.

The following section shows the relation between the Catahoula sandstone and the Vicksburg limestone in Catahoula Parish, the type locality of the Catahoula sandstone.

Section in wagon road near Rosefield, Catahoula Parish, La., in sec. 28, T. 11 N., R. 5 E.

	Feet.
Yellow sand	15
Yellow marl containing *Orbitoides mantelli* and *Pecten poulsoni* in calcareous concretions	2
Yellow sand	10
Yellow clay	18
Yellow sand and friable gray micaceous sand rock which weathers to yellow incoherent sand	25
Red clay	6

No. 1 of this section is a typical weathering product of the Catahoula sandstone, and from the presence of Vicksburg fossils in No. 2 it, together with the underlying material, would be placed in the Vicksburg. However, Nos. 3 to 6 are lithologically similar to the Catahoula sandstone, and it is apparent that the two formations are interbedded at this locality. Farther west the Vicksburg is entirely replaced by the Catahoula sandstone. In addition to being interbedded with the Vicksburg the Catahoula sandstone contains beds of calcareous clay at many localities. The presence of such a clay bed is shown in the following section:

Section of Catahoula sandstone at Harrisonburg, La.

	Feet.
Gray sand	2
Yellow and orange-colored sand containing a few scattered pebbles arranged in thin layers	8
Yellow sand and gravel	3
Yellow sand grading downward into gray sandstone with a thin laminæ of clay	2
Gravel	2
Interbedded gray clay and sandstone, some layers showing cross-bedding	8
Dark-gray clay with greenish tinge where fresh	10
Interbedded gray sandstone and clay	2
Dark-gray clay	4
Yellow sand	4
Gray sandstone	5
Massive green clay	5
Massive green sandstone containing pebbles; surface weathered to light yellow	4
Green clay	2
Massive gray sandstone	4
Massive green clay	15

[1] Harris, G. D., and Veatch, A. C., Geology of Louisiana, pt. 5, p. 95, 1899.

[2] Harris, G. D., Geology of the Mississippi embayment: Geology of Louisiana, pt. 6, p. 28, 1902.

The lowest bed of clay is distinctly calcareous where fresh, the surface of the layers and cracks in the beds being covered with numerous rosettes of calcium carbonate. The sandstone overlying it is also calcareous, though the percentage of calcium carbonate is smaller than in the clay.

FAYETTE SANDSTONE.

Veatch[1] included in his Catahoula formation in central and western Louisiana beds that pass laterally into typical clays and thin-bedded sands and sandstone of the Jackson formation. This portion of the formation is in the present report correlated with the Fayette sandstone of Texas. Harris[2] described the relations of these sandstones to the Jackson formation in western Louisiana as unconformable and regarded the poorly preserved remnants of marine fossils in the sandstone as survivors from the Jackson epoch. Recent study in western Louisiana shows that the irregular contact described by Harris is like those occurring at most places where coarse sandstones have been deposited on clays, the irregularities in the surface of the clay being such as are commonly produced by currents bearing coarse detritus.

The Fayette sandstone of western Louisiana has a thickness of 100 to 200 feet. It is more quartzitic than the Catahoula sandstone (see Pl. LIV) and is locally interbedded with clays that are darker and more calcareous than the clays of the Catahoula. The two formations differ in origin. Both contain silicified wood and imprints of fossil leaves, and in addition the Fayette sandstone contains many imprints of marine fossils. The Catahoula sandstone is apparently nonmarine, being devoid of traces of marine fossils except where it merges with the Vicksburg limestone.

The facts outlined above lead to the conclusion that the Catahoula sandstone of Mississippi and Alabama is conformable with the underlying Vicksburg limestone (represented in Alabama in the upper part of the St. Stephens limestone), because if the Vicksburg had been eroded before the deposition of the Catahoula the uppermost layers of the Vicksburg would be missing in some of the sections. In eastern Louisiana the Catahoula sandstone dovetails with the Vicksburg, and in western Louisiana it is conformable with the Fayette sandstone. These facts indicate that the deposition of the Catahoula followed that of the underlying marine formations without a stratigraphic break and that it began in Texas and western Louisiana and was gradually extended eastward to Mississippi. In Mississippi and Alabama its deposition began at the end of the Vicksburg epoch and extended across the entire area where the Catahoula is exposed. However, brackish-water conditions persisted in places for a short time after the deposition of the upper marl bed of the Vicksburg, as shown by the oyster bed near Waynesboro, Miss.

OVERLYING FORMATIONS.

HATTIESBURG CLAY.

The Catahoula sandstone is overlain conformably by the Hattiesburg clay, of Oligocene age. This formation ranges in thickness from 300 to 350 feet in Alabama and Louisiana and to a maximum of 450 feet in central and western Mississippi. It consists of massive blue and gray clays with subordinate amounts of sands and sandstones. Locally the clay beds are consolidated into hard ledges, though this rock is not restricted to any one formation, being found in all the Oligocene and Miocene deposits of the Gulf embayment. In some places the clays contain fragments of lignitized wood and imprints of fossil plants. A deposit of this character a few miles east of Hattiesburg, Miss., near McCallum, furnished some identifiable remains of fossil plants. At Hattiesburg, the type locality, the clays are exposed in the banks of Bowie Creek and Leaf River and in the lower portions of the hills that border these streams.

The name Hattiesburg was first used by Johnson, whose definition is given on page 211. The type locality of the Hattiesburg clay is the same as the type locality of Johnson's Hattiesburg phase or formation,[3] but a brief statement of the significance of the new term Hattiesburg clay is given here because it is used to include the portion of Johnson's Fort Adams or Ellisville phase that extends from

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 42-43, 1906.

[2] Harris, G. D., Geology of the Mississippi embayment: Geology of Louisiana, pt. 6, p. 28, 1902.

[3] Johnson, L. C., The Miocene group of Alabama: Science, vol. 21, pp. 90-91, 1893.

the mouth of Okatoma Creek eastward past the falls on Leaf River near Eastabutchie to Chickasawhay River between Winchester and Waynesboro.

The Hattiesburg clay is readily recognizable from central Alabama, where it merges into the more sandy fossiliferous beds of the Alum Bluff formation, westward to eastern Texas. In western Louisiana and eastern Texas it is the lower portion of what Veatch[1] mapped as Fleming clay. The relation of the overlying Miocene to the Hattiesburg clay is unconformable, and this permits the separation of what has been called the Fleming clay in Louisiana and along the eastern border of Texas into two parts. The lower part, which, from its stratigraphic relations is included in the Hattiesburg clay, is more sandy and much less calcareous than the overlying Miocene clays.

PASCAGOULA CLAY.

A series of blue, green, and gray clays, locally calcareous, with interbedded sands and more rarely sandstones, lying unconformably above the Hattiesburg clay, has been called the Pascagoula clay. This formation is locally fossiliferous and has furnished remains of marine or brackish-water invertebrates at Shell Bluff and Givhens Landing, on Chickasawhay River, Miss., and in numerous wells in the southern part of the State. A somewhat different fauna has been obtained from the formation at Pine Prairie and southwest of Alexandria, La., and at Burkeville, Tex. The formation ranges in thickness from about 250 feet in Alabama to 450 feet near Mississippi River in Louisiana and along the Gulf coast in Mississippi. In western Louisiana and eastern Texas the thickness has not been accurately determined but it is thought to be about 250 or 300 feet. Local variations in thickness are to be expected, because the Pascagoula clay is overlain unconformably by sands and clays of Pliocene age and rests unconformably on the Hattiesburg clay.

The Pascagoula clay differs from Johnson's Pascagoula phase or formation[2] by including the portion of his Fort Adams or Ellisville phase extending from Tunica, La., to Columbia, Miss. The type locality is, however, the same, and the difference is largely due to a more thorough understanding of the distribution of the formation. West of Mississippi River the Pascagoula clay extends across southern Louisiana and eastern Texas and includes the upper portion of what Veatch[3] called the Fleming clay.

CITRONELLE FORMATION.

The Pascagoula and Hattiesburg clays and the Catahoula sandstone are in places overlain by sands, gravels, and clays that from their fossil flora (identified by E. W. Berry) are known to be of Pliocene age. These deposits, which heretofore have been called Lafayette formation, Orange sand, etc., have recently been named the Citronelle formation,[4] from the town of Citronelle, in northern Mobile County, Ala. The formation consists of yellow and red clays and sands, with lenses and layers of gravel in which the pebbles range from a fraction of an inch to several inches in diameter. Subangular chert is the most abundant constituent of the gravel, though it contains everywhere a varying percentage of rounded quartz pebbles.

The Citronelle formation, which is largely nonmarine, varies greatly in thickness, ranging from a minimum of 30 feet where it overlies the Catahoula to over 150 feet where it rests on the outcropping edge of the Pascagoula and to a maximum of 400 feet nearer the coast, where it underlies the Pleistocene deposits. The relation of the Citronelle to both the overlying and underlying formations is unconformable, a fact which accounts for some of the variations in thickness. Other variations are explained by the character of the surface of the formation, which is composed of a series of plains diminishing in elevation toward the coast and toward the axes of the principal valleys that cross the formation.

CORRELATIONS.

The Oligocene series of western Florida includes in descending order the Alum Bluff formation, the Chattahoochee formation, and the Marianna limestone. The Marianna is of Vicksburg age. The marine Chattahoochee formation passes westward in Alabama by gradation through fossiliferous marls into

[1] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 43–44, 1906.

[2] Johnson, L. C., The Miocene group of Alabama: Science, vol. 21, pp. 90–91, 1893.

[3] Veatch, A. C., Geology and underground water resources of northern Louisiana and southern Arkansas: U. S. Geol. Survey Prof. Paper 46, pp. 43–44, 1906.

[4] Matson, G. C., U. S. Geol. Survey Prof. Paper 98, pp. 167–192, 1916 (Prof. Paper 98–L).

the nonmarine sandstones and clays of the Catahoula sandstone. The equivalence of the Chattahoochee formation and that portion of the Catahoula sandstone lying east of Mississippi River is further shown by the relations of these formations to those above and below them. The Chattahoochee formation of Florida conformably overlies the Marianna limestone, the Florida representative of the Vicksburg limestone,[1] and the Catahoula sandstone of Alabama and Mississippi rests conformably on the Vicksburg limestone.

The Chattahoochee formation is overlain conformably by the Alum Bluff formation, and the Catahoula sandstone is overlain conformably by the Hattiesburg clay. The equivalence of the Alum Bluff formation and the Hattiesburg clay has been established by tracing their physical continuity and by fossil plants identified by E. W. Berry.[2]

The correlation of the Catahoula sandstone west of Mississippi River has already been explained, but it may be summarized by stating that in this area the Catahoula includes sandstones and clays equivalent not only to the Chattahoochee formation, but also to the Vicksburg limestone, rests conformably on the Jackson formation and the Fayette sandstone, and is conformably overlain by the Hattiesburg clay.

The table opposite page IV shows the correlation of the Tertiary formations in the Gulf States.

CONCLUSIONS.

The Catahoula sandstone consists of alternating sandstones and sands, with lenticular beds of clay, the arenaceous sediments predominating. Conglomerates are rare, though small quartz and chert pebbles occur in some of the layers of sand, and pebbles of clay are found at many localities and at different stratigraphic horizons. The formation is nonmarine but was deposited near the strand line, where small bodies of brackish water were isolated and, on evaporation, formed precipitates of salt and gypsum. The streams that transported the materials now constituting the formation had varying velocities and made deposits ranging in texture from clay to fine-grained conglomerates. The floods that transported the coarse materials eroded the surfaces of existing clay deposits, thus forming irregular contacts and incorporating more or less rounded fragments of the clay in the sands. The fossils, which are rare, are mostly leaves, but molluscan remains occur at a few places. One of these localities is at Chalk Hills, near Rosefield, La., where shells of unios (?) are found in a sandstone, and another is in a cut on the Texas & Pacific Railway, 1 mile east of Lena, where fragments of oyster shells occur in a lens of limestone.

Weathering of the formation produces red, yellow, and mottled sands and clays that have commonly been classed as Orange sand and placed in a separate formation called the Lafayette. This classification has resulted from the existence of numerous local unconformities and the general resemblance of these weathered sands and clays to similar materials occurring in other portions of the Coastal Plain.

The sections in the vicinity of Harrisonburg and Rosefield, La., show that the sandstones and clays of the Catahoula are interbedded with the lower Oligocene limestones and marls (Vicksburg limestone). Farther west in Louisiana they replace all the marine lower Oligocene beds. Similar sandstones (Fayette sandstone) containing marine fossils are the equivalents of some of the calcareous and fossiliferous beds of the Jackson formation in western Louisiana and represent nearly all of the Jackson in central Texas. These facts account in part for the increased thickness of the formation in central Louisiana, amounting to several hundred feet, and explain the form of the outcrop of the formation in the Mississippi embayment and the Red River valley.

The belief that the Catahoula sandstone is essentially horizontal, which, if correct, would be a fatal objection to the merging of the Catahoula and older formations, is shown to be an error. Information that was not available at the time of the early examinations shows clearly that the dips of the Catahoula range from slightly more than 21 feet to the mile in east-central Mississippi to about 38 feet in central Louisiana and are probably even greater than 50 feet near the Louisiana-Texas boundary.

[1] Cooke, C. W., unpublished notes.

[2] Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, p. 744, 1912.