CHALK
OF
SOUTHWESTERN ARKANSAS

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DEPARTMENT OF THE INTERIOR--U. S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

CHALK OF SOUTHWESTERN ARKANSAS

WITH

NOTES ON ITS ADAPTABILITY TO THE MANUFACTURE
OF HYDRAULIC CEMENTS

BY

JOSEPH A. TAFF

EXTRACT FROM THE TWENTY-SECOND ANNUAL REPORT OF THE SURVEY, 1900-1901
PART III—COAL, OIL, CEMENT

WASHINGTON
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By Joseph A. Taff.

INTRODUCTION.

The chalk and chalk-marl deposits of southwestern Arkansas were first described by Mr. R. T. Hill in Volume II of the Annual Report of the Geological Survey of Arkansas for 1888. In addition to giving a detailed description of the geology, Mr. Hill mapped the Cretaceous formations in which the chalks occur. Special attention was directed to their nature as true marine-chalk sediments.

In a chapter of the volume above cited Dr. J. C. Branner, then State geologist of Arkansas, briefly described the manufacture of Portland cement, and showed that the chalk of Arkansas compared favorably with the best English chalk as cement material. After further investigation of this region Dr. Branner published a paper on Cement Materials of Southwestern Arkansas, in the Transactions of the American Institute of Mining Engineers for 1897, pages 42–63, inclusive. The chalk and chalk-marls were found to be more extensive than had been before known. The deposits were more precisely located and mapped, and their thickness and structure were shown by sections. The differences in character of the separate chalk deposits and the lithologic variation of each, as well as their quality as cement materials, were brought out.

As a result of the work of the Arkansas survey public attention was called to these chalk deposits, and an extensive Portland cement plant was established at Whitecliffs, one of the type localities where the chalk is exposed in this region. At other localities, where lines of transportation cross or approach the chalk deposits, an active interest has been taken in them by property owners and investors of capital, and a demand has been created for fuller information. In response to this demand the following pages have been written.

GENERAL GEOGRAPHY.

The chalk region of southwestern Arkansas lies in a broad, low plain slightly inclined toward the southeast. The north edge of this plain in southwestern Arkansas is the southern limit of the Ouachita Mountain region. The border between the mountains and plain extends from the vicinity of Malvern, on the St. Louis, Iron Mountain and Southern Railway, westward through Hot Spring County, and the northern portions of Clark, Pike, and Howard counties, and across Polk County into Indian Territory. It is about 45 miles north of Rocky Comfort and nearly 20 miles northwest of Arkadelphia, and is therefore beyond the limit of the geologic map accompanying this report. The mountain ridges making the Ouachita Range near the border are elevated generally 1,000 to 2,300 feet above sea, while the higher levels in the plain to the south are not far from 700 feet above sea. The valleys in the mountains are deep cut, often more than 1,000 feet, while in the plain few have reached a depth of 200 feet. This plain, except where the land has been cleared for cultivation, is densely forested. For this reason, and since the plain is intricately dissected by small stream channels, the broad features of the plain are not readily recognized by the traveler. From occasional eminences near the northern border of the plain, and from the southern hills of the Ouachita Range, the broad and apparently level plain may be seen to the limit of view toward the south.

Ouachita River, with its large tributary, Caddo Creek, Little Missouri, West Saline, and Little rivers flow from the mountains into the plain. Little and West Saline rivers are tributaries to Red River, while the others flow into the Mississippi.

GEOLOGY.

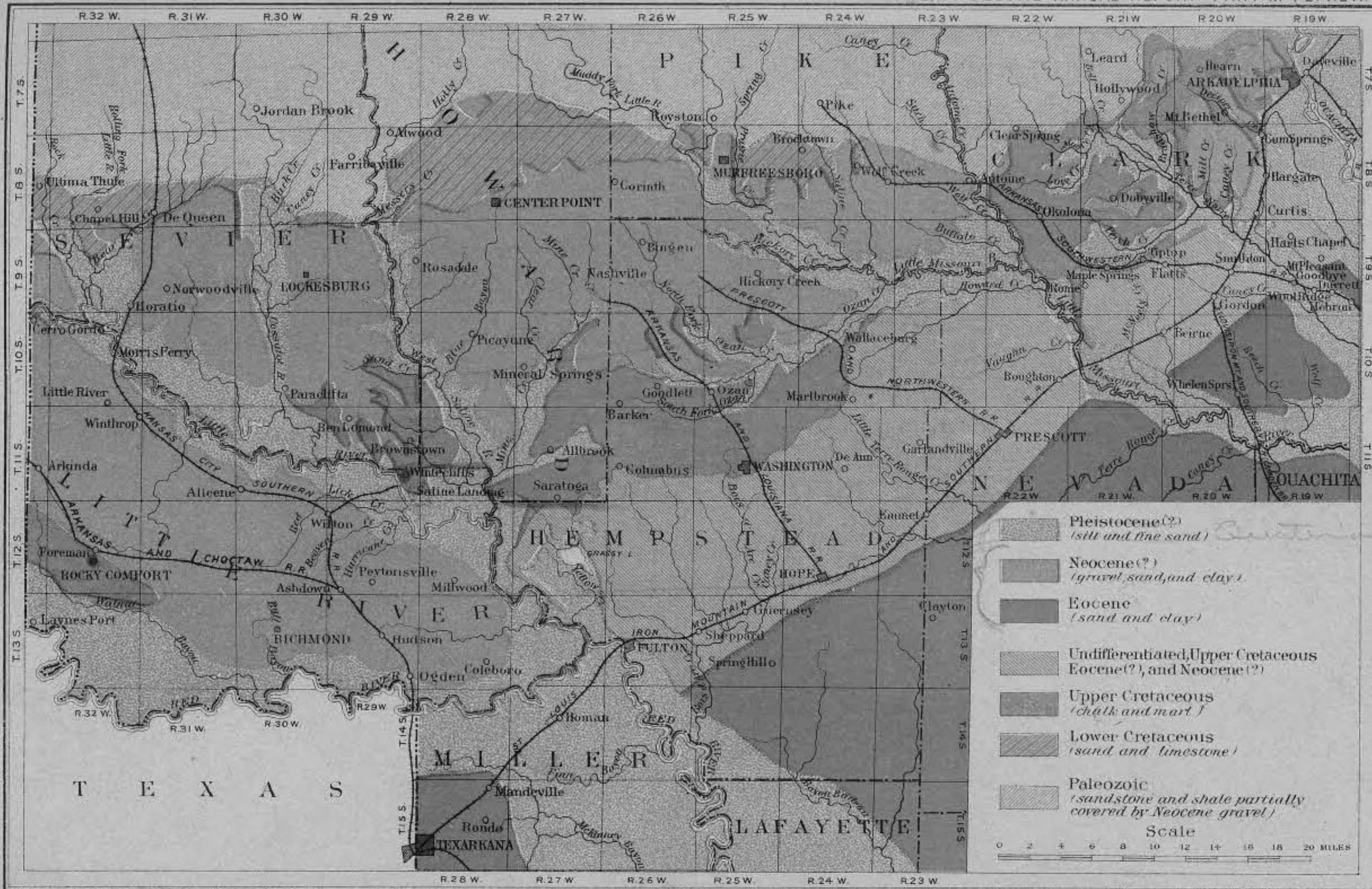
GENERAL GEOLOGY OF THE REGION.

The geologic map of the chalk region of southwestern Arkansas (Pl. XLVII) is based upon the maps of the geological survey of Arkansas. It combines the work of Mr. R. T. Hill, published in the volume above cited, and of Prof. G. D. Harris, in the Annual Report of the Geological Survey of Arkansas for 1892, Volume II, modified in the area of Upper Cretaceous rock according to observations by the writer.

The base map, furnished by the State land office and founded on the general land surveys, was not adequate for accurate geologic mapping. However, it was the only one available.

The widespread surficial deposits of Neocene and Pleistocene gravel, sand, and clay so conceal the Cretaceous deposits in the densely forested country of low relief that detailed geologic mapping can be done only at the expense of great labor and much time.

The rocks in the area represented on the accompanying map as



FROM PUBLISHED MAPS OF THE ARKANSAS GEOLOGICAL SURVEY WITH MODIFICATIONS

GEOLOGICAL MAP OF THE CHALK REGION OF SOUTHWESTERN ARKANSAS

BY JOSEPH A. TAFF

undifferentiated Upper Cretaceous, Eocene, and Neocene were placed in the Eocene by Mr. Hill, though he explained that they were generally concealed by later gravel and sand. Mr. Harris determined, by fossil contents, that Mr. Hill's lowest Eocene formation, the Arkadelphia clay, as exposed at Arkadelphia, was Upper Cretaceous. From this evidence, without being able to map the Cretaceous-Tertiary parting, he considered the base of the Eocene to be approximately as shown on the map, south of the St. Louis and Iron Mountain Southern Railroad. It is therefore clear that this area of undifferentiated rocks contains Upper Cretaceous, and probably also some strata of Eocene age, concealed for the most part by Neocene gravels and sand.

Rocks in the area represented as Paleozoic have been classified provisionally by the Arkansas survey as Lower Carboniferous. They are sandstone and shale interstratified, and have not yielded fossil remains sufficient to determine their age with precision. Besides, they have been excessively folded and worn down and have been concealed, in the southern part especially, by gravel and débris, so that the stratigraphic succession of the beds can be interpreted only with much difficulty and uncertainty, if at all.

SKETCH OF THE GEOLOGIC HISTORY OF THE REGION, BEGINNING WITH CRETACEOUS TIME.

All of the Cretaceous rocks in this region, so far as known, were formed in the sea of materials brought in from the land, and of the shells and skeletons of sea animals.

The Cretaceous sea was open toward the south and east and extended into the region of the Gulf of Mexico. Its shores ran generally east and west, parallel with the Ouachita Mountain region in Arkansas and Indian Territory, and curved toward the southwest in Texas. The earliest shore line of this sea of which the rocks show record is in central Texas, 300 miles southwest of Arkansas. When the shore line was at this point all of the region tc the north of it was land. As the surface of the country became lower, in part by being worn down by erosion and in part by the subsidence of the land, the shore moved northward. Several times during the advance of the sea subsidence of the land ceased for a while and the shore line was temporarily stationary, or even, owing to elevation of the general land surface, moved southward. During one of these periods near the middle of the Cretaceous, the shore receded many miles southward, but only to return again farther north than before. During the slow northward progression of the shore rock materials from the shore were washed into the sea, forming sediments. The sand, pebbles, and other coarse materials were not carried to a depth beyond reach of the waves and strong currents and they formed the conglomerate and sand. Farther out, in greater depths of water, clay and lime were deposited, which formed beds of clay, marl, limestone, and chalk.

At the end of the Cretaceous period the land was elevated and the sea returned southward. When the Cretaceous rocks were elevated into land they were soft, as indeed most of them are at present, and during the long interval since that time they have been worn down by erosion and entirely removed from a large tract of country north and west of the present Cretaceous border.

In the elevation of the Cretaceous rocks into land they were tilted slightly in the direction of the retreat of the sea, so that the beds of rock now dip toward the south and southeast at the low inclination of 40 to 50 feet per mile.

At a relatively recent time the Cretaceous region of Arkansas and a part of that in Texas have been overrun by bodies of water having sufficient current and depth to transport and form large deposits of gravel, sand, and clay. The areas of these gravel deposits are shown upon the geological map as Neocene(?). They cover a large part of the highland of the region.

From Neocene time down to the present the streams have worn through these beds of gravel and sand or have modified them. They have made wide valleys through the Cretaceous chalk and marls, as well as gravel deposits, and in these valleys they have deposited finer sediments, which are illustrated upon the geologic map as Pleistocene. The minor details of the topography of the area are thus due chiefly to stream action in recent time.

THE CRETACEOUS FORMATIONS.

Previous to the present investigation of the Arkansas chalk deposits, the writer, while a member of the Texas geological survey, had occasion to survey the Cretaceous rocks of northern Texas and to study the chalk formation, which is a member of them, from the vicinity of San Antonio, Tex., to Red River west of the Arkansas region.

In order that the Cretaceous rocks of southwestern Arkansas may be clearly understood, it will be necessary to discuss them in connection with the deposits of northern Texas, the nearest locality where all the formations are completely exposed.

LOWER CRETACEOUS.

The Lower Cretaceous is represented in the Arkansas region by two formations — the lower composed of sand and the upper chiefly of limestone. The occurrence of the lower formation is shown upon the map in the several areas near the north side bordering the Paleozoic. The succeeding deposits of the Lower Cretaceous are known to outcrop in this region only in a single small area at Cerro Gordo, on the Little Missouri River, being elsewhere concealed by the post Cretaceous gravel and sand deposits and by overlap of the Upper Cretaceous.

The lower formation, known as the Trinity sand, is composed chiefly of fine, clean sand with pebbles at the base, and in some localities, bowlders which have been derived from Paleozoic rocks similar to those which occur in the vicinity. In places this sand contains quantities of fossil trees which were drifted into the sea from the land at the time the sand was formed. The Trinity sand is the beach and near-shore deposit of the Lower Cretaceous sea in the region of Arkansas and Texas. It is found at the base of the Cretaceous resting upon eroded surfaces of Paleozoic rocks and has a continuous outcrop from Murfreesboro, Ark., westward to the vicinity of Ardmore, Ind. T., and thence southward to central Texas west of Austin.

As the sea progressed northward, successive beds of marl and lime sediments were laid down in the deeper water, with their edges coming successively upon this sand toward the shore. Thus a large body of the lower part of the succeeding lime formation laps upon and grades into near-shore sand and does not occur in the northern part of the Texas region and in Arkansas. Moreover, the limestone formations that are found in Arkansas and in southern Indian Territory become

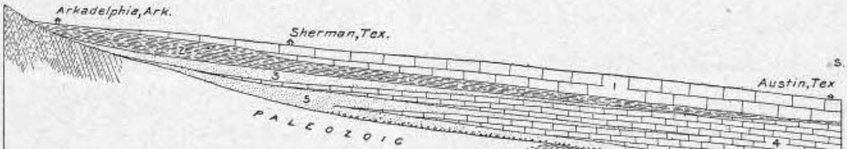


FIG. 57.—Diagrammatic section of the Cretaceous rocks in northern Texas and southwestern Arkansas. 1, white chalk; 2, blue marl; 3, sands at base of Upper Cretaceous; 4, Lower Cretaceous limestone; 5, sand at base of Lower Cretaceous.

much thicker southward in Texas toward the interior of the Cretaceous sea. The relations and structure of the Cretaceous formations are illustrated in fig. 57.

UPPER CRETACEOUS.

At the beginning of the Upper Cretaceous the region north of the Brazos River in Texas was elevated into land or brought very near the shore, but the rocks of the Lower Cretaceous were but slightly eroded. The evidence of the elevation of the land and the retreat of the sea southward is to be found in the sandy, shallow water deposits that mark the beginning of the Upper Cretaceous, which are resting upon the highest eroded surface of the Lower Cretaceous. These sandy deposits are thick in north Texas and in Indian Territory, where they show that the action of waves aided in the formation of their beds, and contain leaves and stems of forest trees which were washed in from the nearby land. Toward the south these sandy rocks grade into marl and lime sediments, which rest upon the smooth undisturbed top of the Lower Cretaceous. This sandy lowest member of the Upper Cretaceous is concealed in Arkansas by a post-Cretaceous deposit of gravel and sand.

Limy clay and marl overlie the basal sand of the Upper Cretaceous, and are in turn succeeded by the chalk.

The marl below the chalk is a continuous formation, which increases gradually in thickness from Austin, in central Texas, to the vicinity of Whitecliffs, in Arkansas. At the former locality it is about 30 feet, while at the latter it is nearly 300 feet in thickness.

THE CHALK—ITS ORIGIN, CHARACTER, AND EXTENT.

The white chalk is exposed from Austin northward to Sherman, Tex., through a distance of nearly 250 miles, without appreciable change in its thickness of nearly 600 feet and with a very slight variation in texture, color, and nature of the material.

When the chalk in this region was formed, the shore of the Cretaceous sea had passed so far north of the region that only small quantities of sediment were brought from the land. It is supposed that the sea was deep; at any rate, the bottom was below the reach of the waves. It is considered that during a long extent of time the conditions of the sea in this region remained nearly constant, while the limy skeletons of countless microscopic organisms settled to the bottom and formed the chalk.

In the vicinity of Sherman, a few miles south of Red River, the chalk formation turns eastward and continues down the south side of the river valley through Grayson, Fannin, Lamar, and Red River counties and into the northwestern part of Bowie County. From the last locality the chalk passes beneath the bottom land of Red River to Rocky Comfort, in Arkansas. Farther east it comes to the surface at Whitecliffs, on Little River, and Saline Landing on the West Saline River. In the Arkansas region it is known as the Whitecliffs formation.

The outcrop of the chalk from Sherman eastward into Arkansas is nearly parallel to the Cretaceous shore, which runs east and west along the old Ouachita Mountain Range. The increasing proximity to shore is indicated by the trend of the Cretaceous rocks, and by the change in character of the chalk sediments which bear toward it.

The lower part of the thick chalk formation of north Texas changes to marl in the vicinity of Sherman, and still farther east higher beds successively become chalky marl, so that within a comparatively short distance only the upper part of the chalk formation as it occurs farther south is true chalk. In other words, the white chalk transgresses upward in the series of Cretaceous rocks from the vicinity of Sherman, Tex., eastward into Arkansas.

The fossils of the main chalk which are not found below it in north Texas, south of Sherman, occur in the chalky marl beneath the chalk from the vicinity of Paris, Tex., eastward. The fauna, including the characteristic species of fossils, such as *Exogyra ponderosa*, *Gryphæa*

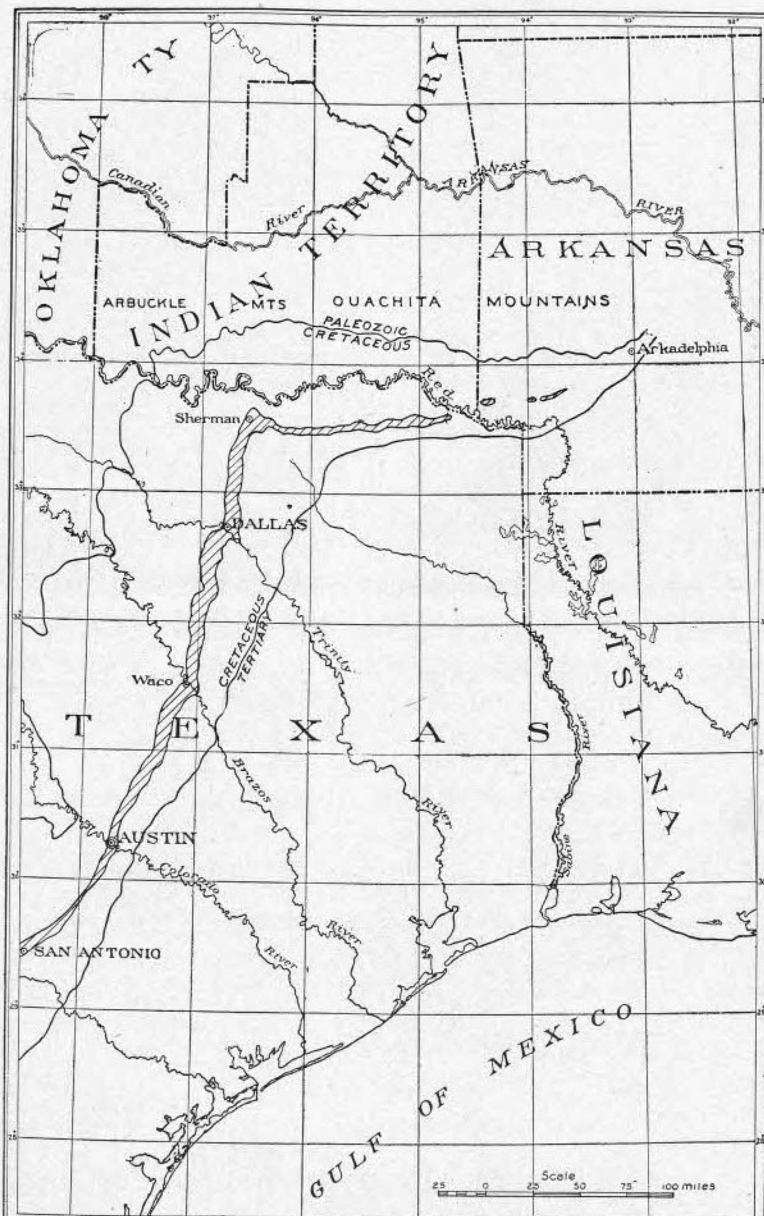


FIG. 58.—Map of the chalk of north Texas and southwestern Arkansas.

vesicularis, *Ostrea larva*, and others which occur only in the upper beds the chalk in central Texas are found in great abundance in the marl at of the base of and beneath the white chalk in southwestern Arkansas.

This white chalk grows thinner in outcrop northeastward as it approaches the Paleozoic border and elevated mountain districts until it ends in chalky marl near the center of the Cretaceous area of southwestern Arkansas. Fig. 58 is intended to show the location of the white chalk from central Texas to southwestern Arkansas.

The Upper Cretaceous of southwestern Arkansas, as indicated on the geologic map (Pl. XLVII), includes the exposed chalk as well as the marls both above and below it. The chalk outcrops of the region are illustrated in figs. 59, 60, 62, 63, 66, and 69.

The marl above the white chalk, in Texas, continues upward through many hundred feet to the top of the Cretaceous.

A second, thinner and less pure chalk formation occurs in southwest Arkansas in the marl above the first white chalk of the Whitecliffs formation. In distinction to the first, this chalky bed is known as the Saratoga chalk or chalk-marl. The name is from the town of Saratoga, Hempstead County, Ark., near which it is typically exposed. It is separated from the white chalk by about 200 feet of blue limy marl, and is succeeded by greensand and clay marls, which extend to the top of the Cretaceous in the Arkansas region.

DETAILED DESCRIPTIONS OF THE CHALK AND CHALK-MARL.

WHITECLIFFS FORMATION.

The Whitecliffs formation in Arkansas occurs exposed in three areas. These are in the vicinities of Rocky Comfort, Whitecliffs, and Saline Landing, for which each area is respectively named. The location of these areas is shown in the maps accompanying the detailed descriptions of each. The formation is continuous from area to area beneath Neocene and Pleistocene deposits.

The formation is a white chalk which occurs bedded between formations of marl, into which it gradually merges.

In the westernmost area in this region the exact thickness of this formation could not be accurately determined, but it is estimated to exceed 100 feet. At Whitecliffs nearly 100 feet of the chalk is exposed and the top of the formation is concealed. At Saline Landing a part of the formation also is concealed. In the eastern part of Saline Landing area, however, it is less than one-half the thickness exposed at Whitecliffs. In the vicinity of Okolona, 30 miles farther east, where the strata are next exposed, the white chalk does not occur. Thus it is seen that the Whitecliffs formation occurs as a wedge with its thick end toward the west and coming to an end near the middle of the Cretaceous region of southwestern Arkansas.

ROCKY COMFORT AREA.

Location and character of the surface.—The Rocky Comfort chalk area lies in the rudely rectangular block of land between Rocky Comfort and Walnut Bayou. It is approximately 2 miles long in a northeast-southwest direction and nearly a mile wide. Rocky Comfort is near the center of the northeast end.

The contact line at the base of the chalk on the northwest side, across parts of secs. 21 and 29, is only approximately located, as it is concealed by deep black soil which covers the white chalk and underlying

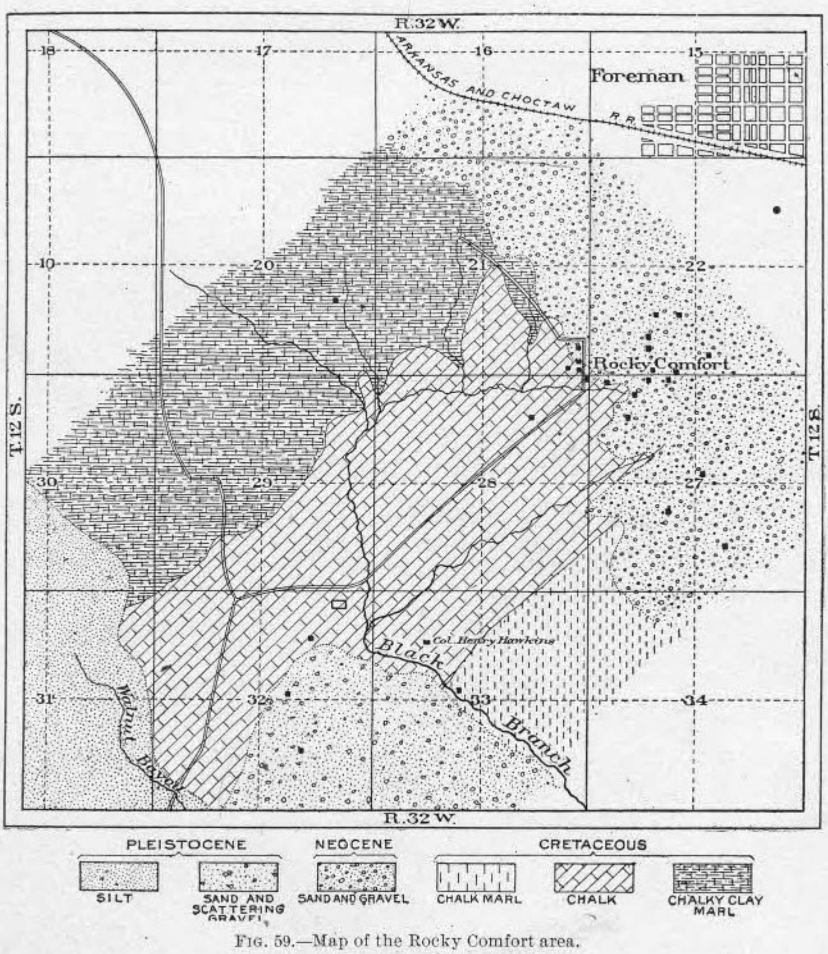


FIG. 59.—Map of the Rocky Comfort area.

blue marl alike. The parting line at the top of the chalk in secs. 32, 27, and 28, T. 12 S., R. 32 W., is also concealed in places by gravel and soil.

Between Black Branch and Walnut Bayou the uppermost beds of the chalk formation are overlain and concealed by a hummocky deposit of second bottom sand and gravel. This second bottom is elevated a few feet above the overflow limit of Red River, is nearly level, and where uncultivated is covered by dense and tall timber.

The outcrop of the chalk terminates abruptly on the southwest side, where it has been worn down by Red River and then covered by its bottom-land deposit of fine silt. At high flood Red River overflows to the chalk contact east of Walnut Bayou.

East of Rocky Comfort the chalk is concealed by highland deposits of gravel, sand, and clay of variable but not great thickness. These are the Neocene and Pleistocene deposits, which occupy a large part of the region and are spread over the chalk formation between Rocky Comfort and Whitecliffs Landing on Little River. In places this surficial deposit is thin, and it is reported that in small areas in the region toward Richmond the black soil of the chalk or marl is entirely uncovered.

The strike of the chalk eastward follows an almost straight belt from Rocky Comfort to Whitecliffs Landing beneath later deposits of gravel, sand, and silt. In this belt no true chalk outcrops are known to occur.

East of the chalk outcrop in the vicinity of Rocky Comfort the gravel and sand deposits are generally of considerable thickness, and it is not necessary to consider the chalk beneath them.

The topography of the chalk belt and of the adjacent marls is gently undulating, and the valleys of Black Branch and its tributary streams are not well defined except near the source of those streams which flow from the more elevated gravel deposits on the east side. These small streams near their sources sap the chalk from beneath the gravel and sand by solution and headwater erosion, thereby cutting short valleys 40 to 60 feet in depth. The lower ridges of chalky land rapidly decline from gravel tongues between the valleys to low divides toward the interior of the chalk area. The chalk country between Black Branch and Walnut Bayou is practically flat, and west of the "line road" is covered in part by a thin mantle of second-bottom silt.

The area underlain by the chalk and its underlying chalky marl is occupied almost entirely by cultivated fields, while the bottom land to the west of the chalk area and the highland gravel to the east have not been denuded of the original forest except to a very limited extent.

The chalk and the chalk-marl above and below it dip toward the southeast in this area, as do the same deposits elsewhere throughout southwestern Arkansas. A deep well drilled in the southeast corner of section 28, for instance, would pass through the entire chalk of the Rocky Comfort area and penetrate the marl which crops out in the black land belt northwest of it.

The thickness of the true chalk in this era is not known, but is estimated to be about 100 feet.

Description of exposures.—The chalk which outcrops in the vicinity of Rocky Comfort is remarkably uniform in physical appearance. It is massive, white, sufficiently friable to soil the fingers, and thin pieces may be broken in the hands, but the hammer is required to pulverize the massive rock. On exposure the chalk breaks into conchoidal fragments which weather to lumps and finally become chalky dust. In the 50 to 60 feet exposed in the hillsides south of the town the bedding is scarcely perceptible.

The composition of fresh chalk from the bed of the branch at the base of the exposure is given in analysis No. 4, Table III (p. 735), while No. 3 shows that exposed in the ditches, 55 feet higher. The former is not many feet above the base of the true chalk and the latter belongs near the middle. This chalk is, in physical appearance, like that of Whitecliffs, and a comparison of the analyses with No. 9, that of the chalk from Whitecliffs quarry, shows them to be practically the same in chemical composition.

The lower beds are exposed by the road in the SE. ¼ of the SE. ¼ of sec. 21, T. 12 S., R. 32 W., also near the middle of section 21, with chalky marl cropping below. These basal beds are more marly and siliceous than those higher in the formation south of Rocky Comfort.

From the center of section 21 to the "line road" in the SW. ¼ of section 29 the chalk is concealed beneath residual black soil. At the latter locality the chalk is well exposed in ditches and on high ground along the road almost through the SE. ¼ of the SW. ¼ of sec. 29. The lower beds of the formation are also exposed in the hill and bluff facing the river bottom in the NE. ¼ of the NE. ¼ of sec. 31.

From the base of the chalk downward there is a transition zone of bluish chalk-marl which grades down into still less chalky clay marls. This transition chalk-marl is exposed at the contact in the SW. ¼ of sec. 29 and in deep ditches on the hill slopes below the Hopson graveyard in the NE. ¼ of the NE. ¼ of sec. 30.

Analysis No. 2, Table III, is of a specimen of the transition chalk-marl from the latter locality. While the analysis shows that the marl contains 25 per cent of silica, sand is not visible.

From sec. 30 northward to the Holman place, near the center of sec. 18, the marl is generally concealed by its residual soil. Grayish-blue, sandy, chalky marl, partially indurated at the surface, crops out at the Holman House and in gullies 500 feet farther west. This marl contains numerous specimens of the large oyster *Exogyra ponderosa* besides the small variety of *Gryphæa vesicularis* and the other small shells so abundant in the marls below the chalk in the vicinity of Whitecliffs. This chalky marl is perceptibly more sandy than that higher in the section immediately below the true chalk.

The crumbling edges of the chalk deposits crop out in the low bluff of Walnut Bayou bottom from the NE. ¼ of the NE. ¼ of sec. 30 southward to the extreme south end of the chalk area in the SE. ¼ of the SW. ¼ of sec. 32.

Excellent exposures of the chalk occur in and near the road in the SW. ¼ of the SW. ¼ of sec. 32. The analysis of this chalk is given in No. 1 of the table. The chief difference between this and the other samples of the purer chalk analyzed is that it contains much more clay. The only perceptible physical difference, however, is that it is a little harder.

A rather large exposure of white chalk, of beds near the top of the formation, appears on the Col. Henry Hawkins's place, in the NW. ¼ of sec. 33. About ¼ mile southeast of the house in the SE. ¼ of the NW. ¼ of sec. 33, the top of the true chalk and the base of the succeeding chalky marl is exposed. A thin mantle of gravel conceals part

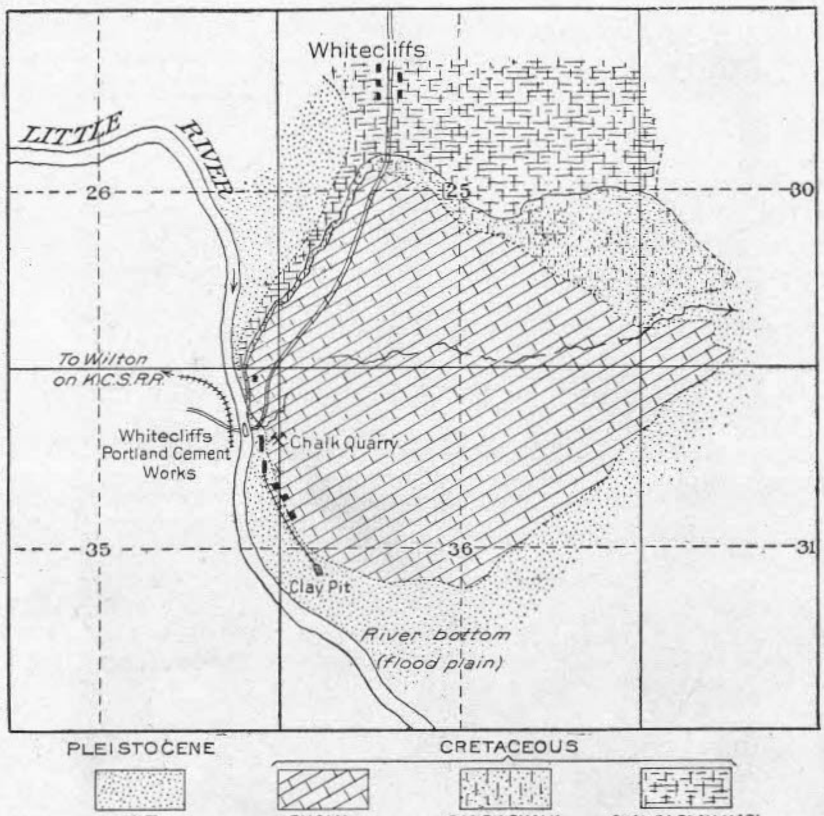


FIG. 60.—Map of the Whitecliffs area.

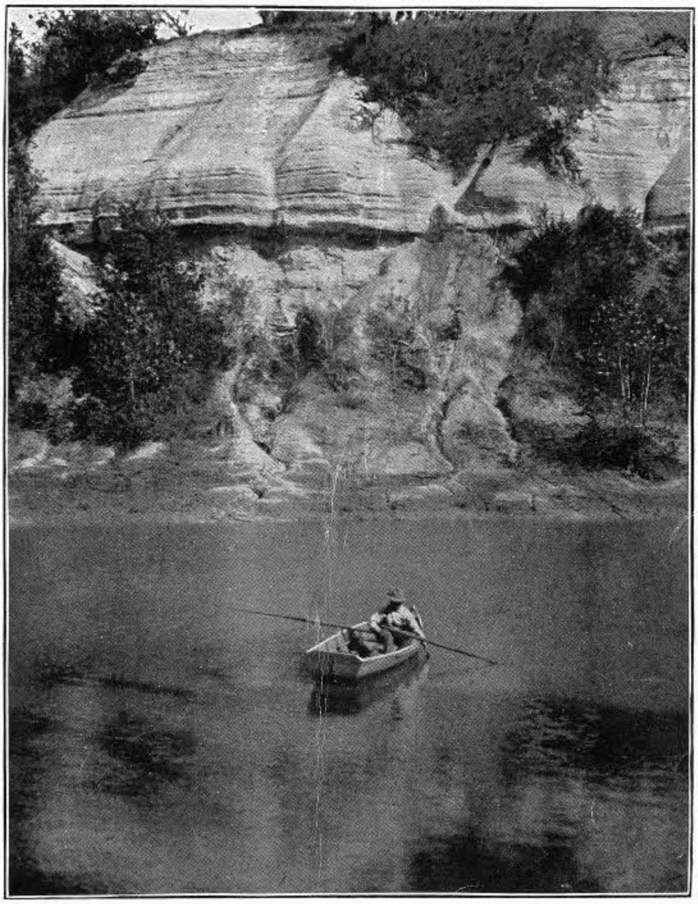
of both the chalk and the marl. The upper layers of the chalk are also exposed south of the branch, in the SE. ¼ of sec. 28.

There are smaller exposures of chalk in this region, but it is believed that those above described are typical.

WHITECLIFFS AREA.

Location and surface features.—The boundaries of this area were established by traverse surveys, checked on section and fractional section corners, and the errors of location are small. The map is shown in fig. 60.

The true chalk here exposed occupies parts of secs. 25, 26, 35, and 36, T. 11 S., R. 29 W., and secs. 30 and 31, T. 11 S., R. 28 W., and covers an area of about 600 acres.



CHALK BLUFF AT WHITECLIFFS LANDING.

The chalk at Whitecliffs forms a low table-land, elevated 25 to 100 feet above the bottom land on the east, south, and west sides, and slightly inclined toward the southeast. The highest point of the table-land is at the west side and extends nearly half a mile north of the Whitecliffs Portland Cement Works, where the chalk outcrops in cliffs and bluffs in the face of an escarpment from 100 to 130 feet above Little River. From the cement works completely around the south and southeast sides of the area to the extreme east end, the chalk stands in a more or less irregular bluff 20 to 50 feet high, partially covered by soil and gravel débris. The silted bottom lands of Little and West Saline rivers extend up to the base of the bluff and conceal the lower part of the chalk. The lower part of the chalk, as exposed, makes a low and indistinct escarpment on the north side of the area from the road south of the village of Whitecliffs to the southeast quarter of sec. 25, T. 11 S., R. 29 W. The lower sandy member of the chalk makes a wide bench northeast of the chalk and is about 20 to 40 feet above the adjoining creek bottom. Near the center of section 25 the outcrop of sandy chalk contracts and joins the low escarpments of the chalk proper, and so continues westward and southward to the cement works.

From the vicinity of Whitecliffs post-office the upland becomes rapidly broader northward, attaining a width of about 6 miles, and continues northward between the Cossatot and West Saline rivers, but the true chalk is not found north of the village.

A large part of the chalk of the Whitecliffs area is covered by a thin mantle of Neocene gravel and sand. In places this gravel may attain a thickness of several feet, but it is believed that it will nowhere interfere seriously with the removal of the chalk. The chalk is also concealed in places, especially near the border of the area, by its own residual soil, with scattered pebbles or a very thin layer of gravel.

A small stream, which has its source near the edge of the cliff in the southwest corner of section 25 and flows eastward, has formed its shallow, swampy valley chiefly by the solution of the chalk. As the rock is disintegrated and removed the gravel descends, covering the slopes of the valley. Another stream, still smaller, which rises in the northwest corner of section 26, and joins Little River at the ferry, descends 100 feet in less than one-fourth of a mile, and has cut a narrow gulch, up the side of which the road passes over the exposed edge of the chalk to the top of the table-land.

Chalk and associated chalk-marls.—The most noteworthy exposure of chalk in southwestern Arkansas occurs in the cliffs overlooking Little River from the east side in the northeast corner of sec. 35, T. 11 S., R. 29 W., immediately above the ferry. Pl. XLVIII is a view of the central and best exposed portion of the cliff.

From the brink of the cliff down to the water level is 115 feet and about 15 feet of chalk is exposed at a higher level by the road which leads from the cement works. The following is a detailed section, beginning at the top, of the chalk and marl in the cliff.

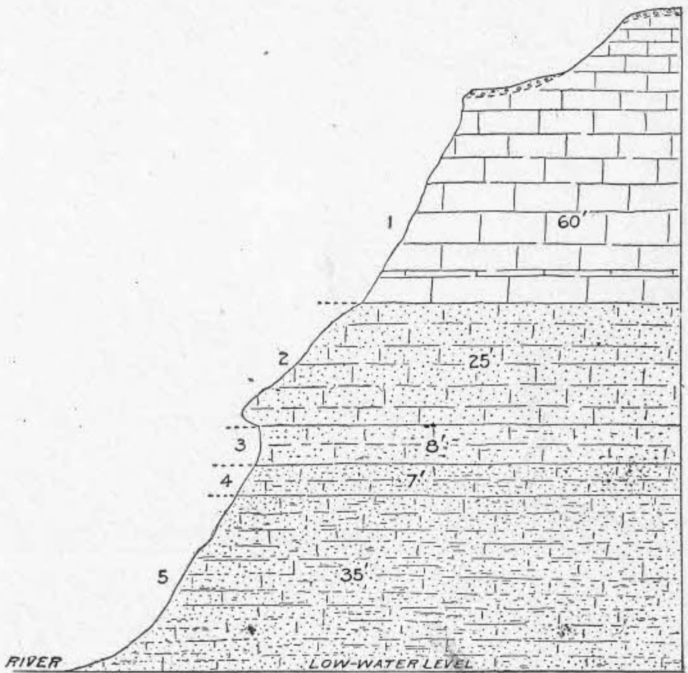
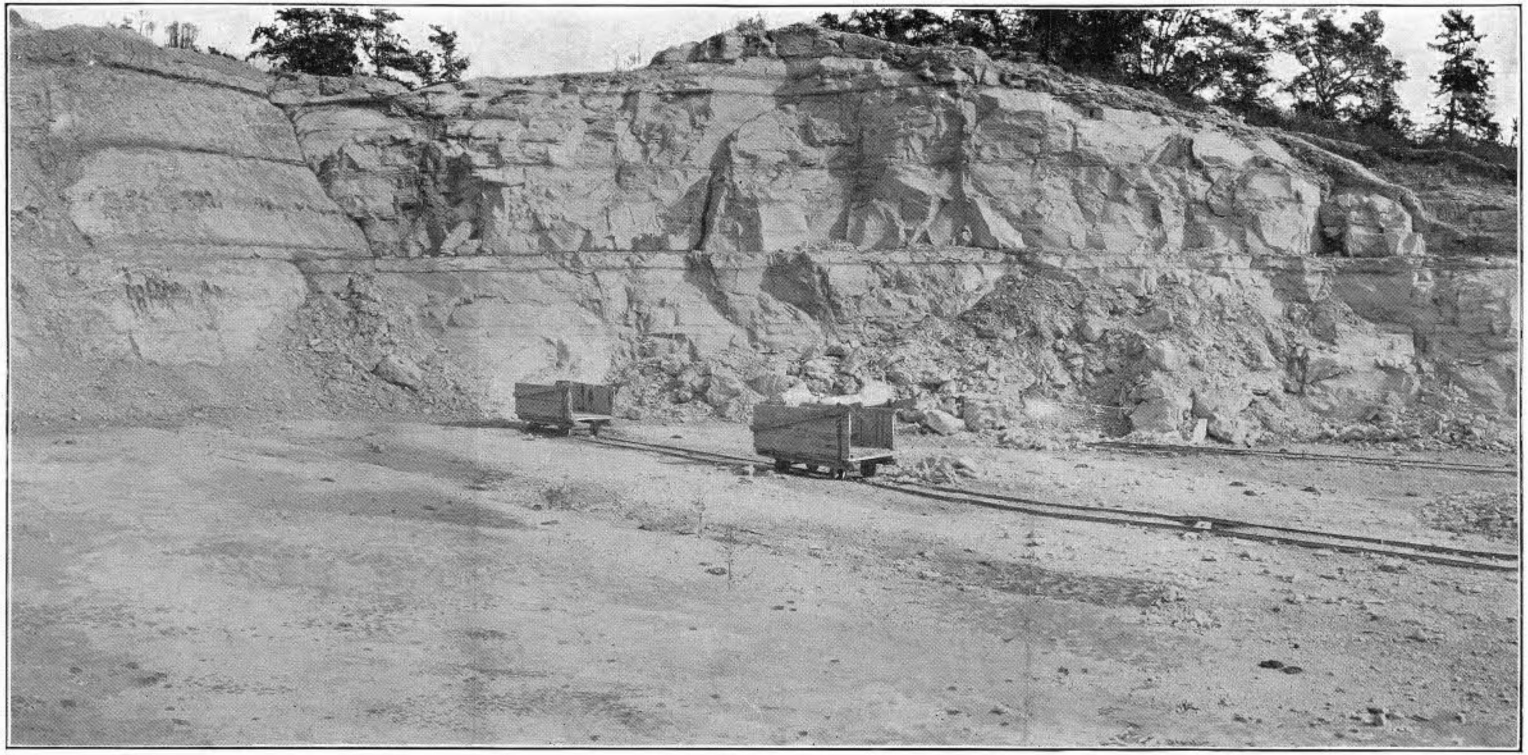


FIG. 61.—Section of the chalk at Whitecliffs Landing (see section below.)

Section at Whitecliffs Landing (see fig. 61).

	Feet.
1. Massive, creamy white chalk, in beds from a foot to about 10 feet thick, separated by thin partings of very slightly laminated chalk. The variation in the character of the chalk from bed to bed is not perceptible on physical examination, and the stratification planes are not clearly defined except upon partial weathering of the rock. Analysis No. 7, Table III (p. 735), is of specimens in the lower part of this chalk, while No. 9 is an average of specimens from each bed in the lower half as exposed in the quarry back of the cement works. Plate XLIX is a view of this quarry. Analysis No. 8 is from about 10 feet below the top as exposed by the road opposite the cliff	60
2. Massive, dull-bluish-white, siliceous chalk. Slightly harder than the pure chalk of 1. This chalk is practically without indication of bedding, and because of its hardness it projects in a steep bench overhanging the less chalky and friable beds below. Analysis No. 6 shows that this chalk contains nearly twice as much silica as the chalk above. This bed occurs in the bench beneath the quarry at the cement works and passes to the level of the river bottom near the clay pit south of the works. An outcrop occurs also near the middle of the bluffs north of the cliffs, spreading out at the surface in the cultivated fields one mile southeast of the village of Whitecliffs. It occurs near the level of the river bottom at the southeast side of the mapped area	25



CHALK QUARRY AT WHITECLIFFS LANDING.

	Feet.
3. Massive, very siliceous, dull-blue argillaceous chalk-marl. This bed contains more than twice as much sand and nearly three times as much clay as the overlying bed No. 2. The rock is quite friable and weathers in recesses beneath the siliceous chalk	8
4. Bluish, sandy, chalky marl, containing great numbers of the fossil shell *Gryphæa vesicularis* variety. Except for the abundant fossils this rock would be classed with 3, though it is probably slightly more sandy. Typical fossils from this bed are illustrated in Pl. L	7
5. Bluish, sandy, chalky marl, gradually increasing in sandiness from the top downward to the level of the river. This bed contains fossils of the *Gryphæa vesicularis* variety, but not so abundantly as in 4; and also many fossils of the large and heavy oyster *Exogyra ponderosa* as well as others common to the Upper Cretaceous marls	35

The lower 30 to 35 feet of the white chalk of 1 is freshly exposed in the quarry at the cement works opposite the landing, as illustrated in Pl. XLIX.

The top of the bluish-white chalk of 2 forms the bench beneath the quarry and occurs at the base of the bluff southeast of the landing.

The sandy chalk members 3, 4, and 5 rise gradually northward from the lower part of the cliff and are found in the high land between the villages of Whitecliffs and Brownstown. The very abundant fossils of the *Gryphæa vesicularis* variety may be seen weathering in the ditches and at the top of the escarpment northwest of the village of Whitecliffs.

The fossil *Gryphæa vesicularis* variety is illustrated, natural size, in Pl. L. These fossils are found in this chalk region only in the bluish chalky marl beneath the white chalk. They may be relied upon as a definite marker for the formation immediately below the chalk.

One-half mile west of Dr. Coats's house, in the NW. ¼ of sec. 23, T. 11 S., R. 29 W., *Gryphæa vesicularis* variety bed No. 4 is exposed at the top of the bluff and below it is the following section, well shown in deep gullies down to the level of the valley:

Section of marl below the Whitecliffs chalk.

	Feet.
1. Sandy, chalky marl. Dull bluish when not weathered, becoming grayish, or whitish yellow after long exposure. It contains numerous specimens of the large oyster *Exogyra ponderosa*, besides *Ostrea larva* and many other fossils common to the Upper Cretaceous marls. The upper half of this member is No. 5 at the base of the cliff at Whitecliffs Landing	60
2. Blue clay-marl containing some large oysters as above, and less lime than No. 1, and much more clay	30
3. Dark-blue, gritty, greensand marl with scattering smooth round pebbles of black and white quartz 1 inch and less in diameter	10
4. Blue clay-marl down to the level of the bottom land, exposed	15

This section is located about 2 miles north-northeast of the chalk cliff which is in the NW. ¼ of sec. 35, and the sandy marl bed, which is here about 100 feet above the river, is at the water level at the cliff. This marl bed with the associated marls and chalks above, which are conformable with it, dips toward the southeast at the rate of about 50 feet per mile. The base of the chalk at the north side of the chalk area is fully 50 feet above the river bottom. At the south side, a mile distant, it is at the level of the bottom. There may be local variations in the dip of the beds, but the general dip is estimated to be nearly 50 feet per mile toward the southeast.

SALINE LANDING AREA.

Location and surface features.—Saline Landing was once the port for the shipment of cotton from this region and stood practically at the head of navigation for small steamers on West Saline River. At the present time it is known only by name and association with the McDaniel place, an old homestead which adjoins it on the east. Saline Landing is at the extreme west end of the easternmost area of true chalk in this region, and is separated from the chalk of Whitecliffs by a space of 4½ miles. The chalk deposits of the two localities are parts of the same formation and are directly connected beneath the river bottom land.

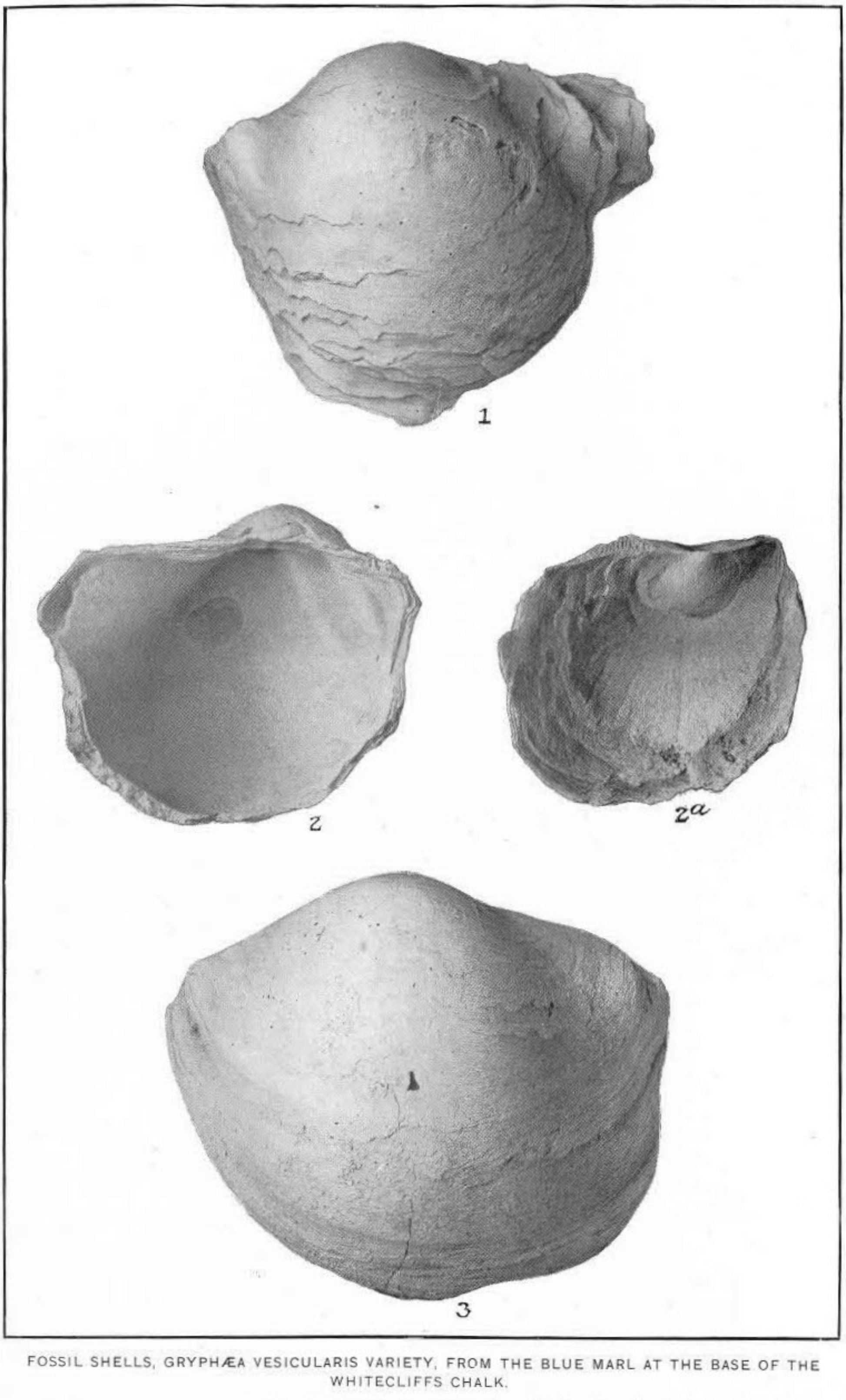
The chalk area of Saline Landing was located by traverse surveys checked on section and half section corners, and the mapping is approximately correct.

It extends with practically continuous exposure from the chalk bluff at Saline Landing in the south half of sec. 35, T. 11 S., R. 28 W., to sec. 14, T. 11 S., R. 27 W., is thus about 7 miles in length, and has an average width of about one-third of a mile. The map of this chalk area is given as fig. 62.

The chalk area is bounded on the north side by the silt deposits of Plum Creek, which conceal the lower beds of the chalk formation along the entire area. The soil of Plum Creek bottom, which has been transported from the soils of the chalk and marl bordering the valley, so resembles the soil of the chalk that the line between the two can be only approximately located through a part of its course. The top of the chalk, which is on the south side, is partially concealed by black residual soil.

The entire area, except in the vicinity of Saline Landing, where the surface is flat, slopes gradually toward Plum Creek bottom and is crossed by numerous swales in which water flows only in rainy weather.

The forest has been removed from the entire area, which is now occupied by inclosed or cultivated fields. When the forest covered the land the chalk was almost entirely concealed beneath its soil, but during the cultivation of the land the soil has been removed by erosion from the steeper slopes and from many of the small divides between the main streams, producing chalk barrens. On the level spaces and in the valleys the residual soil resting on the chalk is dense black and often several feet in depth.



FOSSIL SHELLS, GRYPHÆA VESICULARIS VARIETY, FROM THE BLUE MARL AT THE BASE OF THE WHITECLIFFS CHALK.

1 and 3, Outside view of large valve; 2, inside view of large valve; 2*a*, outside view of small valve of 2. Natural size.

Description of the chalk exposures.—As stated above, the base of the chalk is not exposed in this area, though the lower sandy member crops out in sections 21 and 22, toward the source of Plum Creek.

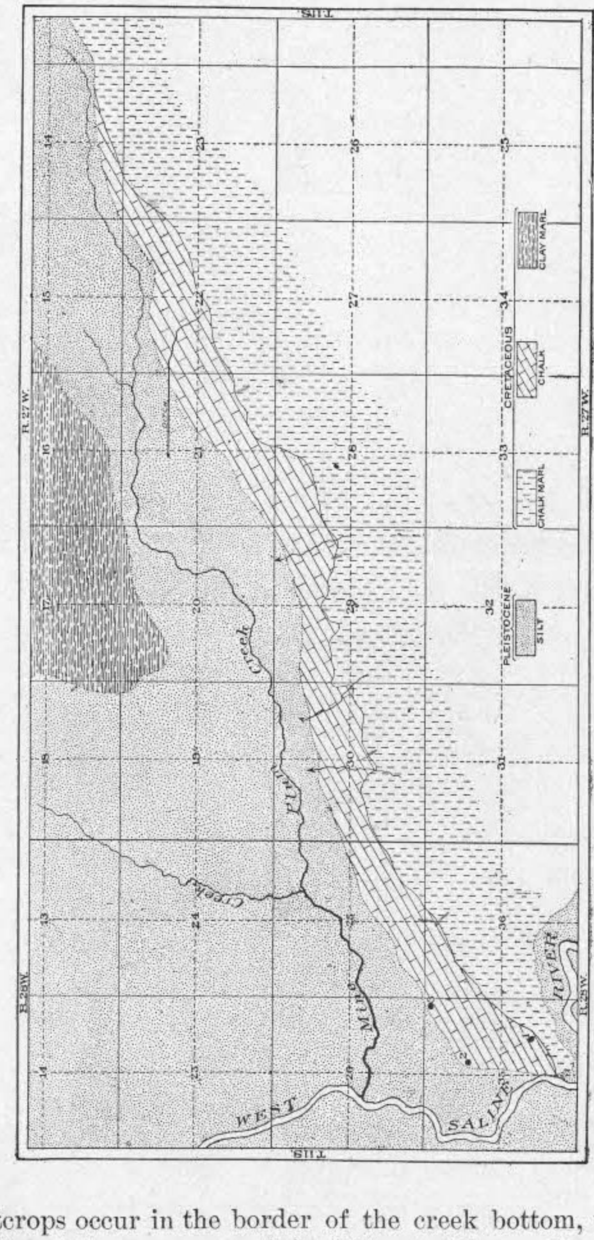


FIG. 62.—Map of the Saline Landing area.

These outcrops occur in the border of the creek bottom, within less than 1 mile of the exposures of fossiliferous blue marl cropping out in the north side of Plum Creek, in sections 15 and 16. The structure of the rocks shows that this marl belongs not more than 50 feet below the base of the chalk.

The chalk at the top, as exposed in many places in the south side of the area, grades up into blue clay-marl through 20 to 30 feet of marly chalk and chalky marl. This gradation is especially well shown in the chalky, barren hill slopes near the Columbus Mineral Springs road, in the south side of sec. 14, T. 11 S., R. 27 W.

The thickness of the chalk in the southwestern part of the area is not known, as its lower portion is concealed. Near the northeast corner of sec. 22, T. 11 S., R. 27 W., the full thickness of the purer chalk above the lower sandy member will not exceed 25 feet. Near the east side of sec. 14, T. 11 S., R. 27 W., the entire chalk bed passes beneath the bottom of Plum Creek.

The divide between the sources of Plum and South Ozan creeks is flat, and the chalk deposits are entirely concealed beneath the soil in the cultivated fields. The crop of the chalk, as indicated by the structure of the rocks, would extend northeastward through secs. 7, 8, 5, 4, and 3, in T. 11 S., R. 26 W., and into Ozan Creek bottom. The location of this probable outcrop is shown in fig. 63.

By the report of Mr. H. H. Hanna, a reputable farmer, wells in the NW. ¼ of the SW. ¼ of sec. 35, T. 10 S., R. 26 W. penetrate a few feet of "white lime rock" and enter blue clay marl after passing through 10 to 13 feet of the surface deposit of red sandy clay. It is very probable that this "white lime rock" is a part of the lower member of the chalk. Between Mr. Hanna's place, located as above, and the Little Missouri River, the Cretaceous rocks in the strike of the chalk are concealed by the bottom land of Ozan Creek.

It would appear that the chalk deposits of this region grow thinner eastward, and gradually change in nature from true chalk to chalk-marl. Where the formations emerge from beneath the bottom land in the vicinity of Okolona, east of the Little Missouri River, and nearly 30 miles east of the exposures on Plum Creek, the lower sandy member of the chalk is present with its abundant and characteristic fossil, *Gryphæa vesicularis* variety, but the position of the purer chalk above it is occupied by a blue chalk-marl. The outcrop of this formation is outlined in fig. 66, which shows the Okolona area of chalky marl.

The chalk bluff at Saline Landing is 20 feet in height (above low water) and about 300 feet long. When visited by the writer the river was at flood, so that less than 10 feet of the rock was exposed to view. The lower portion of the chalk as then exposed is white, massive, and without distinct bedding planes, the upper 5 feet being weathered to a chalky earth. Specimens of the chalk were collected from the water level, which would be near the center of the bluff at the usual low stage of the river. Analysis No. 10, Table III (p. 735), of this chalk is nearly the same as No. 6, which is of the lower sandy member of

Whitecliffs, and suggests that the exposure at Saline Landing is in the lower part of the chalk formation in this area.

East of Saline Landing the chalk country is flat and the rock is concealed by the deep soil in the cultivated fields. The chalk is said to be exposed in deep ditches, one-fourth mile southeast of the residence on the McDaniel place, but on account of the water the report could not be verified.

Three artesian wells have been drilled on the McDaniel place upon the chalk; the one at the house near the landing has a record, according to Dr. Branner's published report, as follows:[a]

Record of artesian well near Saline Landing.

	Feet.	Ins.
Soil and clay	25	...
Brown sand	1	...
White chalk	140	...
Blue marl	290	...
Sandy bed with pyrites		10
Bottom of well in sand at the depth of	457	...

The surface at the well is probably near the top of the chalk. A second well is located on the chalk, one-half mile north of the landing, near the edge of the bottom land. The chalk is exposed here in a low bench and has been quarried for local use in the interior work of buildings.

The third well is about three-fourths of a mile northeast of Saline Landing and is located upon the chalk 20 feet below the top of the formation. A record of this well, published by Dr. Branner, is as follows:

Record of artesian well three-fourths mile northeast of Saline Landing.

	Feet.	Ins.
Soil	1	...
White chalk	110	...
Blue marl	277	...
Sandy bed with pyrites		10
Sand in bottom of well at the depth of	388	...

If the record is correct the chalk at this place is nearly 120 feet thick.

It should be borne in mind that in wells which are bored by the drop drill, as in this case, it is not an easy matter to determine the parting line between two rock formations that are so closely alike in hardness, etc., as the chalk and chalky marl in question.

The chalk has been quarried for interior building purposes near the top of the formation in the northwest corner of the NE. ¼ of the SW. ¼ of sec. 30, T. 11 S., R. 27 W. Analysis No. 11, Table III (p. 735), is of fresh chalk in this quarry and shows it to be of nearly the same composition as that near the top of the chalk at Whitecliffs.

[a] Report cited above.

From the top of the chalk in this vicinity there is a gradual change upward through about 10 feet of marly chalk and then through nearly 30 feet of chalk-marl into the overlying blue clay-marl. The blue marl is continuous for 175 feet to the base of the Saratoga chalk-marl. The section is illustrated in fig. 64.

The middle portion of this chalk is exposed in the large mound which is surrounded by the bottom land of Plum Creek, in the center of the SE. ¼ of the SW. ¼ of sec. 21, T. 11 S., R. 27 W., on Mr. J. E. Johnson's place. Here also the chalk has been quarried for interior building purposes, giving fresh exposures of the rock. Analysis No. 12, Table III, is of fresh chalk taken from this quarry and is nearly the same as that of chalk taken from the quarry of the Whitecliffs Cement Works.

The lower sandy member of the chalk is freshly exposed in the head of the large drainage ditch near the middle of the west side of the SW. ¼ of the NW. ¼ of sec. 22, T. 11 S., R. 27 W. Analysis No. 14 of this chalk is practically the same as that of No. 6, which is of a specimen from the lower sandy member in the cliff at Whitecliffs Landing.

The upper and purer chalk member is well exposed in the ditches and chalk barrens on the lower ridge across the SW. ¼ of the NE. ¼ of sec. 22, T. 11 S., R. 27 W.

Nearly a full section of the chalk is exposed in the hill near the northeast corner of sec. 22, T. 11 S., R. 27 W., a part of the lower sandy member being concealed. A peculiar feature here of the exposed upper part of the lower sandy member is that it is indurated to a sandstone and contains inclusions or pellets of nearly pure white chalk. Upon weathering, the chalk disintegrates easily, forming porous cavities in the gray limy sandstone. It is probable that the weathering of the fossil shells which it contains aids in producing this honeycombed structure in the weathered rock.

This indurated sandy chalk is used locally for the construction of chimneys and foundations.

The easternmost exposure of the chalk, south of Plum Creek, is in the SE. ¼ of sec. 14, T. 11 S., R. 27 W. Here the chalk barrens in the slopes of the hill show the upper edge of the chalk and the succeeding chalk and clay marl for 50 feet above the creek bottom.

Chalk is said to be exposed in the branches of Plum Creek beneath the bottom lands farther east, probably in sec. 13, T. 11 S., R. 27 W.

Many other exposures, especially of the upper beds of this chalk, occur on the divides and low headlands which project toward Plum Creek bottom, between the small valleys.

CHALK-MARL OF THE WHITECLIFFS FORMATION NEAR OKOLONA.

In discussing the chalk of the Saline Landing district, it has been stated that the white chalk of the Whitecliffs formation is not known east of the source of Plum Creek, north of Columbus, because it is covered by deep soil and the bottom lands of Ozan Creek and Little Missouri River. The gradual thinning of the white chalk, by its change to chalky marl, from Saline Landing as far eastward as it could be traced, indicates that the formation, as a true chalk, would not continue probably beyond a distance of 20 miles.

One and one-half to 2 miles west of Okolona, and 30 miles east of the Saline Landing chalk area, the sandy, chalky marl, with its abundant fossil shells, *Gryphæa vesicularis* variety, is found. This is the same bed as that which occurs at the base of the bluff at Whitecliffs Landing, just below the Whitecliffs chalk. It is of the same nature and contains the same abundant fossil shell that is shown in Pl. L. Moreover, it occurs in the same relative position beneath the Saratoga chalk-marl.

This marl is perceptibly sandy, and its analysis, No. 20, Table III (p. 735), shows its highly siliceous nature.

Above this sandy marl is a bluish, very fine-textured, chalky marl that becomes less chalky upward, as do the same beds in the vicinity of Saline Landing. An analysis of specimens of these clay marls, occurring southwest of Okolona, nearly midway between the Whitecliffs sandy beds and the Saratoga chalk-marl, is given in No. 23. This analysis agrees closely with No. 13, which is that of the marl from the same relative stratigraphic position near Saline Landing. In each case the marl contains nearly 52 per cent of chalk.

The approximate outcrop of the chalky marl beds, which may be considered to be in the position of the Whitecliffs chalk, is shown in fig. 66.

With the thinning of the Whitecliffs chalk eastward, there appears to be a decrease in the thickness of the overlying marl. The blue marl, between the Whitecliffs chalk and the Saratoga marl opposite Saratoga, is about 200 feet thick, and that of the same formation at Okolona is probably not greater than 150 feet. The exposure of the chalky marl of the Whitecliffs formation at Okolona is terminated at the ends by the bottom lands of Antoine and Terre Noire Creeks.

The bearing or course of the Whitecliffs beds in this area is due to the combined effects of the structure of the rock and of the rugged surface of the land. The dip of the rock as in other parts of the region is toward the southeast at the low grade of about 50 feet per mile. If the land were level the outcrop would be in a straight band bearing in a northeasterly direction. As it is, the outcrop of the formation rises from the creek bottom level near the northeast corner of sec. 28, T. 9 S., R. 22 W., northward to the top of the ridge near the Okolona-Antoine road, and then bears eastward in the side of the northward-facing escarpment which extends from Okolona to Dobyville.

The formation is not known east of the Terre Noire because the surface of the country is generally occupied by post-Cretaceous deposits of gravel and sand.

Owing to the rugged surface of this chalk land in the vicinity of Okolona, the soil is generally thin and exposures of the fresh rock are very common, especially where the land has been long in cultivation.

Exposures.—At the Bonner place, 2 miles southwest of Okolona, the sandy fossiliferous marls are exposed in an old field. The freshly exposed rock is dull blue, massive, and but slightly indurated. It weathers in roughly conchoidal flakes and readily crumbles on exposure to the weather.

Good exposures may be seen on the place of Ky. Cargle, west of Okolona; also on the Jesse Carroll and Andy Joynes places, at the top of the ridge 2 miles northwest of the town.

The top of the sandy marl crops in the Okolona-Antoine road at Mrs. Tillman's house, 1½ miles west of Okolona.

The same rocks are exposed at the Ware graveyard, north of Okolona, and at many other places farther east in the northern slope of the escarpment.

SARATOGA[a] FORMATION.

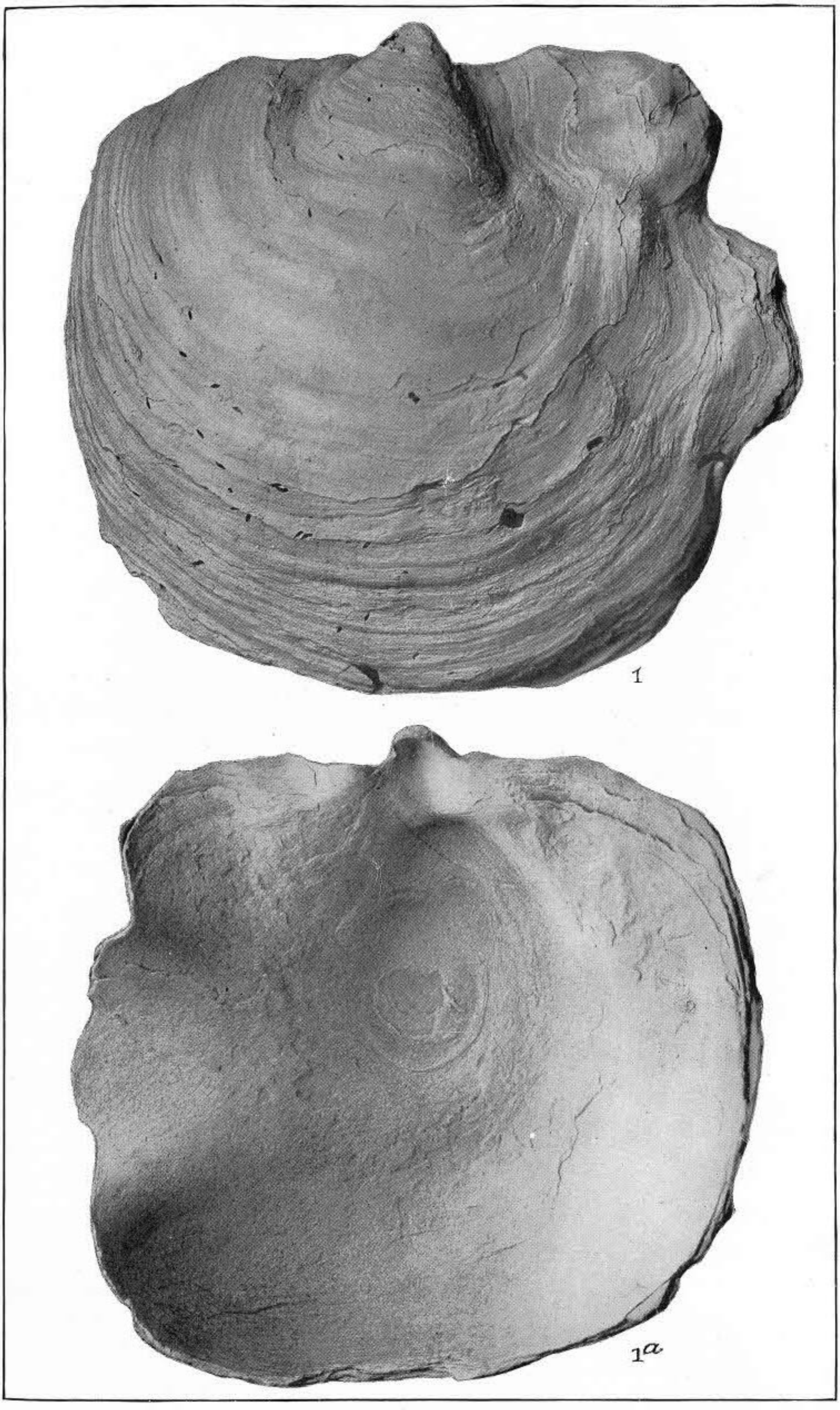
The Saratoga chalk-marl, as explained in the general discussion of Upper Cretaceous rocks, occurs as a formation in the Upper Cretaceous nearly 200 feet above the true chalk and separated from it by marls of less chalky nature.

This formation has a maximum thickness of about 50 feet where complete sections have been found. The nature of the deposit varies only slightly from top to bottom, and there is but little change in character along its outcrop from the vicinity of Saratoga near West Saline River in Hempstead County to Little Deciper Creek near Arkadelphia in Clark County. The Saratoga marl is not known in this region west of West Saline River because of erosion and of concealment by Neocene gravel and sand in the highlands and by Pleistocene alluvium and silt in the lowland and river bottoms.

General section of the Saratoga chalk-marl, beginning at the base.

	Feet.
1. Chalky sandy marl, which contains great numbers of the fossil oyster *Gryphæa vesicularis*. These fossils are found in the marls some distance both above and below this formation, but in no other bed of rock in this region have they been found in such abundance. In natural exposures the chalk weathers from about them so that they usually almost cover the surface of the ground or are scattered in the soil. This shell bed at the base of the formation is such a marked feature that when it is once seen it may be easily recognized again. Some typical fossils from this bed are illustrated in Pls. LI and LII. This shell bed crops at the north border of the Saratoga marl and throughout its extent	3 to 5

[a] Name used by Dr. J. C. Branner in Cement materials of southwestern Arkansas: Trans. Am. Inst. Min. Eng., 1897.



FOSSIL SHELLS, GRYPHÆA VESICULARIS, FROM THE BASE OF THE SARATOGA CHALK-MARL.

1, Outside view of large valve; 1*a*, inside view of large valve. Natural size.

	Feet.
2. Generally even-textured chalky marl, which contains less sand than the beds higher in the formation. Chemical analyses of chalk from this bed show it to contain about 31 per cent of siliceous matter. The sand in this marl is perceptibly finer and the rock is more chalky in appearance than in other parts of the formation	10 to 15
3. Continuing upward from 2 the chalky rock becomes more sandy through imperceptible grades to limy greensand at the top of the formation. Analyses from the chalk near the central part of this member show it to contain from 40 to 50 per cent of silica	20 to 30

The Saratoga marl is a massive bed of dull-bluish, sandy, chalky rock. Exposures do not usually show distinct bedded structure, though a slight variation in weathered surfaces may indicate the direction of the dip of the rock. As the rock weathers it changes in color from dull blue to shades of grayish and creamy white. Its hardness and general physical appearance are almost identically the same as those of the lower sandy member of the Whitecliffs chalk. It breaks in rudely conchoidal flakes and crumbles at a tap of the hammer. Small pieces of the fresh rock may be broken by the hand and crumbled to dust between the fingers, but not without some difficulty.

WASHINGTON AREA.

Location and surface features.—Washington is located upon the greensand south of and stratigraphically above the Saratoga formation, and since the exposures of chalk along the railroad north of the town are typical and convenient to the only line of transportation across the area, the name of the town is most serviceable for reference.

The Saratoga chalk-marl crops in the highland near the divide facing the valleys of Plum and Ozan creeks. The two small streams which flow southward between Columbus and Saratoga cut through this marl and have concealed it by overwash of soil and sand in their immediate valleys. Many small branches which flow northward into Plum and Ozan creeks have their sources in or flow across the exposed surfaces of the Saratoga marl. Thus it is indented by small valleys, and since the rocks dip toward the southeast at a very low angle in a direction opposite to the flow of the streams, the outcrop of the formation, especially its lower and northern part, is very irregular. Generally there is an abrupt rise in the land from the top of the Saratoga marl at its south side into the succeeding greensand marl. This feature is especially marked east of the railroad, where the greensand rises above the chalk in an escarpment nearly 100 feet high. As a result of the steep grade at the top of the chalk, its upper contact or south side is a less deeply indented border than the north side.

The time required to traverse and accurately locate the very tortuous boundaries of the Saratoga chalk-marl was more than the writer had at his command. The limits of the formation on the map were located approximately, however, by means of section lines and subdivision surveys, as established by residents now owning the land. The area as mapped includes practically all the Saratoga marl, together with some of the clay-marl below where it outcrops in the small cross valleys.

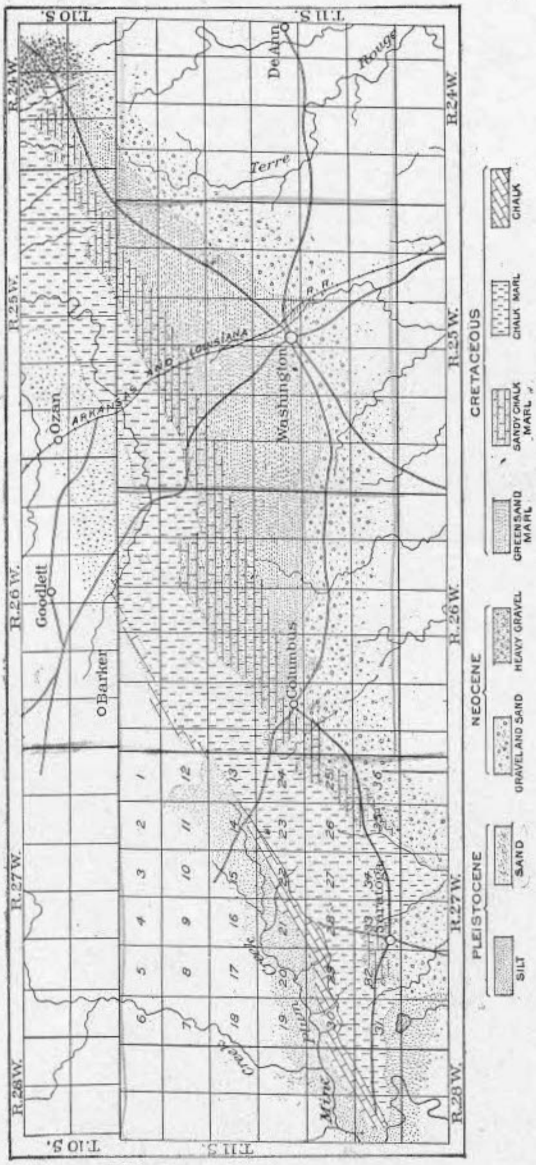
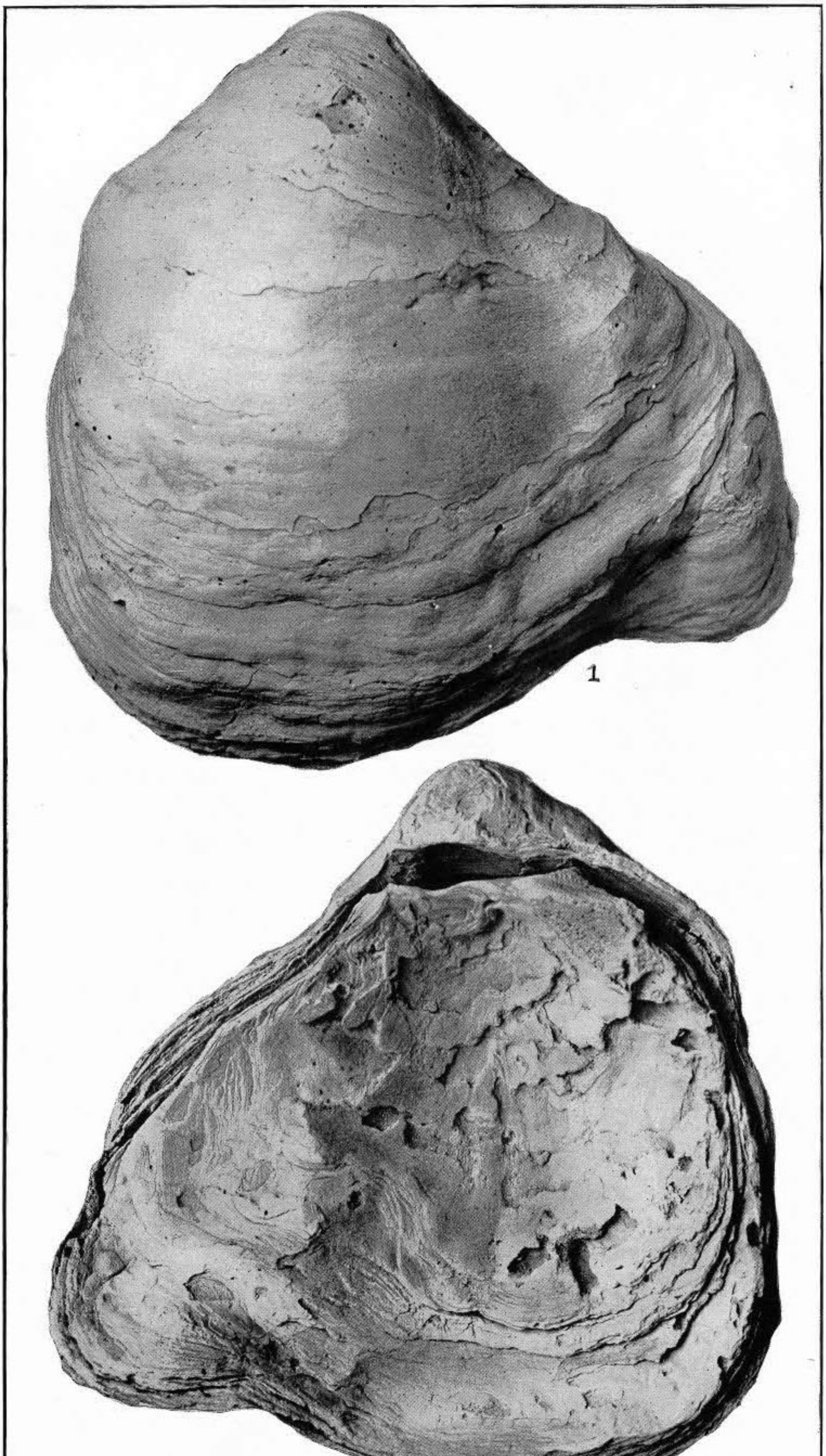


FIG. 63.—Map of the Washington area.

Description of the rock.—The rock section from the Saratoga chalk-marl down to the Whitecliffs chalk of the Saline Landing area is well exposed, as illustrated in section of fig. 64.



FOSSIL SHELLS, GRYPHÆA VESICULARIS, FROM THE BASE OF THE SARATOGA CHALK-MARL.

1, Outside view of large valve; 1*a*, reverse of 1, showing large and small valves together.

Section north of Saratoga (see fig. 64).

	Feet.
1. From the level of Saratoga down to Saratoga marl, surficial deposit of fine yellow sand, about	40
2. Saratoga marl exposed in brink of hill north and east of Saratoga and in knob one-half mile north of Saratoga, lower beds of the formation	20
3. Limy blue clay marl	175
This marl is exposed around the base of the hill at Saratoga, and in the cultivated lands 1½ miles north of the town it becomes gradually more chalky downward from the top to its contact with the chalk-marl below.	
4. Bluish friable chalk-marl	20 to 30
This is the gradation bed from the blue marl above into the purer chalk below.	
5. White chalk in the Saline Landing area	

Chalk-marl exposures.—Thick deposits of loose yellow sand cap the hill at Saratoga, replacing or concealing all of the Saratoga chalk rock, except the lower beds in the slopes east and northeast of the town. On the road from Saratoga to Saline Landing the traveler passes from the surficial sand to the clay-marl below without encountering the Saratoga formation.

The Saratoga chalk has been removed by erosion from the wide valley between Saratoga Hill and Mr. Thomas L. Jones's place in the

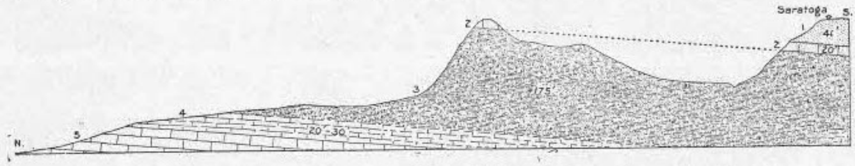


FIG. 64.—Profile section of chalk and marl, north from Saratoga (see section above).

NE. ¼ of sec. 35, T. 11 S., R. 27 W. The chalk rock should crop in the sides of the valley, gradually descending southward to the bed of the stream, about 1½ miles south of the Columbus-Saratoga road, but it seems to be concealed by the loose sand.

The lower part of the Saratoga chalk crops out in a considerable area on Mr. Jones's place in the NE. ¼ of sec. 35, the SW. ¼ of sec. 25, and the SW. ¼ of sec. 36, T. 11 S., R. 27 W. The chalky oyster-shell bed at the base of the formation is well exposed north, south, and west of the house, which is in the NE. ¼ of the NE. ¼ of sec. 35. Two specimens of the rock furnished by Mr. Jones were examined by Dr. Branner, and analyses were made to determine their quality.[a]

The localities of these specimens were visited with Mr. Jones by the writer, and samples of the chalk were collected from beneath the soil. These samples and those submitted to Dr. Branner were taken from the top of the oyster-shell bed near the base of the formation, and are not physically different from the rock occurring in the same bed examined at numerous other localities in this area. The fresh rock is grayish white and perceptibly sandy.

[a] Cement materials of southwest Arkansas.

The chalk-marl and succeeding sand contact extends east and west about one-fourth mile south of Mr. Jones's house, and then bears northward, crossing the road about one-half mile farther east. This surficial sand, resting upon the chalk, covers the high country between Mr. Jones's place and Columbus, in which no exposures of the chalk were observed. The outcrop of the lower beds, however, extends around north of the sand belt in cultivated fields toward Columbus.

The *Gryphæa vesicularis* shell bed at the base of the formation is exposed at the edge of the highland near the Columbus-Albrook road, 1 mile northwest of Columbus. The same bed is exposed also at the crest of the highland 1 mile north of the town. This fossil, characteristically abundant at the base of the Saratoga chalk-marl, is illustrated, natural size, in Pls. LI and LII. The chalk-marl highest in the formation occurs in the cultivated fields between the outcrop of the shell bed and the town.

From the vicinity of Columbus eastward to the end of the formation in the Washington area the whole of the Saratoga formation crops out or is covered only lightly by soil. Throughout this extent the basal shell-bed member of the chalk-marl is almost continuously exposed,

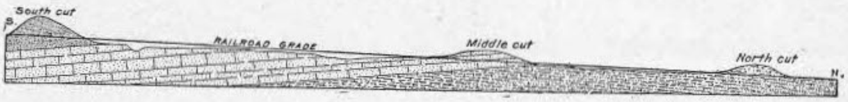


FIG. 65.—Section of chalk-marl along the railroad north of Washington, Ark.

except in the immediate bases of the valleys, and may be easily located through the open fields by means of the abundant shells weathering upon the surface. This bed is harder than the underlying clay marls and crops out near the heads of ditches and low breaks which descend to the more level "black land" bordering the creek valleys. Above the tops of these breaks the upper part of the Saratoga marl occurs in more level land, which, where a covering of soil occurs, is occupied by cultivated fields.

Between Columbus and the railroad north of Washington the chalky marl was not found to crop out more than 30 feet in thickness, and usually 10 to 20 feet of the lower part was all that could be found exposed.

The overlying greensand marl is more friable than the Saratoga chalk-marls, and its soil descends and conceals the contact between the two as well as the upper part of the latter. A section of the Saratoga marl with better exposures than are usually to be found occurs along the railroad north of Washington. This railroad passes up the side of the small valley almost directly across the formation, and the railroad cuts, as well as the near-by ditches descending into the valley, give fresh exposures of the chalk.

The north cut on the railroad is in a blue clay-marl 30 to 50 feet below the base of the Saratoga formation. It is 10 feet deep and about 300 feet long. The marl in this cut, which was originally blue, is weathered a creamy yellow to a depth of about 8 feet. It is transected by many joints, which pass nearly vertically across the bedding and continue down below the base of the cut. Along these joints, even below the zone of general weathering, the blue color of the marl is changed to yellow for a distance of several inches.

Analysis No. 15, Table III, p. 735, is of the unchanged blue marl from the base of the cut, 10 feet below the soil. The fresh marl is friable when dry and plastic when wet. It has a very fine texture and contains scarcely perceptible grit, yet the analysis shows it to contain 43 per cent of silica and 6.5 per cent of clay. Nearly 40 per cent of this silica is in the form of impalpable sand.

The *Gryphæa vesicularis* shell bed, the base of the Saratoga formation, is exposed in the field southwest of this railroad cut. The middle cut is one-third of a mile south of the north cut and is in the lower part of the Saratoga chalk above the oyster-shell bed. This cut is 300 feet long and but few feet deep, exposing an estimated thickness of 15 feet of rock. The structure of the rock indicates a low inclination toward the south, but is not sufficiently clear to determine the degree of dip. Ditches above the south end of the cut expose about 25 feet of chalk marl above that at the railroad, making the whole section of rock exposed at this place nearly 40 feet. Very little change in the nature of the rock could be noted in this section.

Analysis No. 16, Table III, is of the fresh chalk rock near the center of the middle cut, from the lower and more chalky part of the formation, and shows that this marl contains less than one-half the amount of silica found in the blue marl 40 feet below, though in physical appearance it is more sandy.

One-half mile south of the middle cut and a few hundred feet north of the south cut the top of the Saratoga marl is exposed in a ditch at the railroad. The sandy marl in this exposure is but little above the chalky marl at the top of the exposure opposite the middle cut. It is massive, dull blue, and very sandy, approaching a sandstone in composition.

The south cut, which is about 2 miles north of the town of Washington, is in the lower part of the greensand marl which overlies the Saratoga formation. This cut is about 30 feet in depth and about 300 feet long. From the surface downward about 20 feet the greensand is weathered from dark blue or greenish blue to shades of dull brownish yellow. Unaltered marl was collected from near the base of the cut, and its composition is shown in analysis No. 17, Table III. Physically it is very sandy, and the analysis shows that it contains 75.77 per cent of silica and 5.72 per cent of lime. Similar greensand marl occurs between this cut and Washington, and its thickness is estimated to be more than 100 feet.

From the railroad eastward to the end of the formation in this area, in sec. 29, T. 10 S., R. 24 W., the Saratoga chalk crops in an irregular belt one-half to three-fourths mile wide, making an intermediate upland, marked by projecting ridges and spurs between the high timbered greensand country on the south and the flat black land of the clay marls bordering Ozan Creek bottom on the north.

When this country was settled, more than fifty years ago, the soil of the Saratoga marl area was most desired because of its fertility and position on the upland. As a result the forest was cleared and the soil was exposed to subaërial agents of erosion. During the cultivation of this land much soil has been removed by erosion, and steep-sloping gullies render much of the area worthless.

OKOLONA AREA.

Location and surface features.—This area is in the southwestern part of Clark County, south and east of Okolona, between the bottom lands of Antoine and Terre Noire creeks.

As in the Washington area, the Saratoga marl in the vicinity of Okolona was located approximately by reference to sections and subdivision surveys established by landowners. The Saratoga chalky beds at the crest of the ridge south of Okolona are 50 to 150 feet above the lowland to the west and south. The crest of this ridge slopes southward with the dip of the rock, which is nearly 50 feet per mile.

East of Okolona the chalky marl forms a triangular area of rolling upland about 3 square miles in extent.

The stream which rises in the southwest part of the town and flows southeastward past the railroad station separates the area south of the town from that east of it. It is probable that the two areas in question are connected by narrow bands of outcropping marl which extend down the sides of the valley about 2 miles southeast of the village.

Neocene deposits of gravel and sand overlie the Saratoga formation about 2 miles east of Okolona and almost completely conceal it, beginning near the west side of sec. 30, T. 8 S., R. 21 W., and extending eastward to the Terre Noire Valley. This gravel and sand make a highland from the crest of the escarpment southward.

Below these deposits the Saratoga chalk-marl is partially exposed near the crest of the escarpment north of the Okolona-Dobyville road, from the east side of sec. 30, T. 8 S., R. 21 W., to the edge of the Terre Noire bottom, 1½ miles east of Dobyville.

Exposures.—The Saratoga marl, near the middle of the formation, is well exposed toward the top of the ridge at the forks of the road, 1½ miles south of Okolona. In physical appearance this rock is the same as that at the middle of the formation in the vicinity of Washington. It is massive and dull blue on fresh exposure and weathers to shades of drab or light yellow. Analysis No. 19, Table III, page 735, shows

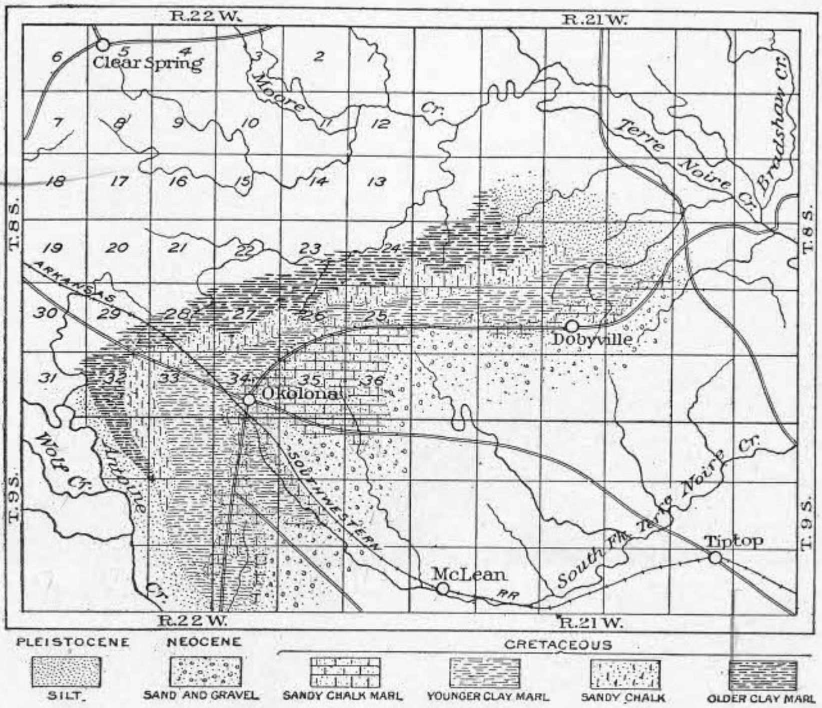


FIG. 66.—Map of the Okolona area.

the chalk-marl in this locality to contain nearly 43 per cent of silica and 49 per cent of calcium carbonate.

Two and one-half miles south of Okolona and one-fourth of a mile west of the road, on the Mat Hardin place, deep gullies expose the

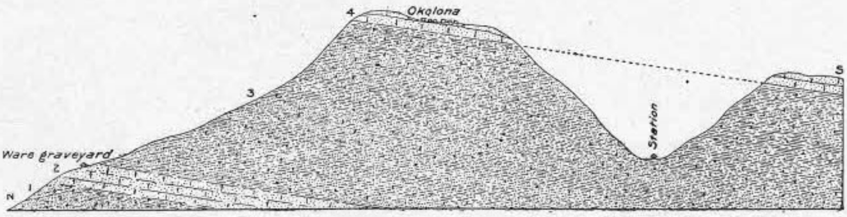


FIG. 67.—Section of chalk-marl at Okolona.

1, blue marl below Whitecliff formation; 2, sandy chalk-marl at base of Whitecliff formation; 3, blue chalky marl; 4, Saratoga chalk-marl.

lower 20 feet of the Saratoga marl as well as the blue marl below. The *Gryphæa vesicularis* bed is well marked, but the fossils are a little less abundant than in the Washington area, 20 miles farther west. In the lower 10 feet of the formation the chalk-marl is finer in texture and more chalky than in the higher beds. The result of an analysis of chalk from this place is given as No. 21, page 735, and shows that the amount of silica is nearly 10 per cent less than in the marl near the middle of the formation.

Numerous other exposures of the lower part of the formation occur in the gullies and slopes of the hill on the west side of the ridge, where the land was once cultivated. The top of the Saratoga marl passes beneath the bottom land of Little Missouri River, about 3 miles south of Okolona.

Five miles south of Okolona the greensand marl, which belongs above the Saratoga chalk, forms the bluffs from the level of the Little Missouri bottom up to the top of the ridge. This is the greensand

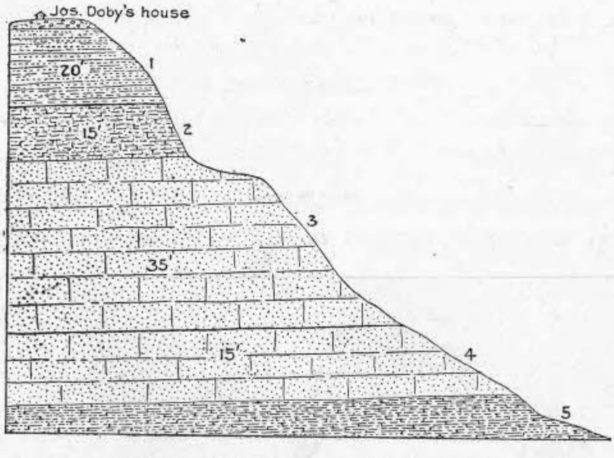


FIG. 68.—Section of chalk-marl at Dobyville (see section on page 723).

formation which occurs between Washington and the Saratoga chalk in Hempstead County.

About 20 feet of the middle portion of the formation is exposed in the Okolona-Garden road, 1 mile east of Okolona.

In the high rolling country east of Okolona the Saratoga chalk-marl is generally concealed beneath its own soil or beneath sand of Neocene age.

The lower beds of the chalk outcrop in the Okolona-Dobyville road, 2 miles west of Dobyville, and at several other places in the top of the escarpment between Okolona and Dobyville.

One-fourth of a mile north of Joseph Doby's house at Dobyville, the full section of the Saratoga chalk-marl is exposed in an old field.

An artesian well was drilled at Doby's house on the top of the hill in 1892, but no record was kept below the 20 feet of gravel and clay forming the crest of the ridge. Following is a section of Saratoga chalk-marl at Dobyville:

Section at Dobyville (see fig. 68).

	Feet.
1. Gravel, reddish and yellow stratified clays	20
2. Blue marl	15
3. Dull-bluish chalky marl	35
This marl is slightly indurated at the top and contains numerous casts of bivalve shells and gastropods. It is a calcareous sandstone at the top. The beds become more chalky downward until the lower part the chalky marl is found to be the same in nature as that described as occurring south of Okolona and in the Washington area.	
4. Even-textured chalk-marl, with *Gryphæa vesicularis* shells at the base	15
This member contains more chalk than those above and has finer texture. In places, also, very fine particles of greensand were noted disseminated through the marl.	
5. Fine-textured blue clay marl	
This is the upper part of the 150 to 200 feet of blue marl which lies between the Whitecliffs chalk formation and the Saratoga chalk-marl.	

From the vicinity of Okolona eastward, the outcrop of the Saratoga marl descends gradually from the brink of the escarpment to the level of the river bottom, nearly 2 miles east of Dobyville.

DECIPER AREA.

The next known occurrence of the Saratoga chalk-marl east of

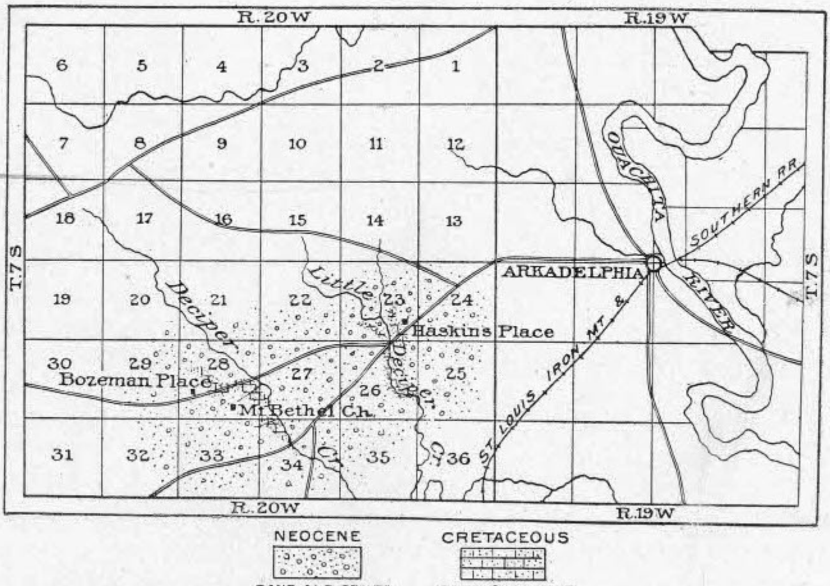


FIG. 69.—Map of the Deciper area.

Okolona is on the Big Deciper and Little Deciper creeks, 3 to 5 miles west of Arkadelphia. The Okolona and Deciper areas are separated by the flat sand and silt deposits of the Terre Noire and the higher broken gravelly land between the valleys of the Terre Noire and Deciper Creek.

The occurrence of the Saratoga chalk on the Deciper creeks is confined to outcrops in the middle and lower slopes of the valley near the Arkadelphia-Dobyville and Arkadelphia-Hollywood roads. The general location of the outcrop is shown in fig. 69.

The chalk-marls are overlain by thick deposits which, in the lower part, are composed of friable yellow sand interbedded with tough blue clay. Where contact exposures could be found these interstratified sands and clays are overlain by surficial deposits of yellow sand and coarse gravel.

From the level-topped ridges near the valleys, deep short gulches descend steeply to the creek valleys. The chalk-marls are exposed frequently in these gulches, occasionally on the spurs between them, and rarely in the valleys of the main creeks.

*Exposures on **Big Deciper** Creek.*—Near the center of sec. 28, T. 7 S., R. 20 W., on the Bozeman place, one-third of a mile northeast of the house, about 30 feet of the Saratoga chalk-marl is exposed from the base upward.

Section of the Saratoga chalk-marl at the Bozeman place, beginning at the base.

	Feet.
1. The blue marl from the *Gryphæa vesicularis* shell bed downward, exposed..	15
2. *Gryphæa vesicularis* shell marl	1–2
The limits of this shell bed are not sharply marked. Through 1 to 2 feet of the marl at the base the shells are abundant, and in it is a thin layer of shells indurated by calcareous matrix	
3. Even-textured blue chalk-marl	15
This chalk contains a sprinkling of fine greensand, and in all respects is the same as the lower 15 feet of the formation at Dobyville and Okolona. Analysis No. 24, Table III, shows this marl to contain about 30 per cent of sand and 61 per cent of chalk.	
4. Chalky marl, more sandy than that of 3	10–15
The sandy element in this marl increases in quantity upward.	
5. Overwashed, sandy soil to the top of the ridge.	

At the two points, one-fifth of a mile northeast, and 500 feet east of the Bozeman house, the chalky marls shown are higher in the formation and still more sandy than that of No. 4 in the section above. These outcrops are in the heads of narrow gulches which descend to the Deciper Valley. At the locality 500 feet east of the house the marl is very sandy, partially indurated, and contains numerous casts of fossils similar to those found near the top of the formation at Dobyville. The exposures here show about 10 feet of marl and are just below the springs which flow from the base of the stratified yellow sands and blue clays.

About 10 feet of interstratified sand and clay is exposed above the sandy marl, and then follows an overwashed yellow sandy soil to the top of the hill 40 feet above.

One-fourth of a mile southeast of Mount Bethel Church, near the northeast corner of sec. 33, T. 7 S., R. 20 W., beds similar to those east of the Bozeman house are exposed. Here a spring issues from the contact between the chalk-marl and the overlying sand and blue clay. The top of the marl is 70 feet below the crest of the hill. A bed of blue clay, having the consistency of putty and being very tough, projects as a ledge in the friable yellow sand above the marls, while thin laminæ of similar clay are contained in the yellow sand itself.

In the Arkadelphia-Okolona road, on the west bank of Big Deciper Creek, near the middle of sec. 34, T. 7 S., R. 20 W., the chalky sand of the upper part of the Saratoga formation is exposed, as well as in the bluff of the creek near by. The top of the sandy marl, which stands here 20 feet above the creek, contains casts of fossils as at the Bozeman place, and is overlain also by the same kind of interstratified sand and clay.

No fossils were seen in the beds above the chalk-marl, and they are distinctly unlike any strata in this region known by the writer to be of Cretaceous age.

Exposures on Little Deciper Creek.—Twenty feet of the even-textured lower and more chalky member of the Saratoga chalk-marl is exposed in the road cut on the Arkadelphia-Okolona road, 100 yards west of the Little Deciper Creek.

Overwashed gravel, sand, and clay conceal the higher beds of the chalk-marl. The *Gryphæa vesicularis* bed with underlying blue marl crops a few feet above the creek bottom.

One-half mile above the road, on the Wright place, the lower 30 feet of the Saratoga formation is exposed in the gullies at the west side of of the creek bottom. The lower 10 to 15 feet of the marl is identically the same as that found at the road and on the Bozeman place west of Big Deciper Creek, as shown in analysis 26, Table III. The basal member of the chalk-marl containing the same indurated shell bed outcrops here at about 10 feet above the creek bottom, and below it is the blue marl. Yellow sandy clays overlie the chalky marl here as in the exposures noted on Big Deciper Creek.

At the east side of the creek bottom on the Arkadelphia-Okolona road, and northward through the Haskins place, the lower part of the chalk-marl is exposed in ditches and gullies washed in an abandoned field.

Stop

ECONOMIC GEOLOGY.

GENERAL STATEMENT.

The purpose of the following brief notes on the nature of hydraulic cements is to place an estimate upon the relative values of the chalk and marl of southwestern Arkansas as cement materials.[a]

Common lime, generally known as quicklime, is calcium oxide (CaO), and is commercially produced by expelling carbon dioxide (CO_2) from lime carbonate ($CaCO_3$), which occurs as limestone, marble, or chalk, by the application of a high degree of heat.

Quicklime has an active chemical affinity for water, and when brought into contact they will rapidly combine, with the production of considerable heat. The lime increases in volume and slacks to a very fine powder. Should the lime when calcined contain about one tenth of its volume of clay, it will slack slowly upon the application of water, producing a slightly hydraulic lime. Where properly mixed with sand and water it will set, making a mortar of high grade. In case the lime rock contains 18 to 20 per cent of clay in combination, it will make a high-grade or eminently hydraulic lime. Such limes will not slack upon being calcined, but require to be reduced to powder in order to be of use. Eminently hydraulic lime of this grade has been used extensively as natural cements.

NATURAL HYDRAULIC CEMENT.

Natural hydraulic cement is made by burning a lime rock which contains lime, silica, alumina, besides magnesia, iron, alkalies, etc., varying in quantity within tolerably wide limits.

The proportion of clay (silicate of alumina) combined with the lime in natural cement, it is claimed, should be 35 to 40 per cent. Analyses of some of the best grades of natural cement are shown in Table I, page 727.

The rock is quarried, broken, and burned in a manner similar to that used in the manufacture of lime, but the burning is carried to higher temperatures. The burned material is ground to fine powder—the finished product—which, when properly mixed with water, will set, making a rock of stony hardness, and will endure for a long period either in air or water. It must be true, however, that a natural cement would ordinarily contain inert an excess of one or more of the substances used in its production, since the true combining proportions of a hydraulic cement can vary only within narrow limits.

An enormous quantity of natural cement is produced annually and used in all kinds of construction where hydraulic cement is in demand.

[a] The following American works on cements are the principal ones to which reference has been made in the preparation of these notes: Q. A. Gillmore, Limes, Hydraulic Cements and Mortars (1888); F. P. Spalding, Hydraulic Cement, its Properties, Testing and Use (1897); Uriah Cummings, American Cements (Rogers and Morrison, Boston, 1898); Addison Clarke, Architects' Hand Book on Cements (Wm. Wirt Clarke & Son, Baltimore, 1899).

TABLE I.—*Analyses of hydraulic limes and natural cements.*

No.	Silica.	Alumina.	Iron oxide.	Lime.	Magnesia.	Carbonic acid, water, and loss.	Alkalies.
1	24.33	1.92	....	71.91	....	....	....
2	29.71	5.35	3.29	59.53	0.95	....	....
3	28.39	11.71	2.29	43.97	2.21	2.44	9.00
4	26.69	7.21	1.30	43.12	19.55	1.00	1.13
5	30.00	11.00	1.50	34.00	16.00	....	....

1. Hydraulic lime, Lyme Regis, England. Used in the construction of London docks.
2. Eminently hydraulic lime, Hollywell, Wales. Used in the construction of the Liverpool docks.
3. Cumberland hydraulic (natural) cement, Cumberland, Md.
4. Akron hydraulic (natural) cement, "Cummings," Akron, N. Y.
5. Average natural cement.[a]

PORTLAND CEMENT.

GENERAL STATEMENT.

Natural rock is rarely found which contains, evenly distributed, the proper proportions of lime and clay, or lime and finely divided silica, which will produce a high-grade Portland cement. The usual Portland cement, therefore, is an artificial product made by burning to semifusion an intimate mixture of materials containing lime, silica, and alumina in proportions which are, within certain narrow limits, fixed and definite, and crushing finely the resultant "clinker." Four points must therefore be considered to be of cardinal importance in the manufacture of Portland cement:

(*a*) The cement mixture must be of the proper chemical composition.

(*b*) The materials of which it is composed must be finely ground and intimately mixed before burning.

(*c*) The burning must be conducted at the proper temperature.

(*d*) After burning, the clinker must be finely ground.

It will be seen that the last three fall properly under the head of processes of manufacture, which can not be discussed at length in the present paper. They are accordingly treated briefly in the section on processes of manufacture (p. 729). The first requirement is, however, of interest in connection with economic geology, and will therefore be discussed at some length in the following pages.

THE MATERIALS.

While chemical analyses of various good brands of Portland cements differ somewhat in the proportions of the various components shown, this variation will be found to be within quite narrow limits, at least

[a] From Architects' Hand Book on Cements.

so far as the more important constituents are concerned. The following analyses are of type brands of Portland cement produced in America and Europe:

TABLE II.—*Analyses of Portland cements.*

No.	Silica.	Alumina.	Iron oxide.	Lime.	Magnesia.	Carbonic acid, water, and loss.	Alkalies.
1	20.42	12.00	1.87	63.13	0.58	2.00	....
2	23.36	8.07	4.83	59.93	1.00	2.16	0.50
3	20.80	7.39	2.61	64.00	....	5.20	....
4	22.74	7.74	3.21	56.68	.57	6.24	.63
5	21.11	11.30	3.36	58.03	2.93	2.05	.71
6	22.00	8.00	3.00	62.00	2.00	....	....

1. Natural Portland cement. Boulogne, France.
2. American Portland cement. "Grant," Egypt, Pa.
3. American Portland cement. "Empire," Warren, N. Y.
4. English Portland cement. Given by Reid as first quality.
5. German Portland cement. Given by Reid as first quality.
6. Average Portland cement. Given by Architects' Hand Book on Cements, cited.

Theoretically a large number of materials might be made use of in the manufacture of Portland cement. Economic considerations, however, restrict the choice to such an extent that in practice only the following materials need be considered.

Two general classes exist:

(*a*) Argillo-siliceous limestones occur, containing the various necessary elements in nearly the proportions to give, after burning, a Portland cement. If the composition of this natural limestone be exactly right, as in the Boulogne (France) deposits, no admixture of other material is required. In Pennsylvania there are deposits of natural "cement rock" which runs somewhat too low in lime and therefore requires the addition, before burning, of a small amount of a purer limestone. The analyses of some of the chalk deposits of southwestern Arkansas, as shown in the pages below, indicate that they approach very near to a natural Portland cement rock. There are other chalks in the same vicinity which contain a large excess of lime, while other deposits contain an excess of silica and alumina in a very finely divided state. It would appear, therefore, reasonable that these chalky materials which occur in associated localities could be economically combined to produce Portland cement. Aside from the works of Pennsylvania, in the Lehigh Valley, and of the adjoining parts of New Jersey, however, almost all of the Portland cement manufactories of the United States belong to the second class, in which—

(*b*) The silica and alumina are obtained from one material, the lime from another. In this case clay or shale is the material commonly used to furnish the necessary amounts of silica and alumina. It should be noted that the silica must occur in combination with alumina as silicate of alumina or in a very finely divided state. As it is economically impossible to separate the sand from a sandy clay, care must be taken to select a clay deposit free from such impurities. Organic matter is of little importance, as it burns out during firing.

Experts on the nature of cements are divided in opinion concerning the chemical reactions produced in burning lime and clay together at the high temperatures used in the manufacture of Portland cement. It is generally considered, however, that the essential reaction in the production of Portland cement is in the combining of silica and lime, producing silicate of lime. The part taken by the alumina of the clay is a matter of varied opinion. It is believed by able chemists that it acts as a flux in aiding the combination of silica and lime and probably combines, in part at least, with them.[a]

Oxide of iron is believed to have an influence in the fusion of the lime and silica similar to that exerted by alumina. Iron is the usual coloring agent in Portland cement, giving it shades of yellowish to dark greenish drab, which coloring depends upon the amount of the iron constituent, and the extent of burning.

The alkalies, potash and soda, in small quantities, are considered to have a beneficial effect as flux in the production of hydraulic cements.

That magnesia occurring in cement material as carbonate of magnesia acts in a way similar to that of carbonate of lime during calcination in the progress of cement manufacture is claimed by some leading authorities, and that it is a strong agent in any cement as long as it is not in excess of its true combining proportion with the silica and alumina present. Other authors of equal prominence assert that when calcined at low temperatures it is active settling, but when present in Portland cement, which is burned at very high temperatures, it is slow of hydration, and on this account will reduce the quality of the cement. Others claim that both magnesia and alumina are inert substances in a cement.

The manufacturers of Portland cement will not admit more than 3 per cent magnesia in their product, while those producing natural cement admit 15 to 18 per cent magnesia in their best grades.

PROCESSES OF MANUFACTURE.

The following procedures are necessary in the manufacture of Portland cement:

1. Preparing and grinding the materials.
2. Mixing the materials.
3. Burning the mixture to clinker.
4. Grinding the clinker.

[a] J. S. Newberry, Mineral Resources of the United States, 1892.

(1) The methods of preparing and grinding will depend upon the nature of the materials. If the material is natural cement rock and hard, it is required to be reduced in a crusher and then ground in emery or other mills that will reduce it to fine powder. If the material is chalk or marl, as that occurring in the Arkansas region, similar mills will be required in grinding, but with greater economy and less time. The clay is dried in open air, over steam coils, or by other artificial dryers, and then ground in emery mills, as is the crushed limestone, or passed through a disintegrator.

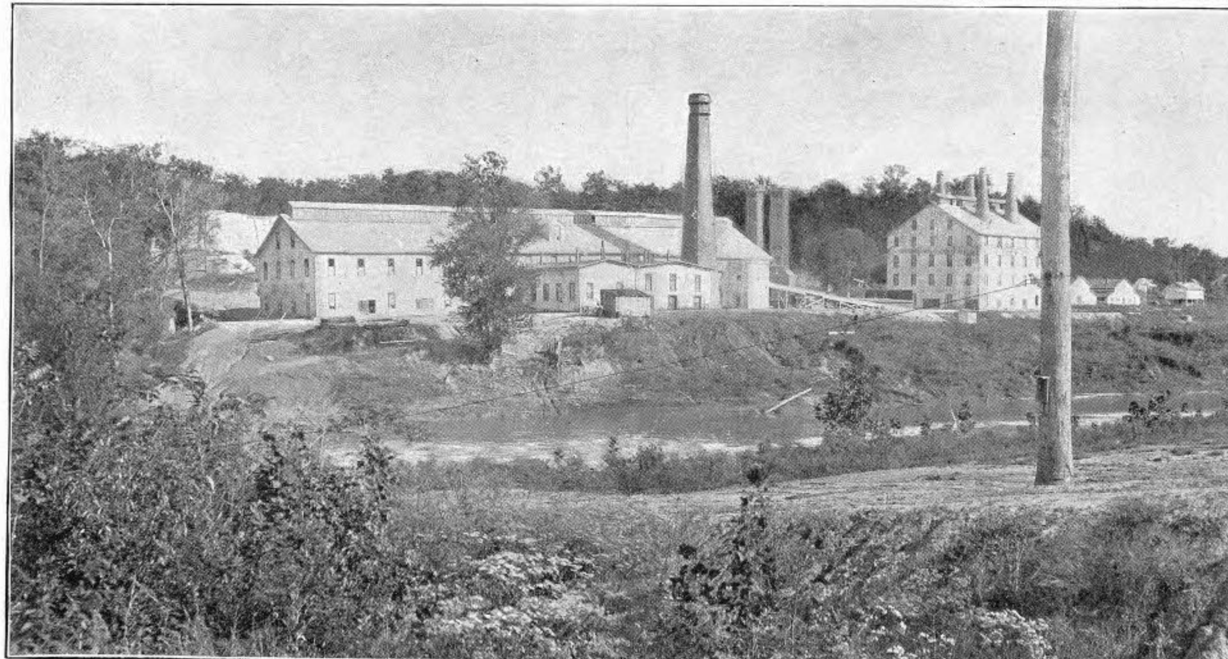
(2) After being thus finely ground separately, the materials are weighed and mixed thoroughly by either the dry or wet processes. In the dry process the mixing usually occurs before the final stage of reduction. This process is considered most economical when the material is formed into bricks and the dome or shaft kiln is utilized in burning. In the wet process the finely divided material is mixed in series of pans or vats, when it is still further reduced. The wet process is used when rotary kilns are employed. In this case the mud or "slurry" is sent in a semifluid condition to the kiln, where it is resolved into pellets in the process of burning. By whatever method the materials are mixed, it is necessary to so intimately associate the particles of lime and clay in the proper proportions that when burned they will chemically combine without an excess of either remaining.

The kilns can not be described here in detail in the space allowed. The dome kiln is practically only a slightly modified limekiln, while shaft and rotary kilns are too complicated to be described briefly.

(3) In the process of burning, the heat should be applied gradually, so that the moisture is completely removed before the carbonic acid is expelled. This demands perfect control of apparatus in increasing and regulating the heat. Gradual increase of the heat is continued until the proper stage of vitrification of the material is reached, producing a clinker.

The texture rather than the color of clinker generally indicates its quality, for the shade of color depends upon the quantity of iron contained. There is a change in color of any cement material in the progress of burning, and the color of the clinker producing the best cement in each case will be determined by experiment.

(4) After burning the clinker, if in large lumps produced by dome and shaft kilns, it is first reduced in crushers to proper sizes for grinding. The next reduction is accomplished in modern plants in ball mills, and the final stage in tube mills. In some cases, however, emery mills are used in place of the ball and tube mills. The clinker produced by rotary kilns, not being in large pieces, does not require crushing, but can be sent direct to the mills. By whatever means the clinker is ground, it is essential that the final product be reduced to the finest powder.



PORTLAND CEMENT WORKS AT WHITECLIFFS LANDING.

TESTS OF THE PRODUCT.

The first requisite of a Portland cement is that it shall not contain free lime, which will cause it to expand and crack after the addition of water in making the mortar. To overcome this defect, air is permitted to have access to the fresh cement in order that the free lime may be hydrated and slacked before the cement is used.

The fineness of a cement is determined by the percentage which passes standard sieves. The three following forms of sieves are generally adopted for use in testing fineness:

No. 50 (2,500 meshes per square inch), No. 35 Stubbs's wire gage.
No. 74 (5,476 meshes per square inch), No. 37 Stubbs's wire gage.
No. 100 (10,000 meshes per square inch), No. 40 Stubbs's wire gage.

The fineness of cements demanded in the market is variable, depending upon the requirement of use and upon the engineer submitting the specifications. In public works the usual demand is that 90 per cent shall pass the No. 50 sieve of 2,500 meshes per square inch.

Requirements vary, also, as to the time of the initial setting of standard Portland cement, depending on the use to which it is applied. Cement to be used in water must be quick setting. The average high-grade Portland cement, when properly mixed, should set sufficiently to bear light pressure of the thumb nail in about thirty minutes. The time of initial setting, however, is not an index of the strength or durability of the cement. The last test usually applied is that for strength and is generally performed by the purchaser, as well as the maker, especially when large quantity is demanded.

The tests to determine strength are tensile, compressive, transverse, and shearing. Of these the tensile test only is usually applied in determining the fitness for commercial cement. The cement is prepared for testing either neat—i. e., without sand, or with sand. In the first case the cement is mixed rapidly and thoroughly with approximately 25 per cent of water, molded in 8-shaped form, and allowed to remain in air for one day. It is then immersed in water and at a specified day or week is tested for tensile breaking strength in pounds per square inch of broken section. In the second case sand is thoroughly mixed with the cement dry, in parts of 1 to 1 or 3 to 1, and then mixed rapidly with 15 per cent or 12 per cent, respectively, of water. The breaking test is performed as in the first case.

Following is the tensile strength which has been required in standard specifications for good Portland cement:

Neat: One day in air and six days in water, approximately 350 pounds per square inch.

One sand to one cement: One day in air and six days in water, approximately 200 pounds per square inch.

Three sand to one cement: One day in air and six days in water, approximately 75 pounds per square inch.

CHALKS AND CLAYS OF SOUTHWESTERN ARKANSAS AS PORTLAND CEMENT MATERIALS.

ECONOMIC NOTES ON THE CHALKS AND MARLS.

Chalk of the Rocky Comfort area.—Analyses Nos. 1, 3, and 4 of Table III (p. 735) are of the average quality of white chalk in the vicinity of Rocky Comfort. They show an excess of lime over silica in the ratio of nearly 7 to 1. No. 2 is of the marl which immediately underlies the white chalk in the same vicinity. This marl is a combination of chalk, clay, and free silica in a very finely divided friable state. The ratio of lime to silica is nearly 1.5 to 1. An association of the chalk and marl, both of which are here accessible in large quantity, can be effected, it is believed, producing desired ratios of lime and silica for Portland cement.

Chalk of the Whitecliffs area.—Analyses Nos. 7, 8, and 9 are of the average white chalk occurring at Whitecliffs. The white chalk here and at Rocky Comfort belong to the same formation, and the analyses indicate that they are approximately of the same nature.

Marl similar to that below the chalk at Rocky Comfort occurs here also below the chalk, extensively exposed in the bluffs northwest of the village of Whitecliffs, 1 to 2 miles north of the Portland cement works at Whitecliffs Landing. A massive bed of siliceous, bluish or grayish white chalk, 25 feet thick, occurs immediately beneath the purer white chalk at the Portland cement works and in the bluffs facing the river immediately above the ferry. This siliceous chalk contains 3.8 parts of lime to 1 of silica—almost the proportions for a natural Portland cement rock. It contains 5 per cent of clay and a little more than 7 per cent of very fine siliceous sand. There is doubtless a small variation in the nature of this siliceous chalk vertically as in the purer white chalk above.

Chalk of the Saline Landing area.—Analyses Nos. 10, 11, 12, and 14 in the table show variations of the white chalk in the vicinity of Saline Landing. This is the eastward extension of the same chalk deposit that is found at Whitecliffs. Only the upper part of the chalk is exposed in this district, however, and the marl beneath is concealed by creek and river bottom silts. Marl similar in nature to that below, however, occurs here above the white chalk. The relations of the chalk and marl are described in the discussion of chalk of the Saline Landing area. Analysis of this marl from near the middle of the formation is shown in No. 13 of the table. Nos. 15 and 18 are of the same marl in the adjoining Washington area. In the case of No. 13 the relation of lime to silica is as 1 to 1.2, while in No. 15 it is as 1 to 2. Other analyses of the same marl formation are found in Nos. 23 and 24 from the Okolona and Deciper areas, respectively.

The clay of this marl is intimately distributed with the chalk and is to all physical appearances remarkably even in texture and quality. There appears no reason why an association of the marl and white chalk may not produce a correct mixture for Portland cement.

Saratoga chalk-marl.—This chalk-marl is described above in the three separate areas of Washington, Okolona, and Deciper as a siliceous dull-blue to whitish chalk rock. The free silica in this rock is in the form of very fine sand, perceptible to the touch but not ordinarily to the eye, except possibly as it occurs in the upper part of the formation. The lower 10 to 15 feet of the deposit is more chalky than succeeding beds. Analyses of this lower part of the chalk-marl are shown in Nos. 16, 21, 22, 25, and 26 of the following table. They are from the three areas of the Saratoga formation in this region and show very slight variation in composition. No. 16, which is of the chalk-marl from the railroad cut north of Washington, contains the highest percentage of chalk, the ratio of lime to silica being nearly 2 to 1. Nos. 21 and 22, from the Okolona, and 25 and 26, from the Deciper area, contain lime and silica in ratios of nearly 1.1 to 1. Dr. J. C. Branner reports analyses of two samples of the Saratoga chalk-marl from the lower shelly part occurring on the place of Mr. Thomas L. Jones, 2 miles west of Columbus, the material furnished by Mr. Jones. One analysis from the rock which was reported to have been plowed up indicates a quality equal to the high-grade chalk. The lime and silica in the other sample have the ratio of 3.3 to 1, almost the quality of natural Portland cement material. The writer visited the localities of these samples with Mr. Jones, found the normal siliceous chalk marl observed at numerous other places near the base of the formation, and was led to believe that the samples submitted were not of the average marl.

The Saratoga chalk-marl becomes more sandy toward the top until it is succeeded by a friable calcareous glauconitic sandstone. Analysis No. 19 is of the medial portion of the marl, giving an approximate ratio of lime to silica as 1 to 1.6.

From the records of these analyses it will be seen that in order to produce Portland cement from the Saratoga chalk marl it will be required to supply chalk instead of clay.

From the vicinity of Columbus to Saratoga, a distance of 5 miles, the crops of the white chalk and Saratoga chalk marl are separated by the outcrop of intervening marl 1 to 2 miles in width.

The chalk is not exposed and is not known to occur east of a point north of Columbus, so that it is separated from the Saratoga marl in the eastern part of the Washington, in the Okolona, and in the Deciper areas.

Considering the practically unlimited quantity of chalk associated with marls near Rocky Comfort, Whitecliffs, and Saline Landing, it is not believed, therefore, that the Saratoga chalk marl can be utilized as economically in the manufacture of Portland as the chalk of the Whitecliffs formation.

Notes on the Texas chalk.—By reference to table of analyses No. IV, page 737, it will be observed that the Texas chalk and marl approximate very closely in quality the Arkansas deposits, of which they are a southward extension. Nos. 1, 2, 3, and 4, Table IV, show the composition of the chalk proper, while No. 5 is of the chalk marl between the chalk and succeeding marl. The lime and silica in the marl, according to the analysis, have the approximate ratio required in a natural Portland cement rock. When calcined the product will contain approximately 60 per cent of lime and 24 per cent of silica. The succeeding blue marl and still higher greensand marl are in quality similar to those in the Arkansas section, occupying the same general positions in the stratigraphic section.

Explanation of analyses.—In the chemical analyses of the chalk and chalk-marl the alumina and iron oxide were not separated, for the reason that the percentage of the latter will average probably not exceeding 1 per cent.[a]

The reaction of the iron is believed to be practically the same as that of alumina in the manufacture of cement, and for this reason also they may be conveniently thrown together. In the case of the marl both below and above the white chalk, the percentage of iron oxide is greater, but it is believed that in no case will it exceed 2 per cent.

The alkalies—potash and soda—are omitted from consideration since it has been determined by a number of analyses of the chalks and marl that both together will average not more than about three-fourths of 1 per cent.

The amount of magnesia, it will be observed, is invariably less than 1 per cent.

The chemical analyses show that there are no substances that would impair the quality of Portland cement. As explained above, under "Processes of manufacture" (p. 730), the water and carbon dioxide are expelled from the rock, leaving the essential substances, silica, alumina, and lime, together with the nonessential small parts of magnesia and alkalies, as constituents of the cement. The quantity of the three essentials are found in the first three columns of the table, and from them, as a basis, the relative values of the chalk and marls as cement materials may be estimated.

By reference to the analyses of standard Portland cements, Table II, page 728, it will be seen that the proportions of lime to silica are nearly as 3 to 1.

[a] An average of 10 analyses of these chalks, made by the Arkansas Geological Survey gives 1 per cent of oxide of iron, the extremes being 0.42 and 1.91 per cent. Cement materials of Southwest Arkansas, by Dr. J. C. Branner: Trans. Am. Ins. Min. Eng., 1897.

TABLE III.—*Analyses*[a] *of chalk and chalk marl from southwestern Arkansas.*

No.	Silica, SiO_2, and insoluble.[b]	Ferric oxide and alumina, $Fe_2O_3+Al_2O_3$.	Lime, CaO.	Magnesia, MgO.	Carbonate of lime, $CaCO_3$.	Carbonate of magnesia, $MgCO_3$.
1	6.15	5.79	46.81	0.33	83.60	0.69
2	25.13	3.90	35.81	.61	64.32	1.28
3	8.53	1.22	48.50	.38	86.60	.78
4	7.32	1.26	49.94	.32	89.17	.67
5	27.28	5.00	34.81	.61	62.15	1.28
6	12.67	1.93	45.56	.43	81.35	.90
7	6.83	.95	50.41	.22	90.01	.46
8	7.86	1.30	49.55	.28	88.48	.58
9	7.97	1.09	49.64	.35	88.64	.73
10	14.68	2.15	45.03	.44	79.40	.92
11	4.91	.93	51.78	.30	92.46	.63
12	7.35	1.06	49.66	.34	88.67	.71
13	34.76	5.18	29.10	.71	51.95	1.49
14	12.65	1.66	45.85	.49	81.87	1.02
15	43.09	6.55	22.77	.92	40.65	1.93
16	21.90	2.35	40.57	.59	72.41	1.23
17	75.77	5.46	5.72	.91	10.21	1.91
18	30.68	4.91	32.60	.48	58.22	1.00
19	43.72	2.76	27.95	.42	49.90	.88
20	35.16	2.85	32.75	.43	58.48	.90
21	31.05	3.46	32.18	.69	57.41	1.44
22	31.01	2.93	34.63	.50	61.83	1.05
23	36.17	5.37	29.16	.48	52.06	1.00
24	32.26	7.05	17.24	.63	30.78	1.32
25	30.84	3.73	34.31	.60	61.26	1.26
26	30.29	3.31	34.77	.55	62.08	1.15
27[c]	5.45	3.87	....	....	88.58	....

[a] By chemists of the United States Geological Survey.

[b] "Insoluble" refers to insoluble in HCl. The other columns refer to the soluble portions only.

[c] Chalk at Medway, England, used in the manufacture of Portland cement. Quoted from Dr. J. C. Branner, on the Manufacture of Portland cements: Geological Survey of Arkansas, 188, Vol. II, p. 294.

References to analyses.

Rocky Comfort area.

1. SW. ¼ of the SW. ¼ of sec. 32, T. 12 S., R. 32 W., 2 miles southwest of Rocky Comfort. White chalk near the middle of the chalk formation.
2. NE. ¼ of the NE. ¼ of sec. 30, T. 12 S., R. 32 W., 2 miles west of Rocky Comfort. The chalky marl immediately below the white chalk.
3. Rocky Comfort, Little River County, Ark., near the NE. corner of the NE. ¼ of sec. 28, T. 12 S., R. 32 W., from lower middle part of the white chalk formation.
4. Same locality as 3, from the lower part of the white chalk formation.

Whitecliffs area.

5. NE. ¼ of the NE. ¼ sec. 35, T. 11 S., R. 29 W., top of the lower sandy marl bed beneath the white chalk.
6. Chalk bluff, Whitecliffs Landing, near the middle of the bluff in the lower part of the white chalk.
7. Chalk bluff, Whitecliffs Landing, 15 feet above the base of the purer white chalk.
8. Chalk bluff, Whitecliffs Landing. White chalk 10 feet below the top of the cliff.
9. Cement Works, Whitecliffs Landing. Average of the lower 35 feet of the purer white chalk in the quarry at the cement works.

Saline Landing area.

10. Saline Landing, Howard County, Ark. Sec. 35, T. 11 S., R. 28 W., from the middle of the chalk bluff.
11. NW. corner of the NE. ¼ of the SW. ¼ of sec. 30, T. 11 S., R. 27 W. White chalk from very near the top of the chalk formation.
12. Near the center of the SE. ¼ of the SW. ¼ of sec. 21, T. 11 S., R. 27 W., from near the middle of the white chalk.
13. Near the base of the knob 1 mile N. 15° E. from Saratoga, Ark. Chalky blue marl 100 feet above the top of the white chalk.
14. Near the center of the east side of the SW. ¼ of the NW. ¼ of sec. 22, T. 11 S., R. 27 W., from the lower part of the white chalk.

Washington area.

15. North cut on the railroad about 3 miles north of Washington, Ark. Chalky blue marl 40 feet below the base of the Saratoga chalk-marl.
16. Middle cut on the railroad about 2½ miles north of Washington, Ark., from the center of the cut in the lower part of the Saratoga chalk-marl.
17. South cut on the railroad about 2 miles north of Washington, Ark., from the greensand marl in the center of the cut.
18. SE. ¼ of sec. 25, T. 10 S., R. 25 W., head of Morisett ditch, from bluish chalky marl about 150 feet below the Saratoga chalk-marl.

Okalona area.

19. Forks of road 1½ miles south of Okolona, Ark., from middle of Saratoga chalk-marl.
20. SE. ¼ of sec. 4, T. 9 S., R. 22 W., about ½ mile southwest of Okolona, from sandy marl bed at base of the Whitecliffs chalk formation.
21. 2¼ miles south of Okolona on the Mat. Hardin place, from the lower 15 feet of the Saratoga chalk-marl.
22. Same locality as 21. Saratoga chalk-marl 16 feet above the base.
23. SE. ¼ of sec. 4, T. 9 S., R. 22 W., about 1½ miles south of Okolona, yellowish chalky marl about midway between the Whitecliffs and Saratoga formations.

Deciper area.

24. J. L. Bozeman's place, ½ mile northeast of the house, in the NW. ¼ of sec. 28, T. 7 S., R. 20 W., from the bluish chalky marl 4 feet below the base of the Saratoga chalk-marl.
25. Same locality as 24, from Saratoga chalk-marl 10 feet above the base.
26. Little Deciper Creek at Okolona-Arkadelphia road, from Saratoga chalk-marl about 10 feet above the base.

TABLE IV.—*Analyses of Texas chalk and marl.*

No.	Silica, SiO_2, and insoluble.	Ferric oxide and alumina, Fe_2O_3 and Al_2O_3.	Lime, CaO.	Magnesia, MgO.	Carbonate of lime, $CaCO_3$.	Carbonate of magnesia, $MgCO_3$.
1	5.77	2.14	50.45	0.28	90.15	0.58
2	5.94	1.72	48.73	....	86.57	....
3	10.32	6.56	45.30	....	79.75	....
4	11.31	7.50	42.61	....	76.47	....
5	15.98	8.47	38.86	....	70.60	....
6	48.02	20.95	14.26	....	24.62	....
7	60.82	21.30	3.66	....	6.51	....
8	23.55	1.50	39.32	.28	70.21	.58

1. Fresh rock from quarry, average material used in the manufacture of cement, Alamo Cement Works, 3 miles north of San Antonio, Tex.
2. Brushy Creek, Williams County, Tex., 100 feet above base of chalk.
3. Brushy Creek, Williams County, Tex., middle part of chalk.
4. Brushy Creek, Williams County, Tex., upper part of chalk.
5. San Gabriel River, Williams County, Tex., chalk-marl at top of white chalk.
6. Williams County, Tex., lower part of blue marl above the white chalk.
7. Williams County, Tex., greensand marl, central part above blue marl.
8. Average fresh rock from quarry, Texas Portland Cement Works, 3 miles west of Dallas, Tex., lower 20 feet of white chalk.

CLAYS AND SHALES.

Introductory statement.—The writer has not been able to make a study of the clays of southwestern Arkansas even in the immediate region of the occurrence of the chalk. All that is known of the clays in the State is contained in the manuscript report on clays by Dr. J. C. Branner. Unfortunately, the State has not yet published this report.

The information below on "Available clays" is from a publication on Cement Materials of Southwest Arkansas, by Dr. Branner.[a]

Available clays.—Clays, to be available for the manufacture of Portland cement, must, besides having the right composition, be sufficiently abundant, uniform in character, and convenient to transportation to make them cheap and trustworthy. In no case with which we are acquainted are the surface clays found in the immediate vicinity of the chalk deposits to be depended upon. Such clays are, as a rule, too sandy and too thin, and, above all, they are not of uniform composition. Reference is here made especially to the leached sandy clays, or "slashes," overlapping the chalk beds to the north and east of Rocky Comfort, and the clays of the bottom lands south and west of Whitecliffs, and those south, north, and west of the chalk exposures at Saline Landing. Fortunately, the Tertiary rocks which overlap the Cretaceous ones to the south and east contain an abundance of

[a] Trans. Am. Inst. Min. Eng., 1897.

excellent clays available for the manufacture of cement. Some of these clay beds are already being utilized for the manufacture of pottery at Benton and Malvern (Perla switch). At these two points the beds are on the railway. There are many other deposits on and near the railway that are as yet unused, and, indeed, generally unknown. Such occur about Arkadelphia, Malvern, between Malvern and Benton, between Benton and Bryant, at Olsens switch, and at Mabelvale. At Little Rock, also, there are extensive beds of both clays and clay shales, while scores of beds of clay shales may be found along the line of the Little Rock and Fort Smith road to Fort Smith and beyond.

The Tertiary clays at Benton, Bryant, Olsens switch, Mabelvale, and Little Rock are all horizontal or nearly horizontal beds dipping gently toward the southeast. They can be had in many places by stripping off a few feet of post-Tertiary gravel and soil; but in places the covering is too thick to be removed, and the clays can be had only by a system of drifts. In some instances the clay beds are so nearly uniform in character as to give rise to the idea that they have the same composition throughout. This, however, is true only in a limited sense; the clays do not seem to vary within the small areas thus far worked, but it is highly probable that they will be found to change to sands when a wide area is taken into consideration. This is not a serious objection to the deposits, however, as there is no possibility of the supply being exhausted.

Location of clays.—The following information regarding the local conditions of occurrence may be useful to those seeking information about the Arkansas clays. Only a few of the many known localities are here mentioned. On account of the geographical relations to the chalk beds, only those places convenient to railway transportation along the St. Louis, Iron Mountain and Southern Railway southwest of Little Rock are spoken of in this paper. Should a factory, on account of fuel or for other reasons, be located west of Little Rock, clays derived from the Carboniferous clay shales would have to be used. Of these there is no lack between Little Rock and Fort Smith.

Clays at Little Rock.—There are two general classes of clays at Little Rock available for cement manufacture: (1) The Tertiary clays that occur in horizontal beds in the southern and southwestern part of the city; and (2) the Carboniferous clay shales exposed in the railway cuts along the south bank of the Arkansas River, in the cuts west of the town, and in others west of Argenta.

There are other clays about Little Rock and Argenta, such as the chocolate-colored clays along the margins of the river bottoms, and the pinkish clays forming the high river terraces and used for making bricks on the north side of the river; but these latter two kinds of clays are not available for cement manufacture, partly because they are too sandy, but also because they are not homogeneous. An analysis of the pink clay of Argenta shows it to contain more than 83 per cent of silica.

The Tertiary clays were laid down, like the other Tertiary beds of Arkansas, as sediments in water. These strata were originally, and are still, very nearly horizontal. After the old sea bottom was elevated, however, the ordinary erosion cut down and washed away these soft sediments rapidly, so that now there remains on the hills but a small part of the original beds, and these have been still further obscured by gravels, clays, and soils that cover most of the region. The original bedding of these clays is to be seen only in a few gullies along the west-sloping hills in the western part of the city, and in the wells that penetrate them. They are of an olive-green to gray color, and upon exposure break up in small cuboidal fragments or, when thoroughly wet, pack together closely. They are cut in several gullies in the southwestern part of the city, and are penetrated by many of the wells.

The Carboniferous clay shales are well exposed in the railway cut near the upper bridge, and where the electric power house stands. Similar shales may be found here and there over a large part of Pulaski County, within the Carboniferous area. The objection to these shales is that they require grinding before they can be used in cement making, and the grinding, of course, makes them more expensive.

Composition of the clays.—The following analyses show the composition of the common run of the pottery clays and fullers' earths of Arkansas. These analyses are of representative samples, and a reasonable assurance may be given that the clays as found in place are as nearly homogeneous as clays ever are. Most of them contain some sand, usually quite fine. In those cases in which the percentage of sand is given the analyses are of the washed clay. This table might be greatly extended, as analyses of a large number of the clays of Arkansas are available. These, however, will give a correct idea of the general nature of the clays.

TABLE V.—*Analyses of typical Carboniferous clay shales from Arkansas, giving silica, alumina, ferric oxide, lime, magnesia, soda, potash, and water.*

No.	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	Na_2O.	K_2O.	Water.	Total.	Sand in air-dried clay.
1.....	53.30	23.29	9.52	0.36	1.49	2.76	1.36	5.16	100.48	......
2.....	62.36	25.52	2.16	.51	.29	.66	1.90	5.32	98.72	......
3.....	58.43	22.50	8.36	.32	1.14	1.03	2.18	6.87	......	......
4.....	65.12	19.05	7.66	.34	.31	.85	1.23	6.12	......	21.88
5.....	57.12	24.32	8.21	.72	1.74	.53	2.07	7.58	......	......
6.....	55.36	26.96	5.12	.30	1.16	1.03	2.69	7.90	100.52	......
7.....	51.30	24.69	10.57	.32	.63	.72	2.18	9.11	......	......
8.....	69.34	22.56	1.41	Trace.	Trace.	2.31	.04	5.12	......	......

1. Clay shale from railroad cut at south end of upper bridge, Little Rock.
2. Decayed shale from Iron Mountain railroad cut at crossing of Mount Ida road, Little Rock.
3. Clay shale from Nigger Hill, Fort Smith.
4. From Harding & Boucher's quarry, Fort Smith.
5. Clay shale from Round Mountain, White County, sec. 6, T. 5 N., R. 10 W.
6. From Clarksville, east of college.
7. From SE. ¼ of SW. ¼, sec. 31, T. 10 N., R. 23 W.
8. From NW. ¼, sec. 23, T. 1 N., R. 13 W.

TABLE VI.—*Analyses of typical Tertiary clays from Arkansas.*

No.	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	Na_2O.	K_2O.	Water.	Titanic acid.
1..........	63.07	23.92	1.94	0.23	Trace.	1.08	1.15	7.07	......
2..........	72.44	18.97	1.59	.18	Trace.	.91	1.35	5.39	......
3..........	69.95	22.34	1.44	Trace.	.08	1.18	1.28	5.98	......
4..........	71.09	19.86	1.81	.11	....	.81	1.45	5.67	......
5..........	65.27	18.75	7.34	.81	1.26	.81	1.10	6.88	......
6..........	64.38	17.29	8.25	1.11	.80	.42	1.41	6.95	......
7..........	63.19	18.76	7.05	.78	1.68	1.50	.21	7.57	......
8..........	64.49	23.86	2.11	.31	Trace.	1.82	.11	8.11	......
9..........	67.90	22.07	1.33	.05	.59	.38	1.15	6.86	......
10..........	48.34	34.58	1.65	.81	Trace.	1.26	.44	12.94	1.56
11..........	62.34	20.63	3.34	.17	.67	.33	.73	9.34	1.49
12..........	68.03	17.19	3.00	.81	1.00	.54	1.00	6.31	......
13..........	63.29	18.19	6.45	.31	2.44	Trace.	.56	......	......
14..........	76.33	16.04	1.24	By difference, .99				5.40	......
15..........	75.99	16.12	1.35	By difference, 1.45				......	......
16..........	73.24	19.61	1.04	By difference, .78				......	......
17..........	45.28	37.39	1.71	1.83	.29	......	......	13.49	......

1. Benton, Hick's bed, T. 2 S., R. 15 W., sec. 12.
2. Benton, Rodenbaugh, T. 2 S., R. 15 W., sec. 12.
3. Benton, Herrick & Davis's bank.

4. Benton, Henderson's pit, upper bed.
5. Mabelvale, A. W. Norris's well.
6. Olsen's switch, "fuller's clay."
7. "Fuller's earth," Alexander, T. 1 S., R. 13 W., SW. ¼ of SE. ¼ of sec. 8.
8. Benton, Woolsey's clay.
9. Ridgwood, T. 1 N., R. 12 W., SW. ¼ of NE. ¼ of sec. 25.
10. Benton, Howe's pottery.
11. Clay from T. 8 S., R. 15 W., sec. 4.
12. Clay from T. 8 S., R. 15 W., sec. 5.
13. Clay from T. 2 S., R. 13 W., S. ½ of sec. 13.
14. John Foley's, T. 13 S., R. 24 W., NE. ¼ of SE. ¼ of sec. 18.
15. Climax pottery, T. 15 S., R. 28 W., W. ½, SE. ¼ of sec. 5.
16. Atchison's, T. 4 S., R. 17 W., NE. ¼ of NE. ¼ of sec. 24.
17. Kaolin, T. 1 N., R. 12 W., sec. 36, Tarpley's.

According to Professor Jameson[a] clays for Portland cement should not contain less than about 60 per cent of silica in combination.

PORTLAND CEMENT INDUSTRY IN ARKANSAS.

WHITECLIFFS PORTLAND CEMENT WORKS.

A Portland cement plant was erected at Whitecliffs Landing, on Little River, 1 mile south of Whitecliffs post-office (see Pl. LIII), and a branch railroad constructed from the river opposite the plant to Wilton on the Kansas City Southern Railroad in 1895. On account of litigation between those financially interested the works have been idle since May, 1900. The members of the company and those involved in the litigation were scattered, and it was not practicable to obtain a correct history of operations. Operations were resumed late in 1901, with the name of the company changed to the Southwestern Portland Cement Company.

Plant, processes, and material.—The works were constructed of the most approved machinery, including crushers, ball mills, and a steam-drying plant. Four continuous dome kilns were utilized, and the bricks passed upon cars from the forming machine through the drying plants to the elevators, which conducted them to the kilns. From the kilns the clinker returned on cars to the crushing plant and mills.

The quarry, which is shown in the rear of the works, is elevated so that the chalk descends by gravity to the reducing machines. Clay silt from the river bottom land near by was utilized as a mixture with the chalk. The economy of using this material, because of its convenient location, instead of clays of high grade was a mistake, it is believed.

Coal and coke of high grade in large quantity occur in eastern Indian Territory on or near the Kansas City Southern Railroad. This fuel may be transported by rail at small cost directly to the cement works.

Market and transportation.—Until the year 1900 the nearest cement plant of any nature to the Whitecliffs works was at San Antonio, Tex., a distance of 375 miles. In this year a Portland cement plant has been erected at Dallas, Tex., where a mixture of Upper Cretaceous chalk from the southern extension of the Whitecliffs formation and

[a] Portland Cement, by Charles D. Jameson, Iowa City, 1895, p. 17.

underlying clay marl is utilized. The product from this plant will naturally supply a large part of the North Texas market at least. The Whitecliffs cement should supply all Arkansas, Indian Territory, central Oklahoma, a large part of Louisiana, and possibly western Tennessee and Mississippi. Transportation north and south is direct by the Kansas City Southern, northeast and southwest by the St. Louis, Iron Mountain and Southern, and east and west by the Choctaw, Oklahoma and Gulf and the Memphis and Choctaw railroads.

The chalk deposits at Rocky Comfort are within 1 mile of the Arkansas and Choctaw Railroad, which connects with the Kansas City Southern at Ashdown. This road is extending westward to tap the Missouri, Kansas and Texas at Ardmore, Ind. T.

The chalk of the Saline Landing area is more than 10 miles by direct line from the St. Louis, Iron Mountain and Southern and the Arkansas and Louisiana railroads. Saline Landing, however, which is upon the chalk, may be accessible to the St. Louis, Iron Mountain and Southern Railway at Fulton by West Saline River, which is navigable to small steamers during a large part of the year.